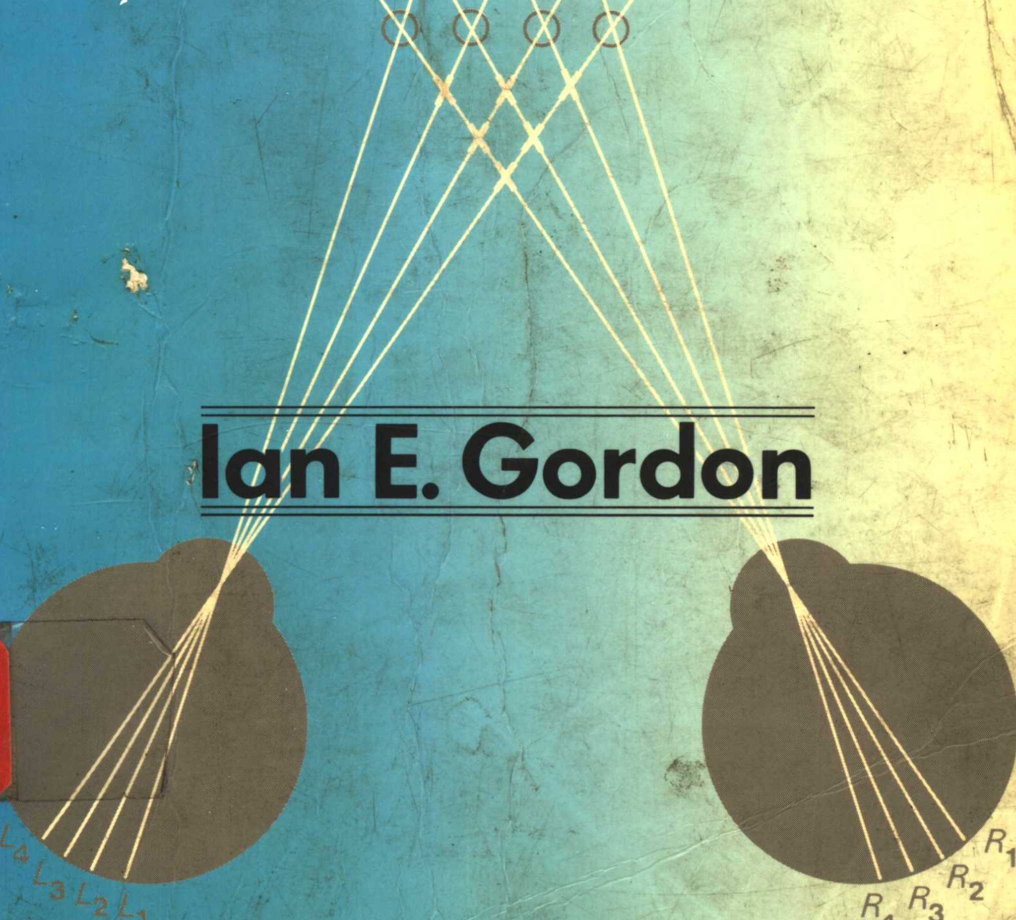
THEORIES OF VISUAL PERCEPTION



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Theories of Visual Perception

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Preface

This book is about theorizing in perception, with particular reference to vision. It is aimed at advanced undergraduate psychology students, but has been written in such a manner that it should be of interest to students in related disciplines such as philosophy and physiology. It is hoped that it will also be of use to others who are interested in the phenomena of seeing, but who lack formal training in experimental science.

Perception is a rewarding subject to teach. It would be a dull person who did not respond with wonder when shown some of the remarkable things which the senses can do. And to be trained to observe perception at work in daily life can have a permanent effect on one's awareness. The formal study of perception brings one into contact with some of the best scientific minds of the past and present: this book describes three pieces of research which have won the Nobel Prize.

