Chapter 1

The Brain as a Survival Machine

This is Charles Darwin writing in 1859: "It is most necessary... never to forget that every single organic being around us may be said to be striving to the utmost to increase its numbers; that each lives by a struggle at some period of its life; that heavy destruction inevitably falls either on the young or old.... Lighten any check, mitigate the destruction ever so little, and the number of the species will almost instantaneously increase to any amount. The face of Nature may be compared to a yielding surface, with ten thousand sharp wedges packed close together and driven inwards by incessant blows...". This book is about how we use our brain in this struggle for existence. It is about how parts of our brain, inherited from our mammalian ancestors, are dedicated to make sure we survive, although we are hardly aware of them; and about how these work together with more recently acquired brain structures to guide us through life, keeping us safe and sound for the most part, so that we pass our qualities on to succeeding generations.

You, like everyone else, have a warm, soft, rather moist, body, needing regular intakes of usable energy. You are here because your parents had the will and opportunity to reproduce. But you live in a tough world. Food, water and essential minerals like salt are not easily available in the environment from which you originally evolved. You have to want them and to know where to look to find them. You have to keep warm in the cold, or keep cool if the weather gets too hot. You have to find a mate, if you are to pass on something of yourself to succeeding generations. Your ancestors will have had to avoid being eaten by another species, whilst making sure that they themselves were effective predators. You are in competitions for many of the things you need, including a mate, with others of your own kind. To survive, you have to adapt. That is, you need the means to mould your behaviour to take account of how your world is, and to change your behaviour when it changes. Some of these changes may be sudden, others slow. Some arrive without warning, others are more predictable. Adaptation means not only changing your behaviour. Your body needs to adapt as well, making sure that it tells you what it needs to keep you going, and that it is resilient at moments of difficulty or shortage. So you survive into better times. No matter that you now live in a world we think of as technologically advanced. No matter that there are some who think that the modern world has removed some of the selection pressures on humans to which other animals are customarily exposed — true, if true at all, for only a small segment of humanity. You still carry with you many of the features that made your ancestors such a success. Otherwise, you would not be around today. The very fact that these qualities are now used in circumstances hardly imaginable, even a few centuries ago, is a tribute to your adaptive capacity.

Your brain not only keeps you alive, well and — as far as it can — out of danger, it also enables you to deal with life's emergencies. This may be a period of food shortage, or dehydration, or intense cold, or a confrontation with a larger, stronger rival, or the demands of giving birth or rearing young or preserving a territory, escaping from danger or keeping down a difficult job or coping with a bereavement. Such a demand may be short-lived and sharp; it may be long and unremitting; or intermittent and unpredictable. A general name for such an event, or set of events is 'stress'. Actually, a better word is 'stressor', meaning some external or internal event that induces 'stress' — the state of demand. Stressors can arise from the physiological world — too little food, too much heat and so on — or from the social and psychological one — a fight, arguments with friends, an unsatisfactory relationship, a demanding job. These are all examples of the need to adapt, and adaptation needs a brain. We will discuss stress more in Chapter 4.

This book is about the role of the brain in everyday life — adapting to intermittent emergencies such as stress. Modern ideas on adaptation began in the 19th century. Claude Bernard, like many other great scientists, is known for only a little of what he actually did. He was particularly

Social and Physical Evolution

Owing to the struggle for life, variations, if they be in any degree profitable to the individuals of a species, in their infinitely complex relations to other organic beings and to their physical conditions of life, will tend to the preservation of such individuals, and will generally be inherited by the offspring. The offspring, also, will thus have a better chance of surviving, for, of the many individuals of any species which are born, but a small number can survive. I have called this principle, by which a slight variation, if useful, is preserved, by the term 'natural selection', in order to mark its relation to man's power of selection. But the expression often used by Mr Herbert Spencer of the survival of the fittest is more accurate, and is sometimes equally convenient.

Charles Darwin. (1872) *The origin of species.* Sixth ed.
Ed. R E Leakey (Hill and Wang, NewYork.)

In recent years, historians have come to see that the most far-reaching change which grew out of the Renaissance was the evolution of the scientific method of inquiry. They have, therefore, given to the period of growth in science between 1500 and 1700 a new name, the Scientific Revolution . . . . Butterfield . . . says . . . that it 'outshines everything since the rise of Christianity and reduces the Renaissance and reformation to the rank of mere episodes'. . . . It was in the first place an intellectual revolution: it taught men to think differently. Only later was this put to a new practical use, in the Industrial Revolution about 1800, which gave our civilisation its outward character.

J Bronowski, B Mazlish. (1960) *The western intellectual tradition.*
(Hutchinson, London.)

. . . A sense of genetic unity, kinship, and deep history are among the values that bond us to the living environment. They are survival mechanisms for ourselves and our species. . . . biological diversity is an investment in immortality.

Edmund O Wilson. (2002) *The future of life.*
(Little, Brown and Co., London.)

To transform a weed into a cultivated plant, a wild beast into a domestic animal . . . to make stout, water-tight pottery out of clay which is friable and unstable . . . to work out techniques, often long and complex, which permit cultivation without soil or alternatively without water; to change toxic roots or interested in digestion, and worked on the way that the liver converts fats and sugars such as glucose in the food to glycogen, a form in which energy is stored. He recognised that the body needed to maintain levels in the blood of important molecules like glucose despite the fact that they were not always available. Hence, his dictum which resonates down the centuries: a constant internal environment is the condition for free life (*La fixité du milieu intérieur est la condition de la vie libre*). You walk around an inconstant, unpredictable and often unsatisfactory world carrying your own private, much more consistent, world with you — the inside of your body. But you have to keep it that way, despite the buffeting it gets from the outside world, a process now called 'homeostasis'. Some great scientists, like Bernard, tend to be resistant to the ideas of others — in his case, those of Darwin. Bernard was a 'generalist': he was interested in general properties of the body, not with individual differences. This does not detract from the stature of Darwin, who was fascinated by the importance of individuality, and showed how small variations in an individual's characters (a longer leg, a sharper claw, a less obvious colour etc.) might make it more or less 'fit;' that is, change the odds ever so little for or against its favour when conditions became tough. Not only were physical features important: slight advantages in the ability to communicate, to be a more effective parent, to learn a new skill, or to recognise a dangerous situation were all part of the Darwinian theory of selection. These abilities depend upon a brain. So, too, does the ability to know when to use your sharper claw to attack, or run away on your longer legs, or to summon help from those whom you know may offer it.

