Sensation, Perception, Action – An Evolutionary Perspective

Chapter 1

Perception as Gateway to the World

'Wheel of the Five Senses' Longthorpe Tower, Peterborough, ca. 1320

An ancient representation of the 5 senses: "The King, as reason, ruling over the physical senses represented by a monkey (taste), vulture (smell), spider's web (touch), boar (hearing), and a cock (sight)".Oxford Archeological Guides: England; Darvill, Stamper & Timby; OUP; 2002

Overview

Why is perception such an important topic of study for psychologists? Throughout every single day of our life we incessantly and effortlessly solve complex tasks related to the collection and interpretation of sensory input, and the planning and execution of action based on what is perceived. We (usually) experince little difficulty to prepare a sandwich, catch a ball, ride a bicycle, or cross a busy road – but each of these seemingly simple tasks requires a huge amount of sensory information processing! Only when we observe the hopeless efforts of robots facing much, much simpler challenges (like walking up a step), do we start to appreciate how difficult it is to navigate and coordinate movements in a group of independently moving individuals, for instance, on a crowded dance floor. To address these questions, and to understand more generally how a person collects knowledge about the world and acts in the world, the information processing paradigm is introduced, together with the computer metaphor for the brain. This approach is closely linked, through the specific relationship between brain and perception, and more generally the relationship between brain and mind, to the study of brain function, which embeds perception in a variety of scientific disciplines that help us to analyse and conceptualise human behaviour. The attempt to localise mental functions in the brain is an illustration of how the information processing approach, and neuroscience, are highly relevant to gain some deep understanding of psychological phenomena. Sensory systems usually are treated as information processing channels that are tuned to particular signals (such as sounds, or odours) and used to solve particular tasks tasks (such as communication). Studying such mechanisms from a scientific and/or engineering perspective allows us to tackle questions of how their designs are optimised in the context of evolutionary adaptation and ecological constraints. In this framework, perception can be described as the window between the physical world and mental states.

What if the purpose of this book?

In a time of rapidly growing competition for resources, be it the time invested by a student in reading a book (as well as the time spent by the author writing it), or the timber harvested from shrinking forests and processed into printing paper at high costs in terms of energy and water pollution, the first question when picking up a book and beginning to turn the pages is “why should I read this book?”. The most simplistic answer for the Psychology student, “because it will help me to get my degree”, is certainly insufficient, and not a good reason to dig into hundreds of pages about phenomena and contexts that sometimes even present some challenge to understand. The reason for writing and reading this book, and for seriously engaging with its topic, is the fact that sensation, perception, and action have a fundamental relevance for all aspects of human behaviour and thinking. How can you prepare your tea and sandwich in the morning? How do you coordinate getting dressed, picking up – and keeping hold of – your bag? How do you cross the road without getting run over, ride your bike without falling over, or steer your car through dense traffic without getting involved in an accident? How do you find your favourite cereal in the supermarket and pick it off the shelf? How do you follow, throw or catch a ball? How do you communicate with the people around you? And how do you actually read a book? In all our daily activities we need to interact with the world surrounding us, and for any interaction we need to use our senses to collect information and control our actions. And yet all of these processing steps are happening completely unaware and effortless! Without being equipped with a sensory system and perception, however, no autonomous agent would be able to act, nor survive, in its given environment. The little sketch in figure 1.1 illustrates this crucial role of sensation and perception: the presence of an apple in the environment is picked up by the sensory system (through the eyes, or possibly by smell) and recognised as a real instance of the concept ‘apple’, which can trigger the behavioural response of grasping and eating (or avoidance, if the apple turns out to be rotten).

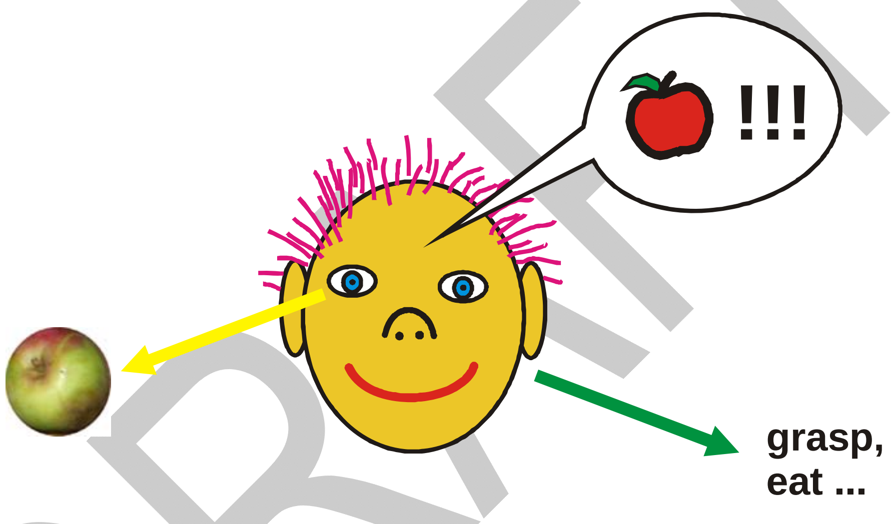


Figure 1.1: Sensation and perception allows a person to detect real objects in the outside world and to control the appropriate action in response to objects and events. In this example an apple is picked up by the visual system of our little egghead, recognised as an instantiation of a highly relevant class of objects (the thought ‘this is an apple’), and the appropriate response will be triggered and again guided by sensory information (grasp, eat…).