Perceptual effects tend to be highly reliable. A demonstration which has worked in the laboratory will not fail in front of an audience. As the subject matter of perception seems to be inherently interesting, the phenomena highly reliable and easy to demonstrate, the teacher is in a most fortunate position. Perceptual experiments tend not to be very complicated (although the equipment may be) and students can quickly learn to appreciate even the most advanced pieces of research.

It is also true to say that although modern perceptual research is basically scientific and experimental, a background in the arts is not a major disadvantage to the student. Provided he or she can acquire some basic knowlege of the physics of stimuli, the biology of the nervous system, and the essentials of experimental design, the world of perceptual research and theory is there to be explored. What is more, whilst knowledge of art and literature is not itself a qualification for entrance to academic perception courses, such knowledge can be invaluable later. Scientists have never had a monopoly of interest in, for example, colour vision. Knowing what the Impressionists were trying to do can yield insights into this aspect of vision which are as interesting as any gained from formal experiments.

Once a visual phenomenon has been discovered it is customary to publish it together with a tentative hypothesis as to its causes. Here too first- and second-year undergraduate students usually cope quite well; most explanations at this level are quite lucid and convincing—journal editors see to that.

Students' difficulties commonly begin when they attempt to learn about the more general theories of perception. For example, any moderately diligent student can come to terms with the differences between Three-Factor and Opponent-Process theories of colour vision (dealt with in Chapter 5). Equally, it is not hard to master the explanation of the perception of contours in terms of neural processes in the retina. But it may be very hard to accept that general theories of visual perception (the main subject of this book) can differ as markedly as do, for example, the Gestalt Theory, Ecological Optics, and the Computational Theory of Vision. These major theories, to be discussed later, approach the same cluster of phenomena in very different ways and seek to explain them using very different concepts. Why should this be so? Why do we find major differences in the style of exposition, the terminology, and the level of explanation—which can vary from mathematical to neural to philosophical? Which is the best general theory? Is it possible to create an amalgam of the successful parts of different theories?

Questions of this sort, which seem perfectly fair, eventually encouraged me to organize a new third-year seminar at Exeter. This had the title, 'Theories of Perception', and during the next few years I and some able undergraduates wrestled with a variety of general theories, particularly those relating to visual perception. Things went quite well until the time came to introduce Marr's book *Vision* as a topic for discussion. This struck most students (and me) as a difficult work, something which stretched us considerably. I therefore began to circulate some notes of my own on the Computational approach to vision. Student feedback led to the refinement of these until it seemed worth expanding them into a chapter-length exposition. But in order to arrive at a balanced evaluation of Marr's work it became necessary to revise my thoughts on some of the rival approaches to visual perception. *Theories of Visual Perception* grew from there.

Preliminary versions of all the main parts of this book have been commented upon by three generations of students. It is hoped that the resulting account of seven major theoretical approaches will be sufficiently clear to help any student studying perception at university level. The choice of theories will display the sheer variety of attacks on the problem of how we see the world, and the inclusion of work from the past should do something to explain the origins of this variety.

Those who study visual perception in a modern psychology department are in the fortunate position of being able to get their hands on the apparatus necessary to generate most of the interesting phenomena of vision. But not all readers will be as fortunate as this. For them, I have gone to some pains to try to describe the key phenomena as clearly as possible, so that they will appreciate the theoretical explanations which follow. Many procedural details are also made quite explicit and I have not hesitated to introduce additional basic material where this might help. Thus what is basically a fairly advanced undergraduate text will, I hope, contain enough clear descriptions to permit lay readers to appreciate some of what is going on in the study of visual perception. Some technical work is very hard to describe briefly and lucidly; this will become apparent in the descriptions of certain crucial experimental tests of some of the theories. However, I have done my best. The references listed at the end of each chapter will be helpful as they commonly contain fuller descriptions than there is space for in this book.

In these ways I hope to have opened up the fascinating problem of explanation in visual perception to a wider audience than is usual. More experienced readers will always know when to skip particular sections.