On their journey through time, everyone brings their individual qualities, which may give them an advantage over others, or at least an increased chance of dealing with the exigencies of their uncertain world. In the terrible siege of Leningrad (St Petersburg) in 1942, between 600,000 and 1 million people died of cold and starvation. But some survived. This was not a random event. Though no doubt chance played a part, other factors tipped the balance between who would live and who would die. Much would have depended on the brain, whose ability to adapt to demands varies from individual to individual, and from time to time, within the same person. This, as we shall, see, is as critical a factor as any other in success or failure, and in determining the cost that even success seeds into foodstuffs. . . there is no doubt that all these achievements required a genuinely scientific attitude, sustained and watchful interest and desire for knowledge for its own sake. For only a small proportion of observations and experiments . . . could have yielded practical and immediately useful results.

C Levi-Strauss. (1962) *The savage mind.*
(Weidenfeld and Nicolson, London.)

Some 10,000 years ago, certain human populations in the near east changed their way of life from that of hunting community to one based on the domestication of plants and animals . . . . The surplus food produced by the farmers could support large numbers of people, who could become labourers, artisans, soldiers, artists, politicians and scientists . . . . It should be emphasised however, that the change was wholly cultural; it took place far too quickly and too recently to be associated with biological changes in individuals.

D Pilbeam. (1970) *The evolution of man.*
(Thames and Hudson, London.)

Darwin's contemporaries saw at once what a heavy blow he was striking against piety. His theory entailed the inference that we are here today not because God reciprocates our love, forgives our sins, and attends to our entreaties but because each of our oceanic and terrestrial foremothers was lucky enough to elude her predators long enough to reproduce.

F C Crews. (2001) *New York Review of Books*.

may entail. Darwin showed us that studying physiological or behavioural control systems, important though this is, is not enough: we also need to know about how they vary between individuals, and how individuals thus vary in their effectiveness to deal with demand.

The brain is not a simple or uniform structure, so we have to ask whether there are parts of it that are more concerned than others with the story I want to tell. To answer this is not as easy as you might think. Suppose that you wake in the middle of the night, and feel hungry. You reach out a hand to turn on the bedside lamp. You get out of bed and put on a sweater. You walk downstairs quietly, so as not to wake others, go into the kitchen, open the door of the fridge and look for something to eat. You select a piece of cheese. Then, you scan the tins of food on the shelf above the fridge, reading the labels. You see one that you fancy and open it with a can-opener. You put it all on the plate, sit down and eat, though you find you have eaten enough before all the food has gone. So you store the remainder in the fridge for tomorrow.

You have just performed an adaptive response: you have defended your body against a too-low blood glucose — though you had no idea that this was the underlying cause of your behaviour. During the series of actions that make up your response, a large part of your brain has been used. It has detected the fall in your blood glucose levels. It has woken up. It has generated the sensation of hunger. It has motivated you to get food. It has decided to go and find some, and has remembered where food is to be found. It has allowed you to feel the light switch. It is also responsible for your knowing what a light switch is. It has recognised that as you get out of bed you are getting cold, and remembered that putting on a sweater can counteract cold. It has enabled you to perform the rather complicated actions of actually putting the sweater on. It has enabled you to walk downstairs without falling over. It has remembered that there are others asleep, and that is it anti-social to wake them — that is, there will be social repercussions (cost) if you do. It has recognised a fridge. It has also recognised a food object. Your brain enables you to read, and to translate what you read into food. That is, you know from the symbols on the tin — also recognised as such by your brain — that inside is a certain sort of food. The skill of opening a tin is only possible because your brain enables you to do so. You eat, using motor patterns generated

Open thy mind, the truth is coming; know,
When the articulations of the brain
Has been perfected in the embryo,

Then the First Mover turns to it, full fain
Of nature's triumph, and inbreathes a rare
New spirit, filled with virtue to constrain

To its own substance whatso active there
It finds, and make one single soul complete,
Alive, and sensitive, and self-aware.

Dante. *The divine comedy. II. Purgatory. Canto XXV. Translated by D L Sayers.* (Penguin Books, Harmondsworth.)

All that is noble and excellent and all that is worst in human commerce has been thought to derive from the brain, a sort of gland that secretes lofty ideas and superior morals when healthy and oozes destructive plans when diseased.

F Gonzalez-Crussi. (1986) *Notes of an anatomist.* (Picador, London.)

Killer instinct. General use, to describe the quality of extreme seriousness thought to be required to win in sport and life.

Nigel Rees. (1996) *Dictionary of cliches.* (Cassell, London.)

Nature, that fram'd us of four elements
Warring within our breasts for regiment,
Doth teach us all to have aspiring minds:
Our souls, whose faculties can comprehend
The wondrous architecture of the world,
And measure every wandering plant's course,
Still climbing after knowledge infinite,
And always moving as the restless spheres,
Wills us to ware ourselves and never rest,
Until we reach the ripest fruit of all,

by your brain. Signals from your body go to your brain, telling you when you have eaten enough. Your brain recalls that food is costly, and that there are means of preserving it for later, and that you will be hungry again quite soon. A great mixture of what psychologists would call motivation, emotion, memory and cognition, and what neuroscientists would call sensory and motor function. Does this mean that to understand the role of the brain in adaptation, we have to discuss everything we know about it?