The purpose of this book, therefore, is to provide a basic introduction of the function of sensory information processing in the context of action control and of a particular lifestyle and environment, and to give some clues about how evolution shaped these systems to make them efficient and reliable, so that an agent (such as a person) can safely navigate in a complex environment and survive. It is important to note that the phrase ‘function’ has a dual meaning. On one hand this word relates to a specific mechanism, i.e. to the question “how does it work?”, which will be touched mainly in an abstract way in this book, because the actual workings of the neural machinery is the topic of more specialised neuroscience textbooks. On the other hand the word ‘function’ relates to a purpose, i.e. to the question “how is it useful, what is it made for?”, which relates much more closely to the behavioural and ecological context. In this distinction, however one should not forget that through evolutionary mechanisms the actual design of mechanisms is closely linked to its role in behaviour and environment, similar to the slogan of the Bauhaus arts and design school “form follows function”. As a result of this conceptual framework, the current text differs from many other textbooks on the topic of sensation and perception by going beyond the mere description of perceptual phenomena, and focussing on the adaptation of particular perceptual mechanisms in the context of their use to solve tasks that we are facing in our everyday ‘struggle for survival’. As such this textbook, whereas mainly directed at students of Psychology and in its level of detail written for psychologists with limited previous exposure to an engineering perspective, it also can serve as introduction to the topic for computer scientists, engineers, and biologists.

Representing the outside world

So how do we perceive the outside world? What initially seems to be a straightforward question, turns out to be a rather tricky philosophical problem. How do we know where we are, what is in the space surrounding us, what the effects of our actions are, how do we communicate with others and understand messages in a complex society? The answer seems to be very simple: we use our senses. We see the furniture, the walls, the trees in our environment, we hear birds, cars and airplanes, and what other people are saying to us, we smell a burning toast, and sense the heat (and sometimes the pain) when trying to remove it from the toaster, we feel the knife in our hand and taste the melting butter and the flavour of the jam. Very simple, and yet quite complicated when you think more thoroughly about it – there are myriads of tricky questions lurking behind these everyday perceptions and actions, some of which will be answered in this book. How do we steer clear of furniture, know the distance of walls and trees, how can we judge the speed of an approaching car? How do we recognize the voice of a friend, the face of our grandmother? What makes us smell the toast burning? When do we feel the heat and when does it turn into pain? How do we know how to grasp the knife at its handle and not at its blade? What makes us discriminate the taste of strawberry and raspberry jam? The common theme behind these questions is the collection of information about the outside world, in order to know, to understand, and to act. It could be argued that through our senses we are building a representation of the outside world in our mind. Although this concept is contested by some authors (such as Gibson 1979), we will accept this notion as a simple description and revisit its limitations later (see chapters 12 and 13).

The guiding question towards the understanding of the visual system therefore is: what are the fundamental steps of information processing to convert the outside (physical) world into internal (mental) events? This question– perhaps not surprisingly, because it touches on one of the most fundamental aspects of the human condition – has been raised by many philosophers for many centuries (see, for instance, Wade 1998). An early description of the fundamental principles of optical projection, (neural) transmission and (cortical) mapping can be found in Descartes (1664) the French philosopher, scientist and mathematician who often is called the ‘father of modern philosophy’. Rene Descartes (1596 - 1650) is regarded as key figure in the ‘Scientific Revolution’ (Kuhn 1962), which replaced previous belief systems and speculations with observations and experiments. Figure 1.2 summarises his attempt to describe how images of the external world (an arrow) are formed and processed in the visual system, leading to an internal representation in the brain, more specifically in the pituitary gland, where it becomes accessible to the mind. We can therefore regard this figure as one of the roots of our understanding of sensory information processing, as we interpret it in the 21st century through the methods of science – and science is what we are interested here.