Regrettably, I have had no formal training in philosophy: the emphasis in this book is always upon experimental psychology. But the problem of explaining vision leads inevitably in the direction of philosophy. After all, the key questions any perceptionist should have in mind are: What can we know about the external world; How do we come by this knowledge? So whilst this is not a philosophical text, many of the questions raised are of a philosophical nature. But the thing about philosophical questions is that they are hard to answer. My goal is to interest the reader in some of the deeper problems of perception, but I do not offer any easy solutions: there are none.

Contents

Chapter 1

Introduction to the various theories of visual perception

There are many theories of visual perception. Few psychologists know them all; no teaching department includes more than a small subset in its perception courses. And the theories are often very different from each other—a fact which can prove perplexing to students. In this short introductory chapter an attempt will be made to explain why theories concerned with a single sense—vision—should differ so markedly in their style and content. The bias towards visual in general theories of perception is also explained. The chapter is intended to provide a general orientation, particularly for those who are new to the study of visual perception and whose knowledge is grounded in areas other than psychology, such as philosophy, physiology, or the visual arts.

We shall begin with a few general remarks about theories, particularly as they have developed in psychology and related disciplines. Note that the remarks represent a very great oversimplification of the continuing debate about the nature of scientific theories. Further, some of the work to be described later in the book does not strictly qualify for the label 'theory': we shall include some very general approaches to perception, such as psychophysics and artificial intelligence, which are of great intellectual and technical importance, but which could be adopted by workers approaching the problems of visual perception from different theoretical starting points. Nevertheless, these general approaches are used in attempts to explain the phenomena of vision; for this reason they are appropriate subjects for discussion.

The following account aims merely to form an appropriate framework for subsequent evaluations of perceptual theories. Readers who wish to learn more about current thinking in the philosophy of science should consult the references given at the end of the chapter.

SCIENTIFIC THEORIES AND THE STUDY OF PERCEPTION

The majority of those who have worked on perceptual problems have adopted the standards and assumptions of experimental science. That is to say, whenever they have theorized about phenomena they have attempted to meet certain accepted scientific criteria. These may be briefly summarized.

(1) Theories should offer economical accounts of a range of facts. A theory is not much use if a description of it is as long as that required to describe the relevant phenomena.
(2) Theories should attempt to explain phenomena, or at least suggest causal links between them.
(3) Theories should be testable. They should be stated in such a manner that deductions can be derived and tested empirically.

These points may be illustrated by reference to a perceptual theory, the Young–Helmholtz theory of colour vision.

Humans can see several million different colours. And our colour vision is *trichromatic* in that all the colours we can see can be generated by suitable mixtures of three primary lights. One of the first scientific theories of colour vision, the Young–Helmholtz theory, used the remarkable fact of trichromacy as its starting point. The theory (which will be described more fully in Chapter 5) clearly satisfies the first of the above criteria. Colour vision is described in terms of three mathematical curves, each representing the absorption properties of a hypothetical receptor in the eye. The curves are, in effect, an elegant way of summarizing human colour sensitivity.

But the Young–Helmholtz theory also attempts to *explain* colour vision. It holds that there are three types of receptor in the eye, each sensitive to a portion of the spectrum, and it is the combined activity of these receptors which underlies colour sensitivity and explains why this is trichromatic. The theory meets the second of the listed criteria.

The Young–Helmoltz theory is no longer accepted as a completely adequate theory of colour vision. It cannot account for changes in the appearance of coloured lights when their intensity changes; it does not explain why yellow appears always as a unitary, primary, colour even when it has been formed by mixing red and green light; it has difficulty in accounting for certain forms of human colour deficiency. The theory is obviously testable and therefore meets the last of the above criteria.

Most theories of perception have this in common: like the Young–Helmholtz theory they attempt to satisfy the basic criteria listed above. For this reason they merit the label 'scientific'. But it is important to state here that theories of perception are in other ways very different from each other. This will become very apparent in subsequent chapters.