Fortunately not. This is because we know that parts of the brain are specialised for particular functions. For example, there is a complex pathway in the brain, starting at the eyes and responsible for vision. This is the visual 'system,' and it enables what we call 'seeing'. Another set of nerve cells and pathways enable us to move. The arrangement of the motor system, as it is called, is rather distinct from the visual one, so that damage to it (for example, following a stroke) can cause paralysis — loss of movement — without blindness. Yet another part of the brain takes the information received by the sensory pathways and uses it to form an imprint, which we call memory. Next time we see, or hear, or feel the same sensation, we may be able to recall having experienced it before. Even more complex functions, like recognising a particular friend (or a fridge), or being able to read, are the responsibility of other parts of the brain. Damage to any one of them will interfere with that function, leaving others intact. These parts of the brain may be used for adaptive purposes (as in our night-time scenario) but they also have other uses. 'Seeing' is what the visual system does: you 'see' for many reasons, one of which is to be able to adapt. But the visual system is not a dedicated adaptation system: it does not tell you that you need to adapt, or how to do it: it provides the means (or part of them). You 'move' all the time; sometimes as part of adaptation, but for many other reasons. During the episode of your nocturnal feast, you used many of these parts of the brain. But many of them can be used in other, and quite different contexts. Later that day, you may play a game of tennis, or read your e-mail, watch television, or go to the office and write a memo. You will interact with colleagues and friends. You will use many of the same areas of the brain that were so useful during your midnight meal. None of these parts of the brain is dedicated to survival, though clearly essential for it.

That perfect bliss and sole felicity,
The sweet fruition of an earthly crown.

Christopher Marlowe. (1564–1593) *From: Tamburlaine the great.*

. . . The intellectual, to my mind, is more in touch with humanity than is the confident scientist, who patronizes the past, over-simplifies the present, and envisages a future where his leadership will be accepted. . . . It is high time he came out of his ivory laboratory. We want him to plan for our bodies. We do not want him to plan for our minds, and we cannot accept, so far, his assurance that he will not.

E M Forster. (1951) *Two cheers for democracy.* (Edward Arnold, London.)

But there is a brain system which has, as its main function, our preservation and that of our species. This part of the brain is particularly concerned with making sure that we do the things that maximise our health, keep us in good condition, and reproduce. As part of all these functions, it detects threats to our survival, recognises what they are, and devises the strategy by which we will overcome or compensate for these demands. It is clear that such an adaptation system cannot work on its own. No good being hungry or thirsty if you cannot move to where there is food or water, or recognise it when you see it. That means there must be co-operation between different parts of the brain, obvious enough. But none of these other systems has survival, adaptation and procreation as its major concern. We need a brain system that recognises our needs, and how to go about meeting them. A brain system that also keeps us out of trouble as well as continuously assessing threats to our wellbeing. A system that enables the right adaptive response, whether this means a particular sort of behaviour, or an appropriate pattern of hormone secretion, or alterations in the response of the 'emergency' nervous system — the process of coping, as some would call it. We have one: it is a part of the brain called the limbic system. It is a very special part of the brain, and it is the focus of this book.

Whoever it was that first cut across a human brain will never be known. Our inability to see things that are obvious until someone else points them out probably means that brains were cut up countless times before someone realised that the inside of this curious, wrinkled structure was not all the same. There are areas that appear almost white but others that are decidedly darker. Moreover, if our early observer had seen enough cut-up brains, he (she, perhaps) would have noticed that the arrangements of these lighter and darker areas are very similar from brain to brain. The inside of the brain appears to have a structure. The paler areas came to be called 'white matter', and the darker ones 'grey matter', suitably neutral and descriptive terms that give no clue to either their structure or function. This did not stop those with a passion for labelling from giving the different areas names. Names are important for at least two reasons: they define objects as distinct (that is, one area of grey matter from another), and they may also give a clue as to its supposed function or significance. The problem for the early anatomists of the brain is that

We all assume that the future will be like the past — it is the essential but unprovable premise of all our inductive inferences, as Hume noted. Mother nature (the designer-developer realized in the processes of natural selection) makes the same assumption. In many regards, things stay the same: gravity continues to exert its force, water continues to evaporate, organisms continue to need to replenish and protect their body water, looming things continue to subtend ever-larger portions of the retina and so on. Where generalities like these are at issue, mother nature provides long-term solutions to problems: hard-wired, gravity based which-way-is-up detectors, hard-wired thirst alarms, hard-wired duck-when-something-looms circuits. Other things change, but predictably, in cycles, and mother nature responds to them with other hard-wired devices, such as winter-coat-growing mechanisms triggered by temperature shifts, and built-in alarm clocks to govern the waking and sleeping cycles of nocturnal and diurnal animals. But sometimes the opportunities and vicissitudes in the environment are relatively unpredictable by mother nature or anyone — they are, or are influenced by, processes that are chaotic. In these cases, no one stereotyped design will accommodate itself to all eventualities, so better organisms will be those that can redesign themselves to some degree to meet the conditions they encounter.

Daniel C Dennett. (1991) *Consciousness explained.* (Little, Brown and Co., New York.)

I hope I am not giving the impression that Davey's whole life was centred around his health. He was fully occupied with his work, writing and editing a literary review, but his health was his hobby, and, as such, more in evidence during his spare time, the time when I saw most of him. How he enjoyed it! He seemed to regard his body with the affectionate preoccupation of a farmer towards a pig — not a good doer, the small one of the litter, which must somehow be made to be a credit to the farm. He weighed it, sunned it, aired it, exercised it, and gave it special diets, new kinds of patent food and medicine, but all in vain. It never put on so much as a single ounce of weight, it never became a credit to the farm, but, somehow, it lived, enjoying good things, enjoying its life, though falling victim to the ills that flesh is heir to, and other, imaginary ills as they had very little real knowledge of what the different parts of the brain did. That, of course, did not stop the name-calling, or even speculative ideas — based on rather little evidence — on what they might do. Many of the names given to parts of the brain are based on appearance, or a fancied resemblance to other objects in the (medieval) world. Note, however, that the idea that the different regions of the brain might have different functions is itself important. Parcelling the brain into definable areas is what we would now call the modular approach to brain function. We think of a complex structure like the brain as made up of a number of sub-components, just as, for example, the engine of a car is constructed from a number of different components (carburettor, cylinder block, distributor etc.).