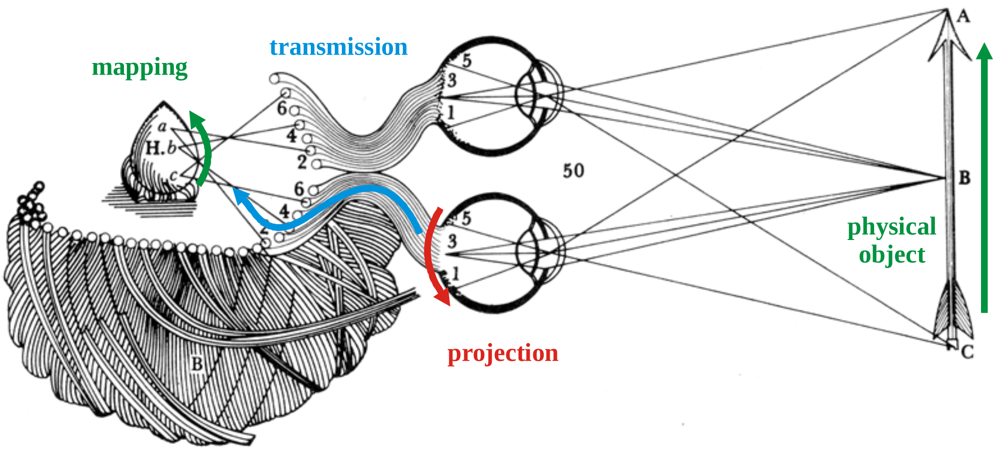


Figure 1.2: Representing the outside world in the brain (adapted from Descartes 1664). The arrow is viewed – and inverted through the eyes, the image is transmitted through the optic nerves to the brain, where it is mapped on the pituitary gland (which Descartes believed to be the seat of the soul). Whereas some anatomical and physiological features are recognised correctly, such as the inversion through the eye’s optics, there are other aspects in this sketch, such as the reversion of the image in the optic nerve and the mapping on the pituitary gland, are not supported by modern science (see Hubel 1979).

From Descartes’ sketch of the visual system in figure 1.2, we can already recognise a number of important questions to ask about the relationship between the physical world surrounding us and the internal, mental world:

- Why do we think that the mental world is located in the brain?
- How do we ‘read’ the mental map, what turns it into a percept?
- Why is the perceived world not upside down after the optical inversion in the eye?
- Is the internal representation a veridical picture of the world?

- Is the perceived world the same for each of us?

Some answers to these questions will be given in the course of this book, others are challenging enough to be still disputed by philosophers. When Descartes claimed the pituitary gland to host the ‘soul’, which today we would call the mind, he showed himself as a representative of a ‘dualist’ position – the coexistence of a material body and a non-physical mind. Contemporary scientists, in contrast, tend to support a ‘materialist’ position, according to which only the physical world can be proven, and the mind is an emergent property of the body (see Valentine 1992). The key scientific approach to investigate perception was defined as discipline by Gustav Theodor Fechner as ‘Psychophysics’ – as the study of “functionally dependent relations … of the material and the mental, of the physical and psychological worlds” (Fechner 1860). Many clues on the relationship between the physical and the mental world arise from looking at visual illusions (Gregory 1968): what you see is not what you have!

Sensation and Perception – and neighbouring disciplines

In many cases when you hear about Perception, you are confronted with a sibling term, Sensation, and indeed many books on the topic are entitled ‘Sensation and Perception’ (e.g., Goldstein 2007). What makes these two terms such close companions, and what are they referring to? They belong together because they are regarded to be two important steps in human information processing, from the raw data in peripheral sensory organs, such as images in the retina, to the central extraction of features or categorical information, such as objects or faces. Sensation, on the one hand, is traditionally believed to be related to low-level signals which undergo only basic, unaware processing and are not easily accessible to others. Perception, on the other hand, refers to high-level ‘stuff’ that is available to consciousness, and therefore can be communicated to others. It is immediately clear that it would be very difficult to exactly separate such two processing levels, and that the low-high-level boundaries between sensation and perception might be even impossible to define. As a matter of fact, there is a continuous processing stream from the signals captured by the sensory organs to the point where we recognise objects and events in our environment. Furthermore, we would end up struggling with giving a precise and comprehensive explanation of terms like ‘awareness’ or ‘consciousness’ (Crick 1995), and we cannot deny that we are able to build high-level representations of the outside world without being aware of their contents (Koch and Crick 2001). Just imagine how safely you can navigate a vehicle through dense traffic without being aware of most of the scene around you (Land 2001)! To avoid such theoretical and practical difficulties, the distinction between sensation and perception will be largely abandoned here, and the term ‘perception’ will be used at all stages of the processing stream. The benefit of this approach will become obvious when the information processing paradigm ha been introduced later in this chapter.