THE ORIGINS OF THEORIES

In the history of experimental psychology one can see very different approaches to the activity of theorizing. In one tradition the curiosity of researchers is triggered by the discovery of a new phenomenon. As more is learned about the phenomenon it becomes possible to offer explanatory hypotheses. These become broader, stimulating the search for related phenomena and tying them together. Eventually a theory emerges. This Baconian approach to science was endorsed by one of the founders of experimental psychology, Gustave Fechner (1801–1887), who recommended that in the study of aesthetics one should start 'from below'; in other words, do simple, analytic studies from which general patterns may emerge. Many examples of this continuing tradition will be seen in subsequent chapters; it will be very noticeable in the accounts to be given of psychophysics and neurophysiological theories.

There is, however, a diametrically opposed tradition of theorizing in experimental psychology, one in which the starting point may be a philosophical belief that something must be the case; that the fundamental nature of human perception or thought is such that certain experimental outcomes are only to be expected: they are merely confirmations of a theory which depends upon some reasoned analysis of human capacities or behaviour.

A good example of such theorizing 'from above' is the work by Piaget (e.g. 1967) into children's reasoning. Many readers will have some familiarity with the famous demonstrations in which, for example, it can be shown that children of a certain age think that if a lump of clay is rolled out into a long shape, this shape contains more clay. Or that liquid poured from a squat vessel into a tall thin one increases in volume. But Piaget's theory of intellectual development (including the development of perception) did not *arise from* such simple experiments. It was his views on the nature of logic and thought that prompted his demonstrations. It is as if (to use a hypothetical and non-Piagetian example) an analyis of arithmetic in logical terms showed that addition is more basic than, and prior to, multiplication; that the one must exist before the other is possible. Then if this is true about the logic, must it not also be true of the users of the logic? So, one would expect children to be able to master these mathematical skills only in the right order. It is in this sense that Piaget's demonstrations are *confirmations*: they represent an extrapolation of an epistemological theory to the intellectual development of the child.

In Chapter 3 we shall see something of this approach when considering the work of the Gestalt theorists. To some extent it can be said that these workers arrived at a conception of what perceivers are really like, that the functioning of the nervous system is such that the world is seen in the only way possible. Then in Chapter 7 it will be shown how a major challenge to accepted views of perception stemmed from a critical analysis of these views and a desire to replace them with what seemed like a truer account of perception. In both these cases the thinking is really more important than the experimental research; the experiments are really demonstrations rather than sources of new hypotheses.

A third source of theory is one which is stressed less frequently in formal treatments of the philosophy of science or the history of psychology. This is the influence upon research and theory of new techniques and methods of analysis. Techniques do not exert a direct influence upon theorizing, rather they open up new possibilities for the exploration of phenomena which in turn can provoke new explanations.

In the early 1950s the first twin-track tape recorders became available. This now seems like a fairly small technical advance. But it was such a machine that allowed Cherry (1953) to conduct his famous experiments on dichotic listening in which he showed, for example, that a person who is shadowing a message in one ear may learn very little about a message delivered simultaneously to the other: although the sex of the speaker can be identified, the language they are speaking, for example English or German, will not be noticed. This single demonstration stimulated a host of similar studies, and these led eventually to Broadbent's widely influential Filter Theory of attention (Broadbent, 1958).

Research on personality and intelligence has made intensive use of the technique of Factor Analyis. Without this statistical method it is very doubtful whether it would have been possible to detect the underlying regularities to be found in batteries of test scores. Now there are theories both of intelligence and personality which are couched in the technical language of factor analyis: the factors which are a basic part of the technique have been adopted as psychological explanatory constructs within major theories.

Good examples of the influence of technique will appear in later chapters, particularly in discussions of psychophysics, neurophysiological theories, and the computational approach to visual perception.

A final stimulus to theorizing is the availability of models. This will be dealt with more fully below. For now it suffices to note that models have had a very important influence on perceptual theories. In the next chapter we shall describe the impact on psychophysical research of the Theory of Signal Detection. Not only did this provide psychologists with a valuable new technique for the exploration of sensory thresholds, it suggested a new model for the observer, a model which was rapidly adopted in several different areas of enquiry.