But is the brain an assembly of distinct components, each with a defined and separate function? One of the many difficulties in studying how the brain works is precisely because it is not arranged in this way. That does not mean that one cannot assign specific functions to anatomically recognisable parts of the brain. Indeed one can: for example, the great cortical mantle (the cerebral cortex) that forms most of the outside of the brain and gives it its typically wrinkled or folded appearance has areas that we know are concerned with identifiable actions. One is responsible for generating movement, another for analysing incoming visual information, yet another for receiving sensation from the skin (which we interpret as 'touch') and so on. Similar functional boundaries have been recognised in other parts of the brain, the so-called sub-cortical areas. That is not an issue. What is, however, is whether there are clearly defined boundaries between these areas, either anatomically — where does one begin, or the other end or functionally — is there a circumscribed areas of the brain that has an equally precise function? The answer to both questions is a resounding 'no.' Take vision, one of the better-understood parts of the cerebral cortex.

We know that nearly all information from the eyes ends up in a rather small area of cerebral cortex at the back of the brain. This is the visual cortex. That is why a bang on the back of your head makes you 'see stars'. But from this region, visual information is passed forwards to other parts of the cortex, each part doing different things — extracting particular bits of information out of the mass of data arriving from your eyes at the *well, through which it was nursed with unfailing care, with concentrated attention, by the good farmer and his wife.*

Nancy Mitford. (1945) *The pursuit of love.*
(Hamish Hamilton, London.)

What's this flesh? A little crudded milk, fantastical puff-paste. Our bodies are weaker than those paper-prisons boys use to keep flies in; more contemptible, since ours is to preserve earthworms.

John Webster. (1623) *The duchess of Malfi.*

These memories are the memorials and pledges of the vital hours of a lifetime. These hours of afflatus in the human spirit, the springs of art, are, in their mystery, akin to the epochs of history, when a race which for centuries has lived content, unknown, behind its own frontiers, digging, eating, sleeping, begetting, doing what was requisite for survival and nothing else, will, for a generation or two, stupefy the world, bring to birth and nurture a teeming brood of genius, droop soon with the weight of its grandeur, fall, but leave behind a record of new rewards won for all mankind; the vision fades, the soul sickens, and the routine of survival starts again.

Evelyn Waugh. (1945) *Brideshead revisited.*
(Penguin Books, Harmondsworth.)

visual cortex. The processing itself gets ever more complex as it passes forward, but there is no clear boundary at which we may say that visual information has ceased to be processed. It mingles with other sorts of information — for example, from the 'language' part of the brain, so you can read when you see a collection of words, or with the part that stores memories so you can recognise a familiar face and so on. You cannot cut out a chunk of brain and say 'this is the seeing brain' because the brain uses many parts to decode visual information, and 'seeing' by itself is not a very useful brain activity: you need to do something with the information. The same arguments go for the movement ('motor') parts of the brain and for any other brain area. If you were to lose a limb, or your sight, then the areas of the cortex responsive to sensation or vision will alter their boundaries. This is a long-winded way of saying that the brain works as a whole, there are parts that specialise in particular aspect of the things it has to do, but these parts interconnect and interact with one another, and that the brain itself is malleable.

So how do we reconcile this notion of a functionally and anatomically blended brain with the apparently opposite idea of brain 'systems'? By taking a much more flexible (and intellectually less comfortable) position: we are looking at a impressionist gouache, rather than a geometric design. The analogy with parts of the car has broken down: the brain is not the kind of machine we are familiar with in our mechanical world, but it is a machine nevertheless. Certain parts of the brain can, indeed, be confidently said to have a single (or a set of related) functions: but there are many areas where this is not so. This does not meant that they do not have a definable role, only that we need to describe this in a different way. The bottom line, however, is that if we are to recognise a 'system' in the brain, we have both to give it a physical reality (that is, say which parts of the brain are in our system) and a functional one (what it does that distinguishes it from other parts of the brain). Let's see whether this applies to the limbic system.

Limbic means 'edge' or 'border' and was originally applied to the brain by the great French neurologist Paul Broca. Broca is actually famous for his recognition that there was a special part of the brain responsible for spoken language, but, like many talented scientists, he was a versatile man. He gave the name 'the great limbic lobe' to a part of the

The Human Brain

More than one writer has asked, why have some animals had their mental powers more highly developed than others, as such development would be advantageous to all? Why have not apes acquired the intellectual powers of man? Various causes could be assigned; but they are conjectural, and their relative probability cannot be weighed.

Charles Darwin. (1872) *The origin of species*. Sixth ed.
Ed. R E Leakey (Hill and Wang, NewYork.)

The brain is waking and with it, the mind is returning. It is as if the milky way entered upon some cosmic dance. Swiftly, the head-mass becomes an enchanted loom where millions of flashing shuttles weave a dissolving pattern, always a meaningful pattern though never an abiding one; a shifting harmony of sub-patterns.

C S Sherrington. (1940) *Man on his nature.*
(Penguin Books, London.)

Each nerve cell receives connections from other nerve cells at sites called synapses. But here is an astonishing fact — there are about one million billion connections in the cortical sheet. If you were to count them, one connection (or synapse) per second, you would finish counting some thirty-two million years after you began.

Indeed, the chemical and electrical dynamics of the brain resemble the sound and light patterns and the movement and growth patterns of a jungle more than they do the activities of an electrical company.

G Edelman. (1992) *Bright air, brilliant fire.*
(Allen Lane, London.)

About two decades ago, a new science was launched, variously called neurobiology, brain research or neuroscience. This statement will offend many who would divine a much earlier origin for the subject. But I would say that the recognition that many individual research workers from a variety of university departments and other institutions, with backgrounds in very different disciplines, share a common objective — the explanation of the functions of the brain — dates from only about 20 years ago.