Why is perception so important for psychologists? Psychology is the study of human behaviour and thinking, or more specifically “the science of the nature, functions, and phenomena of the human mind” (Oxford English Dictionary). Thinking is an extraordinary phenomenon: we spend all our life thinking (which doesn’t mean, obviously, that we always produce clever thoughts) and can’t switch it off – which is fundamentally different from most kinds of other activities. Therefore it is one of the most exciting challenges for contemporary science to find out about the machinery of thinking. The mechanisms of thinking are studied in cognitive psychology, and its biological substrate – commonly assumed to be the brain – is studied in neuroscience. Some core thought processes, related to the acquisition, handling, storing and application of knowledge, can be grouped as ‘cognition’, and Cognitive Sciences comprises a multidisciplinary group of scientific approaches (psychology, linguistics, artificial intelligence, neuroscience, philosophy) with the common goal of understanding the human mind (Eysenck 2006). Some authors regard the study of perception as part of (experimental) cognitive psychology, because it is the starting point for acquiring knowledge about the world, for all higher thought processes, and for the control of behaviour. Just think about language – communication is based on reading text, watching signs, or listening to sounds and spoken words. Even if one doesn’t want to treat perception as part of cognition, it is obvious that thinking and behaviour is based on a chain of information processing in the nervous system which starts with the collection of sensory signals and perception. As illustrated in the simple block diagram of information flow of figure 1.3, it might be better to talk about a network rather than a chain of information processing, because bottom-up processes transmit information from the sensory organs into higher areas of the human nervous system, whilst at the same time lower areas are modulated through top-down connections. This design of recursive information flow is called by engineers a ‘feedback loop’.

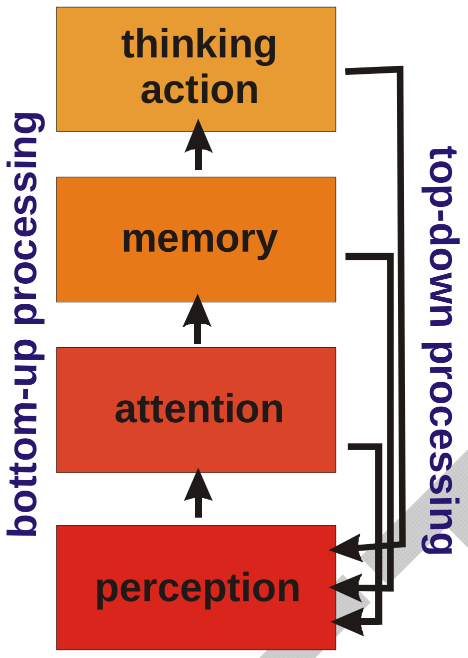


Figure 1.3: Perception is the starting point for higher cognitive processes: the selection ('attention'), storage and retrieval ('memory'), and reorganisation of knowledge ('thinking'), and through this also for the control of behaviour ('action'). Whereas the initial flow of information is 'bottom-up', from lower processing levels of sensory to more higher processing levels handling more complex and abstract representations, there are 'top-down' mechanisms which modulate early processing.

To fill the abstract block diagram with some specific meaning, let's run through a rather trivial, everyday example, which illustrates different aspects and levels of processing – demonstrating how little effort is needed for a lot of simple and complex processing tasks. Imagine you meet your friend in the café to work on your statistics exercise – what are the necessary processing steps in your brain? Perception: you enter the café and look around, identify tables, desks, the people populating the place, smell the coffee; attention: you ignore almost everything and find your friend; planning and control of action: you approach the table without knocking over chairs; learning and memory: you find the problem sheet in your bag; language: you start a conversation; knowledge handling: you try to memorize the contents of the lectures; reasoning: you select the right equation and compute the result.

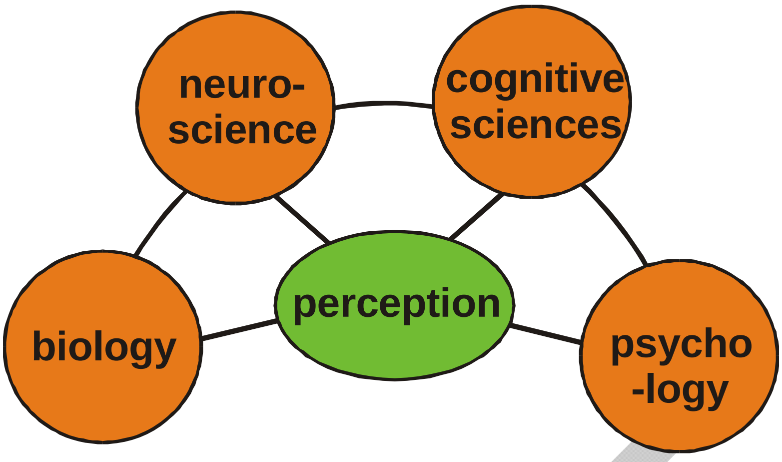


Figure 1.4: Perception, the 'window' between the outside (physical) world and inside world (mental states), is studied in the context of a variety of overlapping disciplines: biology, neurosciences, cognitive sciences, psychology. All of these disciplines are concerned with the question of how information about the environment is collected, stored, interpreted, and used to control behaviour.

Because perception is the starting point for all other areas of psychology, and is equally relevant for our understanding of how the brain works and how behaviour is organised in a wide range of animals, the study of perception is closely linked to, and overlapping with, other disciplines, including neurosciences and behavioural biology (see figure 1.4). As a result, this book on perception will make repeated references to crucial topics from neuroscience, and even will offer an excursion into some exciting areas of biology – with the goal to extend our understanding of the crucial design features of perceptual mechanisms and their limitations.