DIFFERENCES BETWEEN THEORIES OF VISUAL PERCEPTION

At this point we will attempt to explain why theories of perception are commonly so different from one another. There are many theories within the area of visual perception which can be described as specific or local. These include, for example, theories concerned with certain aspects of colour, movement, acuity and depth perception. As these areas of perception are very different from one another, it is hardly surprising that they require very different explanations: the theories differ because the phenomena they seek to explain are themselves very different. But there are also several general theories of perception, and here too one finds great variety of style and content. This is perhaps more surprising. At least three different reasons can be given for this variety.

First there is the influence which the past exerts upon the present. It will be shown later how, for example, the recognition of serious flaws in knowledge-based models of perception led some theorists to concentrate upon the environment in an attempt to show that it provides stimulation of such richness that objects and events may be perceived directly, without the involvement of reasoning and inference. The recoil from a theory which seems to be basically wrong in its assumptions may encourage theorists to produce something very different.

A second reason concerns the availability of models. Much scientific thought has been shaped, directly or indirectly, by the models or metaphors currently available to theorists. For example, in the 1640s Descartes was developing what were to become very influential views on the mind–body problem. The essence of Cartesian Dualism is that the human body is a physical machine controlled by the mind. This control is exercised by 'animal spirits' flowing through channels in the body, with the pineal gland in the brain forming the point where the body interacts with the mind or soul. It is interesting to ask what physical models would have been known to Descartes at the time he was writing his *Discourse on Method*. The answer is that in the Royal Parks of France were a number of remarkable automata. These were mechanical human figures driven by water pressure and connected to hidden pipes in such a manner that the weight of people crossing adjacent flagstones caused them to move. Familiarity with these ingenious machines (which are mentioned in his writings) contributed significantly to Descartes' thoughts on dualism.

The nineteenth century was a period of great social change. The full impact of the new technology had created the large industrial cities of the western world. Pockets of discontent throughout Europe convinced many that social revolution was imminent. Indeed, a new stereotype emerged: the bomb-throwing anarchist. During this same period the most widely admired and influential model of brain function—that proposed by the neurologist Hughlings Jackson (1835–1911)—stated that the function of the most recently evolved, 'higher' centres of the brain was to exert control over the older and more primitive functions of the remainder.

> 'When the highest centres were damaged there was a release of the lower functions. In normal functioning the highest centres were 'protected' and partially insulated from the lower; in cases of brain damage they were the first to suffer dissolution.'
>
> (Hearnshaw 1964)

Substitute 'revolution' for 'damage' and 'social classes' for 'centres', then it seems quite possible that this model of the brain is more than a neutral account of clinical and anatomical data. It may be revealing some of the hidden anxieties of an upper-class British scholar.

The early behaviourists formulated a model of learning in which the results of experience changed connections between stimuli and responses. This new approach to learning was undoubtedly influenced by a new invention: the telephone exchange.

For the past twenty years psychological theorists in a variety of areas have based their models upon the modern digital computer. The result is that much contemporary description within psychology is peppered with terms such as *stages, retrieval, control, content-addressable memory, buffer memory, information*, and so on. For some, the computer has become an intriguing and indispensable model of the human brain.

No wonder that, with such very different models available to influence thinking, psychologists and others should have produced such a variety of theories. Nowhere is this effect more noticeable than in theories of visual perception.

A third reason why general theories of perception should show such great variation in style and language needs a slightly fuller discussion. We need to consider what it is that a general theory of visual perception is trying to do. Figure 1.1 is a simple diagram of a perceiver in an environment. The diagram shows various regions which are commonly delineated by researchers. Each region may be described quite briefly.