C Blakemore. (1986) The nature of explanation in
the study of the brain. In: *Functions of the brain.*
Ed. C Coen, pp. 181–200. (Clarendon Press, Oxford.)

cortex which, he thought, formed the inside border (or boundary) of the cerebral cortex of the mammalian brain. In the human brain, this is a C-shaped region that is coiled round the inside of the cerebral hemispheres. So it was an anatomical definition, and one limited to the cortex. Judson Herrick, an American comparative neuroanatomist, found out that Broca's limbic lobe had a somewhat less elaborate structure than the rest of the cortex, and he suggested it might be concerned with more 'primitive' functions, such as feeding and sex, leaving the other parts of the cortex to deal with 'higher' mental activities. Others thought it was particularly concerned with the sense of smell. But it was James Papez who dropped the real bombshell. In 1937, he pointed out that the limbic cortex was actually connected to a variety of other structures, and that these formed a sort of cerebral loop (such interconnected circuits were much in vogue at the time as a way of understanding brain function). Finally, he proposed that this circuit was the neural basis of emotion.

The significance of this idea should not be underestimated. It proposed that there was a dedicated system in the brain that was responsible for an emotional state, without specifying in any way how the brain might actually generate an emotion. So there might be separate brain structures responsible for 'thoughts' and 'feelings'. This was a striking idea, though not a new one: it implies that the two sorts of mental activity are carried out in separate parts of the brain (Papez called them 'streams'). It also implies that somehow, they have to be amalgamated if one is to associate a particular sensation or event with its attendant emotion. It is important to note that Papez described emotion as the only function of the limbic system.

The term 'limbic system' was introduced by Paul MacLean, following a visit to James Papez, in 1952. MacLean had a panoramic view of the way the brain was built. He proposed what he called the 'triune brain'; that is, the brain actually consisted of three concentric structures which, he thought, were typical of the brains of reptiles, more primitive mammals and 'higher' mammals, respectively. The middle one corresponded, largely, to the limbic system. He originally called the limbic system the 'visceral' brain, because he thought it responsible for processing sensation from the viscera (including the gut), though he associated it also with smell. The phrase 'gut feeling' may occur to you, as you try to relate this idea to that of an emotional state.

Science progresses by way of metaphor and analogy. Electricity is likened to a fluid, valency bonds to hooks and eyes, atoms to billiard balls. The science of the brain is no exception to this rule. Descartes, in the seventeenth century, likened the brain to the intricate hydraulic mechanisms of his day; the nineteenth and early twentieth centuries saw a powerful analogy to the telegraph cable and the telephone exchange; nowadays, in the late twentieth century, the computer metaphor is all-pervasive. Metaphors and analogies both help and bias our understanding. The power of the computer analogy perhaps prevents us from seeing the brain from other equally significant viewpoints. In particular, it prevents us from seeing the brain as if it were an immense gland. Yet, this view has much to commend it. Neurons can be seen not so much as relays or on/off valves but as secretory cells. The electrical phenomena of electrotonic and action potentials can, on this analogy, be seen merely as triggers for the release of secretions — the neurotransmitters and modulators.

C U M Smith. (1989) *Elements of molecular neurobiology*. First ed. (Wiley and Sons, Chichester.)

There are some who say that 'emotion' is an insufficient criterion for defining a brain system, others that the function of the limbic system is too vague for it to be a valid concept. Both are incorrect arguments, though for different reasons. There is no doubt that one very important function of the limbic system is the generation, expression and recognition of emotion. There is also equally no doubt that this is not its only function. Emotion is an essential ingredient of survival. In its absence — for example, without the ability to experience fear — no animal, including any of us, would survive for very long. But you need more than an emotional response to survive. By slavishly following Papez's original idea (still good but a limited one), these critics have mistaken a component of what the limbic system does for its entire function. Emotion is part of what it does. A part of what? Promoting survival of course; and to survive, as Darwin taught us, we need to adapt. Since adaptation is a complex but coherent activity, it comes as no surprise that there are parts of the limbic system that are principally concerned with elements of the ability to adapt other than emotion. Emotional responses have to fit in with the rest of this process, but are an essential part of it. Just because there are parts of the limbic system that do not seem to be directly concerned with emotion does not refute the validity of the system as a whole. It only means we need to redefine what it does. It is our survival machine. No other part of the brain can do what the limbic system does. Those who have argued that the concept of the 'limbic system' depends on emotion alone or that it is so all-embracing and vague that it includes the whole brain have missed these essential points. This misapprehension has even found its way into august works of reference, such as Gray's Anatomy. Perhaps a future edition will take a more thoughtful approach.

Many distinguished neuroscientists have pondered the limits of the limbic system. Walle Nauta emphasised its role in bringing together internal ('visceral') and external stimuli, and included parts of the midbrain (those that receive information from the viscera) as well as the hypothalamus. Rudolf Nieuwenhuys (another example of the tradition of outstanding Dutch neuroanatomists) added other areas of the forebrain, and some bits of brainstem, particularly those that have nerve cells containing the monoamines, such as noradrenaline and serotonin into the

Those Rules of old discover'd, not deviz'd,
Are nature still, but nature methodiz'd;
Nature, like Liberty, is but restrained
By the same laws which first herself ordain'd.

Alexander Pope. (1688–1744) *From: An essay on criticism.*

Freud was in his fortieth year when Studies in Hysteria appeared —almost at that crucial age after which, it is often speculated, no scientist ever achieves much that is worthwhile. Yet, 1895 was to mark the beginning of an extraordinary five years of activity. . . later in the year, he wrote, in a few weeks, an elegant paper in which he tried to describe psychical processes in terms of quantifiable forces, an attempt in which he only just failed to outline the neurone theory put forward by Wilhelm von Waldeyer the following year, and describing the nervous system in terms of neurones . . . .

Ronald W Clark. (1980) *Freud. The man and the cause.* (Jonathan Cape, London.)

Nervous systems that are hard-wired are lightweight, energy-efficient, and fine for organisms that cope with stereotyped environments on a limited budget. Fancier brains, thanks to their plasticity, are capable not just of stereotyped anticipation, but also of adjusting to trends . . . . For truly highpowered control, what you want is an anticipation machine that will adjust itself in major ways in a few milliseconds, and for that you need a virtuoso future-producer, a system that can think ahead, avoid ruts in its own activity, solve problems in advance of encountering them, and recognize entirely novel harbingers of good and ill. For all our foolishness, we human beings are vastly better equipped for that task than any other self-controllers, and it is our enormous brains that make this possible.