The information processing paradigm

You may be surprised how often words like 'signals', 'information', or 'processing' were used in the preceding paragraphs, and might be puzzled about this rather technical language. This terminology reflects the scientific paradigm – information processing - which guides our current understanding of perceptual and cognitive systems, as well as the control of behaviour. Whereas early studies of perception focused on phenomena, such as illusions, and led to abstract explanations in terms of 'constructing' perceived representations (von Helmholtz 1924), the contemporary approach is dominated by major conceptual and technological developments in the mid 20th century. During this dramatic period of scientific progress, the American mathematician Norbert Wiener (1894-1964) founded the discipline of Cybernetics (Wiener 1948), which enabled us to systematically describe basic control systems and in the last decades has been successfully expanded to the mathematical modelling of complex systems, artificial as well as biological (e.g., Marr

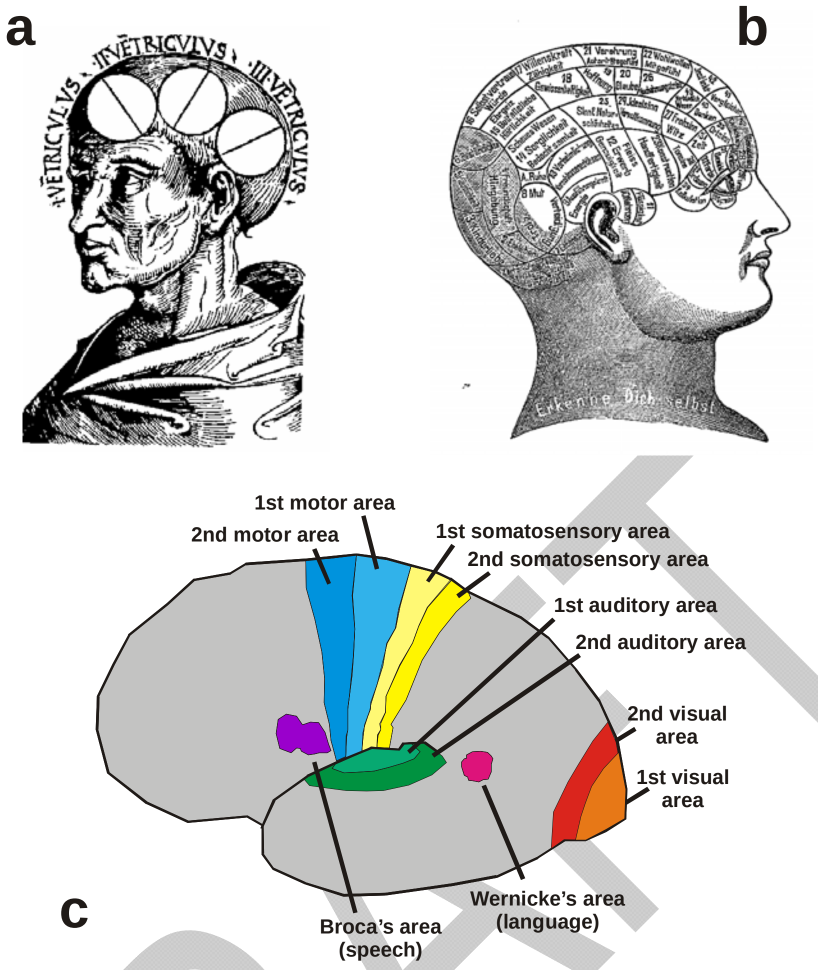
1982). Based on these advances of information theory, the first powerful digital computer was developed by John von Neumann (1903 - 1957). This revolutionary design was the foundation for modern microprocessors and computers that nowadays populate or world in astounding density – you find them in cars, washing machines, I-Pods, digital watches, mobile phones, laptops, and all other fancy gadgets that you are accustomed to, and which continue to flood the market place with growing speed. Perhaps more importantly, digital computing changed the way we are thinking about things.

In particular, information theory and digital computing changed our understanding of how the brain works. The central scientific approach to describe nervous systems, perception and cognition pivots around the acquisition, selection, storage, recall, and processing of data, which is called the ‘information processing approach’ (Lachman et al 1979). Correspondingly, although there are wide-ranging differences between the brain and man-made IT devices, most obviously in relation to the underlying hardware and plasticity, an often used metaphor for the human brain is a computer. As a natural extension of this approach, we can test our explanations of perceptual or cognitive processes: if we can build a machine that does exactly the same as the brain, then we are successful in understanding the underlying processes (Braitenberg 1984; Minsky and Papert 1988). In order to appreciate the progress made by applying the information processing paradigm, we should have a brief look at some historical metaphors of brain function, keeping in mind that identifying the importance of the brain for thinking and control of behaviour was a scientific achievement in itself. Rene Descartes (1644), inspired by the first micro-anatomical descriptions of nerve fibres, suggested that information is transmitted in nerves by fluids travelling through these fibres – a ‘hydraulic’ model of brain function! In the 19th century, the mathematician and self-made mechanical engineer Charles Babbage (1791 – 1871), designed a mechanical computer at a gigantic scale, driven by a steam engine, to calculate astronomical tables. He compared this ‘difference engine’ to the workings of the brain, leading to the label ‘cogwheel brain’. A partial reconstruction of his ingenious machinery can be seen, sometimes even in action, in the Science Museum in London (Swade 2000). It is worth noting from these examples that the understanding of brain function is related to the lead technology of the period: hydraulics, mechanics, IT. Try to image yourself in a fifty or hundred years time, when digital computing might be replaced by a new advanced technology – what do you think the metaphor for brain function will be?