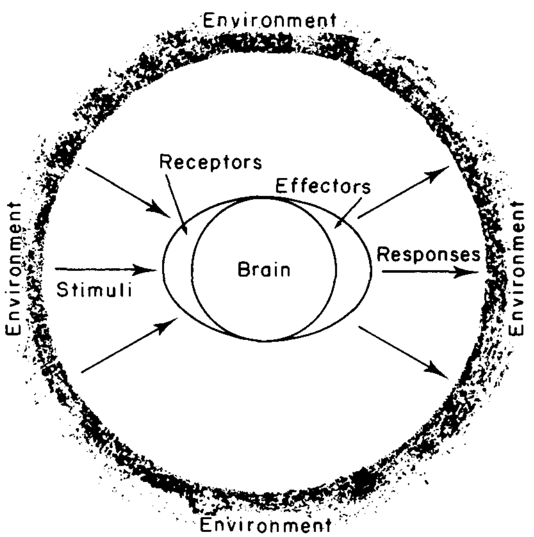

Figure 1.1 The regions of interest to perceptual theorists. (1) the environment, (2) incoming stimulation, (3) receptor surfaces and the peripheral sensory nervous system, (4) the brain, (5) peripheral effector processes, (6) motor responses by the perceiver

1. The environment. This is the physical world of surfaces and objects which we assume to have an existence independent of the perceiver. When this region is studied, it is typically described as the organism's *ecology*. To date, the study of ecologies has been the province of geologists, geographers and biologists, but this is an area of increasing relevance to the psychologist.

2. Incoming stimuli. Objects in the world give rise to events, some of which can be detected by perceivers. Knowledge of the important properties of stimuli has come mainly from physics (light, sound, heat, pressure) and chemistry (volatile substances).

3. Sensory surfaces and peripheral neurons. Before a perceiver can respond to stimuli there must be a change whereby stimulus energy becomes converted into a neural code. It is important to know the nature of this transduction: how light is absorbed by the eye, how changes in frequency affect the ear, how substances are absorbed by the nasal membranes. Important questions concern the pathways taken by neural messages, the codes which are used to represent differences in quality, intensity and duration, and the interactions which take place between neurons. Anatomists and physiologists have sought answers to these questions for more than a century, and are still doing so.

4. The brain. The problems here are almost too obvious to list. Most behaviour depends upon brain processes, but these are commonly not available to direct study and must be explored indirectly—by making inferences from behaviour. Indeed, the whole of the activity labelled Psychology can be viewed as an attempt to gain insights into how brains perform their functions. Very often, and for good reasons, the term Mind has been preferred to Brain. We shall not become enmeshed in the notorious Mind/Brain problem; rather we shall bypass it in subsequent expositions, noting simply that mind and its relation to brain has been the subject of lengthy debate by psychologists and philosophers, whilst the direct study of the brain has been the province of neurophysiologists and neuroanatomists, some of whose work will be described later in this book.

5. Effector systems. Organisms make explicit responses. Stimuli trigger numerous kinds of events in the body. For example, the pupil constricts in response to light; careful study of this response has enabled researchers to detect which wavelengths of light animals are or are not sensitive to. And in Chapter 6 reference will be made to the effects of very brief visual exposures of taboo words on the sweat rate of the palm. This can be used as a sign that the words have been detected and that they have induced emotional responses in the subject.

6. Motor responses. Perceivers are not passive, they move around in the world and in this way partially determine the stimulation they receive. The quickest action any human is capable of is an eye movement. What triggers and guides these movements and what role do they play in perceiving? It has been discovered, for example, that the eye takes in much less information during an eye movement than when it is stationary. We make eye movements which are abrupt and ballistic (in that once started they cannot be stopped) and also

movements which are smoothly graded: what guides the selection of appropriate movements? This area of research has been dominated by psychologists and physiologists.

At a more general level, the study of motor activity is simply the study of the behaviour: what organisms actually do. And this is, of course, the major concern of experimental psychology.

Finally, the environment. The behaviour of organisms does not take place in a vacuum, but in the world. And so this classification ends where it began: with the physical world in which living things dwell and which they act upon in so many different ways.