Daniel C Dennett. (1991) *Consciousness explained.* (Little, Brown and Co., NewYork.)

Also people think they're not computers because they have feelings and computers don't have feelings. But feelings are just having a picture on the screen in your head of what is going to happen tomorrow or next year, or what might have happened instead of what did happen, and if it is a happy picture they smile and if it is a sad picture they cry.

Mark Haddon. (2004) *The curious incident of the dog in the night-time.* (Vintage, London.)

'greater limbic system'. We will have much more to say about these intriguing neurochemicals later in this book (Chapter 3). He also pointed out that the limbic system has many nerve cells that contain a wide variety of another type of chemical signal, the peptides. Some brainstem nerve cells also have similar peptides, so he included these as well. We will say much more about peptides as well (Chapter 2), for within these chemicals, I believe, lies a good part of the code for successful adaptation.

The limbic system is like other systems. It is made up of a number of neural components, represented by chunks of brain that have two properties: they are connected together, and they have a common function. In the case of the visual system, it is for seeing; for the motor system, it is for locomotion; as for the limbic system, it is for the preservation of self and species. The first proposition of this book is that this is the part of the brain that specialises in adaptation and survival. The second is that the limbic system has a number of ways of making sure we overcome physical, social or psychological challenges: note that preservation requires us to cope with them all. Effective adaptation to events such as lack of water, or a confrontation with a dangerous antagonist, is a complex business. You need to do the things that enhance adaptation (that is, behave appropriately), your nervous system needs to take the necessary actions to stabilise your physiology in the face of deficiency or demand, and the whole process is helped enormously by changes in the secretion of your hormones. The limbic system formulates this co-ordinated set of reactions by which such demands are met. The third proposition is that the limbic system has its own way of working. Though it shares many of the features of other parts of the brain, it has some peculiarities of its own. The most important one is that it uses a chemical code to formulate adaptation to challenges. If we understood this code, we would know a lot more about how this part of the brain is so good at what it does. Since our survival depends on our limbic system, we need to know how it works. Finally, we have to think about situations in which, despite its best efforts, the limbic system cannot cope, and adaptation is insufficient. What are the consequences, either personal or for the social group or even for the species, of failure? And what about success? As we shall see, even if we do succeed in overcoming the current challenge in some way, there may be a price to pay, such as an increased chance of

Arguments Against the Limbic System

The term, "limbic system," has come into vogue during the past decade or two, but it is difficult to find either anatomical or physiological justification for lumping a diverse, multi-functional collection of cortical areas and subcortical structures together as the *limbic system*, and this designation appears not to have sufficient descriptive value to justify its continued use.

L Van Atta, J Sutin. (1972) Relationships among amygdaloid and other limbic structures in influencing activity of lateral hypothalamic neurons. In: *The neurobiology of the amygdala*. Ed. B E Eleftheriou, pp. 343–369. (Plenum Press, NewYork.)

We have seen that a large and increasing number of brain structures and functions has been implicated with the limbic system. This heterogeneous collection cannot be defined by a single criterion. . . . The limbic system is not a piece of nature given to us. It is just one out of many scientific concepts. From an empirical point of view this concept is not adequate and there is nothing to justify its continuing use in a general and indiscriminate sense. . . . It may turn out that the limbic system becomes more and more obsolete as our knowledge increases. But so far it has a very important role to play: it meets our need and desire for explanatory concepts in the neurosciences which is reflected in the influence that the limbic system has in many areas of the neurosciences. . . . The term, however, is simple and enjoys universal recognition: everyone thinks he knows what is meant when he hears it.

R Kotter, N Meyer. (1992) The limbic system: A review of its empirical foundation. *Behavioural Brain Research* **52**, pp. 105–127.

If the limbic system is the emotion system, then studies showing which brain areas are involved in emotion should tell us where the limbic system is. But this is backward reasoning. The goal of the limbic system theory was to tell us where emotion is in the brain on the basis of knowing something about the evolution of brain structure. To use research on emotion to find the limbic system turns this criterion around. Research on emotion can tell us where the emotion system is in the brain, but not where the limbic system is. Either the limbic system exists or it does not. Since there are no independent criteria for telling us where it is, I have to say that it does not exist.

J LeDoux. (1998) *The emotional brain.* (Weidenfeld and Nicolson, London.)

illness. Whether the triumph is worth the price is something else the brain may be able to tell us. That is our fourth proposition.

But our brains are more than a limbic system. Surrounding this ancient and highly successful limbic survival machine is another, even more complex, but typically human structure: the cerebral cortex. All mammals have a cortex, but the human brain is distinguished from others by the size and complexity of its cortex, not its limbic system. So the human brain brings to the problem of survival not only an efficient limbic system, but also the analytical, decision-making, concept-forming abilities of the huge human cortex. This is going to have a dramatic impact on how the human brain solves the survival problem, and the number of people on earth shows how well it has done. I am going to suggest that the two parts of the brain use rather different ways of working. Your cortex is a very large, unique, biological computer (nothing like the computer on your desk), and it encodes and decodes information by using a huge number of — perhaps quite simple — neural 'circuits' or assemblies of nerve cells. The 'code' it uses is thus based on way these assemblies function together. Your limbic system, as we have already suggested, has a different method: it uses a complex chemical code to signal its operation. It is a sort of huge gland. Now, it is important not to over-stress these differences: the cortex also uses chemical signals (though a bit differently to the limbic system) and the arrangement of nerve cells in the limbic system matters as it does in the cortex (though for different reasons). But your limbic system looks rather similar to that of other mammals, even a rat; it is your cortex that distinguishes you as a human being. And they have to work together, if you are to survive the rough and tumble of the real world. An important objective of this book is to discuss how the cortex and limbic system interact and depend on each other, as they surely do, so that humans solve their ancient survival problems in distinctively human ways.