The workings of the brain in perception, cognition, and the control of action

When lecturing perception, cognition, action control, or neuropsychology to Psychology students, one often is confronted with the expectation, or angst, that these areas are difficult, irrelevant and not really a part of psychology, and possibly even boring. Part of these concerns might be generated by the discrepancy between the common image of Psychology as a discipline that often looks at topics like the interaction of humans in groups or the patterns and causes of ‘abnormal’ behaviour, as well as the rigour and technical challenges imposed by methods of natural sciences imposed on the study of the human mind. Some readers will still be sceptical at this stage about the relevance of perception and the value of an information processing approach and ask themselves whether a psychologist should really need to be exposed to all this technological jargon and would gain anything from the understanding of brain function. Although the full benefit of this – let's call it, in want of a better word, 'science-engineering pursuit' – might only be clear at the end of the book, the strength of such an approach will be illustrated with some examples in the following (for a wider view of such evidence, see Blakemore 1977).

Is the science-engineering pursuit difficult? It certainly will be outstandingly difficult to fully understand how the brain, or the mind, works; and many scientists argue it would be impossible as a matter of principle (Gierer 1983). However, complex systems can be approached at difficult levels of understanding, and science offers theoretical frameworks to describe them in compartments or reductions (Valentine 1992). We are used to operate machines (like cars or computers) and understand their function, even if they are quite complex - so why should we not look at the brain in action and try to understand it? The validity of such attempts obviously needs to be carefully evaluated; but if we can build a simple contraption or 'model' which generates the same behaviour as the system we want to explain, we have come a long way! A straight forward and simple approach to understanding how the brain or mind works, is to divide processing in functional units (or components), or to identify brain regions that are responsible for distinct operations. This approach has a long history, going back to scholars like Albertus Magnus (c.1206 - 1280) who localised mental functions in the ventricles, the cavities in the brain filled with fluid which were believed to be the 'animal spirit'. Although there is some dispute about the exact nature of the three basic functions (Stratton 1931), in general sensory analysis (*sensu communis*), reason (*ratio*) and thought (*cognatio*), and memory (*memoria*), were attributed to the three respective compartments (see figure 1.5a). Emerging from a scholastic background, this figure has little support from what today would be accepted as 'scientific evidence', but it demonstrates a clear attempt to break a complex problem down into simpler components. Exploiting the dramatic progress in neuroscientific imaging techniques, most notably magnetic resonance imaging (MRI), during the last two decades (e.g., Le Bihan 2003; Salvador et al 2005; e.g., Tootell et al 1995), we can now advance from speculation to hard scientific evidence, and draw up a coherent, and rather detailed, picture of the functional architecture of the brain (as sketched in figure 1.5c). In various imaging studies it has been shown in great detail, for instance, which different brain areas are active when a participant is communicating with others by means of language, demonstrating the different and shared networks in the brain that are activated during reading words, listening to spoken words, or speaking (Price 2000).



nderstanding the brain in terms of compartments. (a) At the outset of a long tradition; it was generally believed that the three ventricles host sensory analysis, reason and thought, and memory, respectively. From the 1506 edition of Albert Magnus' 'Philosophia pauperum' (after Blakemore 1977). (b) The 'Phrenology' map of human brain areas that are believed to be responsible for individual attributes (including personality traits) and for organising behaviour Franz Gall, 1758 - 1828) is a historical – and seriously flawed – document, which nevertheless demonstrates the relationship between the mind and the brain as its substrate which therefore will set constraints to the working of the mind. (c) The distribution of activity in the human brain during various activities can be determined with modern imaging techniques, which allow us to assess the 'functional architecture' of the brain (Zeki 1993), as illustrated in this rough sketch. *Is the science-engineering pursuit irrelevant for Psychology?* On the contrary - it is fundamental to other areas of psychology! Perception is crucial for many other aspects of human life because these are mediated through the brain and its sensory systems: how we interact with the world, how we select, store, and retrieve acquired information, how we communicate, how we organise our social life, how we maintain mental health, how we plan actions, make decisions. More generally, neuroscience today is believed to be the key to understanding the processes underlying mental events (Kandel and Squire 2001). Once again, the historical fascination with brain maps (see figure 1.5b) reflects this important relationship between our understanding of human mental capacities, the subject of Psychology, and the understanding of the brain, the subject of Neuroscience. Charting the human brain into maps of regions that were believed to determine individual attributes and behaviour was the ambition of 'phrenologists' (Zola-Morgan 1995). These maps were based on data collected by methods which today are recognised as seriously flawed – generating ideas that were much closer to fiction than to science! However, the idea of functional components in the brain is now supported with a wealth of hard scientific evidence (Gross 1998; Zeki 1993)**,** and there is a growing variety of human behaviour, such as the rapidly growing field of ‘Neuro-Economics’ (Sanfey 2007), that is studied with neuroscientific methods. Although there are sceptical voices that speak of a ‘new phrenology’ (Uttal 2003), it is becoming increasingly obvious, that the science-engineering pursuit provides a solid scientific basis for understanding issues in social, personality, occupational, health psychology, etc..