The foregoing is merely a sketch, an oversimplification, and as such it must not be taken too seriously. Indeed, as schemes such as Figure 1.1 cannot be arrived at in a theoretically neutral manner, they are doubly dangerous. For example, it will be stated in later chapters that there are those who hold that movement of the observer is a vital component of perceiving and that to delineate the motor aspect of perception as a separate 'region' does violence to the truth. Nevertheless, although our classificatory scheme begs some important theoretical questions, we shall use it as a way of highlighting important characteristics of particular theories. One thing the scheme does is to help explain the variety to be found among those theories of perception to have emerged during the first 100 years of experimental psychology.

For a theory to have any psychological relevance it will refer directly or indirectly to region 4, the brain. It must, for the brain is the seat of all psychological functions. But there is something else which can be noted about general perceptual theories and how these differ from theories which are of psychological interest but belong mainly to physics, chemistry, physiology or anatomy. This point will be defended in subsequent chapters; for now we shall simply assert that, commonly, the greater the number of regions of Figure 1.1 to be included in a theory, the more that theory tends to be general in form. This is almost a tautology. But, as will be shown, *the particular subset of possible regions among which underlying relationships are sought differs from theory to theory*. It is this fact which makes general perceptual theories so confusingly varied, as a few examples will show.

Consider first theories which are somewhat restricted in focus. Three-factor theories of colour vision (which will be described more fully in a later chapter) state that there are three pigments in the cone cells of the eye, each maximally sensitive to a particular region of the visible spectrum. Each theory clearly attempts to link two parts of Figure 1.1: incoming stimuli and activity at the receptor surface. The brain is also involved, of course, because the theory is attempting to explain part of our general response to light. But three-factor theories are not general theories, even of colour vision. They explain the appearance only of what are described as 'film colours': the colours we see when looking at surfaces through narrow apertures. Three-factor theories cannot predict the appearance of coloured textured surfaces, nor can they explain how we see objects as having stable colours under different illuminants. The theories cannot do these things because, in their present form, they do not embrace enough regions of Figure 1.1 to enable them to do so.

The same generalization applies to theories in senses other than vision. For example, an advance in our understanding of pain has come from a theory which attempts to explain some important pain phenomena in terms of possible interactions among sensory neurons in the spine. Of course, the theory arose from thinking about a very important psychological experience: pain itself. And the fully developed theory has an important cognitive component. But the central, novel, part of the theory is about how neurons in the spine inhibit or amplify each other's behaviour in a manner which psychological and neurological evidence seems to demand. The theory does ultimately address the question of remedial pain procedures, thus relating neural function to experience. But this is not its main job, which is to give a plausible account of how certain interactions between neurons could achieve certain outcomes, given what is known about their individual functions. Not surprisingly, the theory is couched in the language of neural function, rather than subjective experience. And it is clearly not a general perceptual theory. It cannot, for example, explain individual or cultural differences in pain responsiveness, nor does it deal with the important problem of what initiates the neural pain response in the first place.

Now consider another group of related phenomena and the different ways in which they can be approached theoretically. As an object recedes from a perceiver the angle it subtends at the eye diminishes in a lawful manner. This simple fact is known from the application of geometry to aspects of the physical world (regions 1 and 2). The same geometry (using the theorem of similar triangles) permits the calculation of corresponding changes in the size of retinal images (region 3). These are different regions of course, but in this case the manner in which the effects of distance on stimulation are described is not really important. Descriptions of things and events in regions 1, 2 and 3 can be rendered essentially equivalent.

We can now ask about the size of the smallest stimulus which a person can detect: how far can the object recede (or shrink) before it becomes invisible? This obviously involves the sizes of visual angles and their corresponding retinal images (regions 2 and 3). Either description will do for most purposes, unless we wish to relate detection to the number of cells per unit area of the retina, in which case image size may be the more convenient. Note that we cannot use object size alone as an adequate description: a tree at 100 metres subtends roughly the same angle as one's thumb. And whilst the brain (region 4) clearly plays a vital part in threshold performance, this performance is commonly described only in terms of visual angles or retinal image sizes.