It is not easy for a scientist to think about ignorance as opposed to knowledge, but we should acknowledge the limits of our understanding of the brain. We should never forget that, at the start of the twenty-first century, the brain remains a profound mystery, despite all the cohorts of neuroscientists, the masses of papers, the erudite books, in a way that is not true for other parts of the body. No mystery about the heart, or liver, or lungs or gut: we know the principles of how they work. Not so for the brain.

What is undeniable is that the hypotheses of Papez and Maclean have served the essential function of stimulating enormous amounts of research on the neural basis of emotion, so much so that the belief in a limbic system is entrenched in the literature and attempts to reappraise it may seem eccentric . . . But it is now equally clear that the areas included within the limbic system do not function as a system specialized for emotional processing, as opposed to other forms of information processing. Indeed, the hippocampus, while clearly the centrepiece of the limbic system concept, is not at all the centrepiece of the brain's emotional system. This structure and some of those connected with it, including those of the Papez circuit, are now widely accepted to be involved more with cognitive processes including mnemonic functions, perhaps especially spatial short-term memory. . . . It would appear to be of doubtful utility to continue to explore the function, or functions, of the limbic system since the anatomical criteria for defining it are at best imprecise and its purported unitary function in emotion is untenable.

Gray's anatomy. (1995) 38th ed.
(Churchill Livingstone, NewYork.)

I cannot tell you precisely how your brain makes you feel hungry, or feel fear, or recognise a friend, though I can tell you something about which parts of the brain might be involved in each of these functions, and some general ideas about how those areas work. This is not despair, but reality. We need to recognise the limits of our knowledge, even in the optimistic world of the neuroscientist. However, there are some things we do know.

We know that your limbic system ensures that you eat when you need to, or that your body tides you over bad times when your have to fast. It makes you feel thirsty when your body runs short of water, or defends you against involuntary dehydration; to seek out extra salt when you run low on this essential molecule, or restrict salt loss from the body if supplies are scarce. It drives you to put on a sweater when the weather is cold, or makes you shiver if you cannot find one; it wakes you up in time for the day, and puts you to sleep at night; it makes you like those things that are good for you, and avoid situations that may harm you; if you are harmed, it takes the necessary steps to help you mend; it makes sure that enough of us breed, and that we take care of our young, and each other, so that there will be members of our species to follow us in future generations. It makes us fight for survival; live in social groups; respond to the demands of others; and seek help when we need it.

It brings joy and sadness, success and failure, love and hate, sometimes illness, as part of the deal. What do we know about how it does all this? What happens if it fails? This is what this book is all about.

But before we go any further, I want to say something about 'you' and 'your brain.' You will see I have used both terms rather interchangeably. In fact, 'you' — the individual you — is largely (some would say exclusively) your brain. Other parts of your body may be unique — your fingerprints, for example, but your brain is what defines you as a person and as an individual. As someone said, a brain transplant is the only situation where it is much better to be the donor. There are various ways to talk about the brain. Sometimes, it makes sense to say the brain (or parts of it) does this or that, or performs functions through the agency of the rest of the body. Sometimes, it makes sense to say we use our brain to gather information about our environment, or to make best-choice decisions about actions or conduct. There can seem to be deep differences between the various ways of talking about the brain, particularly when one

. . . Arthur of England was a champion of civilization which is misrepresented in the history books. . . . In those despised Middle Ages of theirs, you could become the greatest man in the world, by simply having learning. And it is a mistake to believe that Arthur's civilization was weak in this famous science of ours. The scientists, although they happened to call them magicians at the time, invented almost as terrible things as we have invented — except that we have become accustomed to theirs by use. The greatest magicians, like Albertus Magnus, Friar Bacon, and Raymond Lully, knew several secrets which we have lost today, and discovered as a side issue what still appears to be the chief commodity of civilization, namely gunpowder. They were honoured for their learning, and Albert the Great was made a bishop. One of them who was called Baptista Porta seems to have invented the cinema — although he sensibly decided not to develop it.

T H White. (1958) *The once and future king.*
(Fontana/Collins, London.)

Scientists in modern times tend to specialise; few have the interdisciplinary base which would give them a view of the whole scene.

John Peyton. (2001) *Solly Zuckerman. A scientist out of the ordinary.*
(John Murray, London.)

Do you remember the bust of Socrates, the man who died rather than profess his belief in the gods of the time. . . ? Take this bust in your mind's eye, colour the beard black, dashing it here and there with puffs of grey; clap the head thus made on a portly body of middle height, and the doctor is before you. Throw a veil over the upper part of the face and you might be in the company of a born vestreyman. Reveal the essential feature, the immense brows, and you know at once that you have to deal with that most formidable of all composite forces — a dreamer who thinks, a thinker who dreams.

Contemporary description of Karl Marx.
Francis Wheen. (1999) *Karl Marx.* (Fourth Estate, London.)

Enter the experts . . . Enter the Science of Psychology. Officially installed in a cellar, it abolishes the art of knowing what people are like, and ensures that they are incomprehensible to themselves as well as to others.

E M Forster. (1951) *Two cheers for democracy.*
(Edward Arnold, London.)

considers issues like — what is a person, what is a conscious self, what is 'knowing' or what is an individual. Such issues have been much written about, mostly by philosophers, in books not at all like this one. These matters — important and intractable as they are — are not, in my view, central to the theme of this book. So when I write that either the 'brain' or 'you' 'knows' something or other and 'does' or 'decides' something else, and forget the apostrophes, you will understand.

Evolution of Man

So, there he stands, our vertical, hunting, weapon-toting, territorial, neotenous, brainy, naked ape, a primate by ancestry and a carnivore by adoption, ready to conquer the world. But he is a very new and experimental departure, and new models frequently have imperfections. For him, the main troubles will stem from the fact that his culturally operated advances will race ahead of any further genetic ones. His genes will lag behind, and he will be constantly reminded that, for all his environmentally-moulding achievements, he is still at heart a very naked ape.

Desmond Morris. (1967) *The naked ape.*
(Jonathan Cape, London.)

Our lives. . . are a constant dance between. . . surges of ancient emotions and their impulsive behaviours on the one hand, and the slower cognitions and admonishments of the evolutionarily later cerebral cortex on the other.