Is the science-engineering pursuit boring? Obviously this is a matter of taste, and readers will have to answer the question themselves. Just as a taster to help with the decision, here are some typical questions (for a more comprehensive list, see Lewin 1992) addressed in this pursuit :

- How do we know that what we see (hear, smell, etc.) is what we have? Do two individuals always/ever see the same? How do you compensate for the loss of sight? How does a magician make us not see things which are out in the open in front of our eyes?
- How do we plan and coordinate complex motor patterns? Why does it sometimes go wrong? (for instance in Parkinson’s disease, after stroke, when you are exhausted, or drunk…)
- What is the basis of addiction? What happens in the brain? How do drugs affect perception? What makes drugs feel pleasant? How do they change our consciousness?
- What is consciousness? Does it depend on the brain? How is it related to neural activity? How does it interact with perception? Why do we need it? Are animals conscious? How can we know this?
- How is memory organised? How much can we memorize? Are some things easer to remember? Why do we forget? Can you train your memory?

Most importantly, the science-engineering pursuit is addressing some of the most exciting questions of mankind, such as: How do we think? What constitutes the mind?

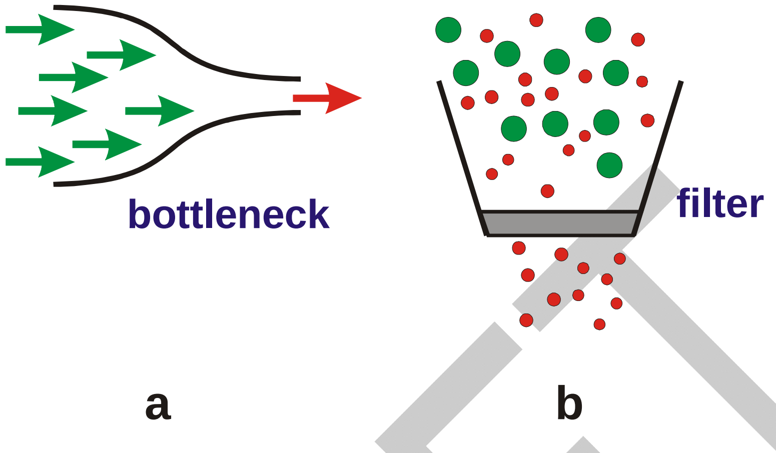
To conclude, there are three main reasons why its is important for Psychologists to engage with the scientific study of the brain, and study perception, and cognition: (i) Pure scientific curiosity: the aim to understand the human mind as such. (ii) The wish to design ‘intelligent’ applications: the objective to implement knowledge in thinking machines

(Artificial Intelligence). (iii) The search for a theoretical basis to understand pathology and manage impairments (as investigated in Cognitive Neuroscience). To indicate the relevance and scope of the clinical aspects, just think of one prominent example, the memory loss in Alzheimer Type Dementia, which is expected to affect 6 Million individuals in the US population in 2020 (Hebert et al 2003) and currently has no treatment.

Perception as initial 'data mining' to feed the human mind

We need to navigate through and operate in a dangerous world and we need to collect 'intelligence' (knowledge) in order to 'make sense' (understand) the world. There is no computational work, no controlled behaviour, no knowledge, no decision making, without sensory input. Sensory information, just as any information, needs to be accessible, manageable and reliable in order to be useful. Whenever you search the internet for some topic you want to learn something about, you are facing two basic problems: Firstly, your search engine may return too few or too many hits, which makes it difficult to select from the vast amount of information that is available on the web those entries that seem to be most relevant. Usually you would respond to by refining your search profile or make sure that the list of information returned from your search is ordered (according to popularity, relevance, chronology, etc.). Secondly, having selected the relevant pages, you need to consider the reliability of the particular source – you don't want to draw conclusions about the best beaches in you holiday destination from some questionable comments released in the internet by someone who happens to runs a bar on a particular beach, would you? To reiterate, information needs to be accessible, manageable and reliable, otherwise it is useless. Similar to you depending on your internet access which opens for you the window to the internet, the human mind is depending on the sensory systems to open the window to the outside world. Interestingly, unlike you browsing the internet, sensory information processing is completely incessant and effortless. Whereas you can shut down your browser and load it again when you want (at least one would hope so), you don't need (and you can't) switch your senses on or off, and you are not getting exhausted from the unbelievably vast amount of sensory signals streaming through your nervous system. Given the sheer amount and variety of input information processed by the sensory systems, together with its automaticity, computer scientists would talk about 'data mining' – we are steadily digging through all these visual, auditory, and chemical signals which are continuously bombarding our sense organs.