Ian Robertson. (1999) *Mind sculpture.*
(Bantam Books, London.)

E M Forster's novel *Where Angels Fear to Tread* gives a good example of teleology making the difference between description and explanation. Philip is trying to find out why his friend Caroline helped to bring about a marriage between Philip's sister and a young Italian man of whom Philip's family disapproves. After Caroline reports all the conversations she had with Philip's sister, Philip says, 'What you have given me is a description, not an explanation'. Everyone knows what Philip means by this — in asking for an explanation, he wants to learn Caroline's purposes. There is no purpose revealed in the laws of nature, and not knowing any other way of distinguishing description and explanation, Wittgenstein and my friend had concluded that these laws could not be explanations. Perhaps some of those who say that science describes but does not explain mean also to compare science unfavorably with theology, which they imagine to explain things by reference to some sort of divine purpose, a task declined by science.

Steven Weinberg. (2001) Can science explain everything? Anything?
New York Review of Books.

And Gandalf said: 'This is your realm, and the heart of the greater realm that shall be. The Third Age of the world is ended, and the new age is begun; and it is your task to order its beginning and to preserve what may be preserved. For though much has been saved, much must now pass away. . . . And all the lands that you see, and those that lie around them, shall be dwellings of men. For the time comes of the dominion of men, and the elder kindred shall fade or depart.'

J R R Tolkien. (1954) *The lord of the rings.*
(George Unwin and Allen, London.)

A sense of stupidity can easily descend on and darken the brain; and when I for one say I do not understand this or that, I do not necessarily imply the suspicion that there is nothing to be understood. In all sincerity, or stupidity, there are many of my own affairs that I do not understand.

G K Chesterton. (1958) Tagtug and the tree of knowledge.
In: *Essays and poems*. Ed. W Sheed.
(Penguin Books, Harmondsworth.)

So long as you write what you wish to write, that is all that matters; whether it matters for ages or only for hours, nobody can say. But to sacrifice a hair of the head of your vision, a shade of its colour, in deference to some headmaster with a silver pot on his head or to some professor with a measuring-rod up his sleeve, is the most abject treachery. . . .

Virginia Woolf. (1928) *A room of one's own.*
(Penguin Books, London.)

Doctor Jeddler was. . . a great philosopher, and the heart and mystery of his philosophy was to look upon the world as a gigantic practical joke.

Charles Dickens. *The battle for life.*

Never have I listened to such an extraordinary speech. At any other time, it would have been ludicrous, for here was a boy, with no sense of beauty and a puerile command of words, attempting to tackle themes which the greatest poets have found almost beyond their power. Eustace Robinson, aged fourteen, was standing in his nightshirt saluting, praising and blessing the great forces and manifestations of Nature.

He spoke first of night and stars and planets above his head, of the swarms of fireflies below, of the great rocks covered with anemones and shells that were slumbering in the invisible sea. He spoke of rivers and waterfalls, of the ripening bunches of grapes, of the smoking cone of Vesuvius and the hidden fire-channels that made up the smoke, of the myriads of lizards who were lying curled up in the crannies of the sultry earth, of the showers of white rose-leaves that were tangled in his hair. And then he spoke of the rain and the wind, by which all things are changed, of the air through which all things live, and of the woods in which all things can be hidden.

E M Forster. (1947) *Collected short stories. The story of a panic.* (Penguin Books, London.)

When I was at school, I studied biology. I learned that in making their experiments scientists will take some group — bacteria, mice, people — and subject them to certain conditions. They compare the results with a second group which has not been disturbed. This second group is called the control group. It is the control group which enables the scientists to gauge the effect of his experiment. To judge the significance of what has occurred. In history, there are no control groups. There is no one to tell us what might have been. We weep over the might have been, but there is no might have been. There never was. It is supposed to be true that those who do not know history are condemned to repeat it. I don't believe knowing can save us. What is constant in history is greed and foolishness and a love of blood and this is a thing that even God — who knows all this can be known — seems powerless to change.

Cormac McCarthy. (1993) *All the pretty horses.* (Vintage International.)

Zaphod lounged under a small palmtree on the bridge trying to bang his brain into shape with massive Pan Galactic Gargle Blasters. . . and Arthur took to his bed to flip through Ford's copy of The Hitch Hiker's Guide to the Galaxy. . . he came across this entry.

It said: 'The history of every major Galactic civilization tends to pass through three distinct and recognizable phases, those of survival, inquiry and sophistication, otherwise known as the how, why and where phases.

'For instance, the first phase is characterized by the question: How do we eat? And the second by the question Why do we eat? And the third by the question Where shall we have lunch?'

D Adams. (1979) *The hitch hikers guide to the galaxy.* (Pan Books, London.)

Great scientists can kill their subject. Newton killed physics in Cambridge. What, it was asked, was there left to do? As a result the advances in science and technology on the Continent were ignored. So were Faraday in London and William Thomson (Lord Kelvin) in Glasgow. Obsessed by the belief that an undergraduate must learn what was true, Whewell opposed the study of modern science: he argued that not until a century had passed could we be certain that scientific theories were true. . . . After more than twenty years of. . .arid discussion it was at last decided to set up a committee on the teaching of experimental physics (in Cambridge). . . .

Noel Annan. (1999) *The dons. Mentors, eccentrics and geniuses.* (Harper Collins, London.)

'Tis most true that many are possessed by an incurable itch to write. . . desirous of fame and honour, he will write no matter what. . .toiling for a frothy name among the vulgar masses. 'Tis pride and vanity eggs them on. They turn authors. . .to prove they have existed.

And if thou vouchsafe to read this treatise, it shall seem not otherwise to thee than the way to an ordinary traveller, sometimes fair, sometimes foul; here champaign, there enclosed; barren in one place, better soil in another. . . . I shall lead thee over steep mountains, though treacherous valleys, dew-clad meadows and rough plowed fields, through a variety of objects, that which thou shalt like and surely dislike.

Robert Burton. (1621) *The anatomy of melancholy.*