The comparison with searching the internet for information highlights two issues that are central to all information processing (illustrated schematically in figure 1.6) and will accompany us through the following chapters. (i) Each system, be it technical, sensory or cognitive, has capacity limits of data flow (a 'bottleneck'), which call for intelligent coding strategies to minimise information loss. Similar to measuring flow capacity of a water pipe in litres per minute, transmission capacity in digital systems is expressed as bits per sec [bps], which can be used for all kinds of information channels, such as a printer or a WiFi connection. (ii) In order to make optimal use of the available capacity, irrelevant data is removed from the information stream, whereas relevant data are retained – such selection mechanisms are usually called 'filters', defining an information processing channel.



a) a **bottleneck** limits the amount of information that can be processed at the same time within a channel; (b) a **filter** selects the type of information (a particular grain size in this 'literal' example of a filter) that is to be processed in a given channel, which helps to optimise processing performance.

In a computer, information is entering the system through devices such as a keyboard, a webcam, a microphone, a modem, etc.. In the nervous system, information is collected to be processed in the brain through the senses – these sensory channels are the topics for the next chapters. Following the ideas of the Greek philosopher Aristotle (384 – 322 BC), there is a tradition to distinguish five senses (Everson 1997): vision, touch, hearing, taste, and smell (Gonzalez-Crussi 1990). However, closer inspection reveals that there are additional senses in humans, such as temperature, pain, or balance, and further senses can be found in other animals, such as infrared vision, ultrasound, magnetic or electric sense. We will return to this question in chapter 13, illustrating the wide range of sensory channels in the context of evolution. A cursory assessment of the human sensory channels illustrates that despite the huge differences between the specific designs of particular sensory systems, the information processing paradigm offers a conceptual framework, which emphasizes unifying principles that hold the key to the understanding of the function of sensation and perception. More specific aspects of these and other sensory channels will be discussed in relation to the information processing paradigm in the following chapters.

Hearing (auditory perception) is used to pick up acoustic signals about events in the environment; it is crucial for communication and orientation, and it mediates emotional responses such as relaxation, stress – the ear is, as we shall see later, an intelligent microphone that employs a number of filter operation to maximise the information that can be transmitted through the auditory nerve to the brain whilst capturing a wide range of acoustic information.

Touch (somatosensory perception) is essential for detecting and recognising objects through physical contact, for maintaining the position and integrity of the body, and for controlling movements. This channel depends on mechanosensors distributed all around the body which define the type and amount of information that is made available to the control circuits in the brain. It is a very powerful and highly adaptive system we are usually completely unaware of – can you feel the glasses on your nose or the shoes on your feet?

Smell and Taste (olfactory and gustatory perception) are very basic sensory systems which are often forgotten, but help us importantly to keep us safe in a complex and dangerous world, and are crucial for our well-being and emotional balance. These channels are defined, and their capacity are limited by the kinds and numbers of molecules that can be absorbed by the sensory epithelium to assess the chemical composition of the air, or food, respectively.

Sight (visual perception) is often regarded as the most important of the senses, because it is an immediate and very rich source of information. In a technical sense, it is most impressive due to its large channel capacity. With 100 million receptors in the retina of each retina, 1 million nerve fibres transmitting the information from each eye to the brain, where it is processed in about 30 brain areas which amount to more than 20% of brain and contain some 10 billion cortical neurons (Wandell 1995), the visual system is not paralleled in its processing power and richness of output information by any technical system built so far.

Take home messages

- studying perception, together with cognitive psychology is part of a multidisciplinary attempt to study the human mind : how do we think?
- the central scientific paradigm is the information processing approach : the brain is interpreted as a computer dealing with huge and complex data sets
- by localising and modelling brain function we can address a number of interesting questions with great cultural and practical importance
- perceptual processes are required as input for the neuronal machinery, providing the information necessary for a wide range of vital functions
- perception is both a bottleneck reducing the amount information and a filter selecting relevant information - we speak of channels, tuning, capacity

Discussion Questions

- Describe the relationship between the physical properties of the outside world and its internal representation.
- What is the information processing approach?
- Describe the historical development of understanding the functional architecture of the brain.
- What are the main channels of the human sensory system?

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