CHAPTER 1

INTRODUCTION

"You have been in Afghanistan, I perceive."
Sherlock Holmes had just been introduced to Dr. John Watson
and his perception was the result of the following chain of deductive and inductive reasoning:
By introduction, a medical man;
By observation, of military bearing.
Therefore, likely an army doctor.
By observation, dark skin with white wrists.
Therefore, sun-tanned; therefore, probably just back from the tropics.
By observation, haggard face with stiff arm.
Therefore, probably wounded.
General knowledge: War in Afghanistan.
"Perception": Army surgeon from Afghanistan.

PERCEPTION

A great perceiver was Sherlock Holmes. Or was he an observer? Few people would volunteer the definitive distinction between these terms, but that is the sort of activity we must undertake if we are to examine the very pith and core of the process of perception – which is a cardinal aim of this book.

If you discriminate between the loudness of two tones, are you engaging in an act of perception?

If you read on your monitor that an atom in an excited state has just released a photon or light particle, have you *perceived* the quantum event?

If a source of light is made 1000 times more intense (that is, it releases 1000 times more energy per unit time in the form of light), it may appear only about 10 times brighter. Does this phenomenon have anything to do with the rapidity with which you can stop your car at a stoplight?

Will extraterrestrial creatures (if they exist) be limited, as terrestrial creatures are, to receive about $\log_2(2\pi)$ bits of information by perceiving a flash of light?

Is there a correction factor required in the theory of evolution introduced by the evolution of the creatures who are, themselves, formulating the theory of evolution?

Does the now-vanished odor of wet paint which permeated the room only a moment ago have anything to do with the optical illusion produced by the Necker cube shown in Figure 17.1?

Can we possibly construct machines that perceive, or only machines that observe? (That distinction again.)

Is it possible the Fechner's and Stevens' laws are just different approximations of the same sensory law?

The answer that I shall suggest to each of the above questions is "Yes." I raise these titillating issues prematurely and out of sequence in an unabashed attempt to capture your imagination, and to illustrate the process of unification within and among the sciences that we shall pursue through our study of perception. I am also raising these "glamorous" questions now so that the reader may keep them in mind as we proceed through some rather hard slogging in the early chapters of the book.

We shall spend much of our effort, particularly in the central chapters, in the study of rather simple, "atomistic" aspects of perception. We shall confine our attention to stimuli of the simplest kind: signals of the "intensity" type, such as the intensity of a light signal or the density of an odorant gas. Moreover, the discussion will remain confined to stimuli that are applied in the form of a step function (Figure 1.1). Only in the later chapters will we relax that restriction.

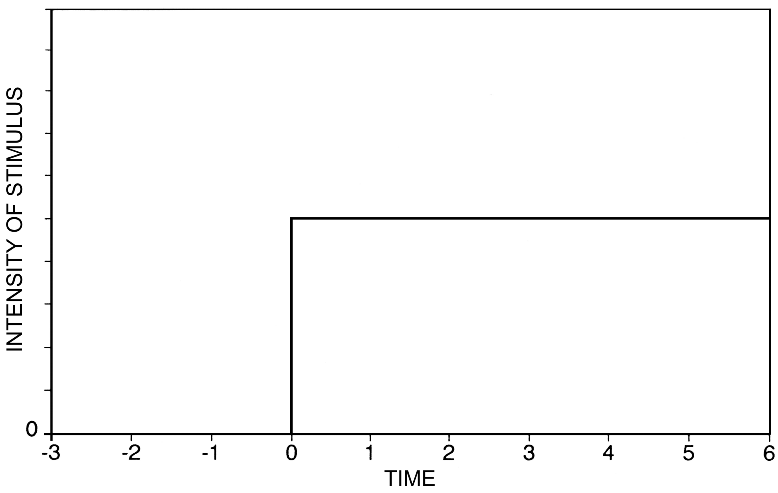

Figure 1.1 The type of stimulus dealt with in this book is in the form of a step function in intensity applied at $t = 0$. It is represented by

$$\begin{aligned} \text{Intensity} &= 0\,, \qquad t < 0 \\ &= I\,, \qquad t > 0\,. \end{aligned}$$

This is a theoretical treatise. The general approach, I think, is that of the physicist. A year of calculus and the introductory concepts of statistics will take you a long way, and many psychologists around the world have been able to get to the heart of the theory. In some cases, detailed mathematical arguments have been relegated to "boxes" or appendices. There is a distinction between the material placed in boxes and that in appendices. The material in the boxes is necessary for thorough understanding of the theory, while that in the appendices can be skipped or the conclusions taken for granted. However, I wanted the complete mathematical argument to be present in the book.

Occasionally, I have found it convenient to assign two different equation numbers to the same equation when it appears in different parts of the text. To remind the reader of the dual assignment I have used the slash. For example, "(A4.7)/(4.21)" means that Equation (A4.7) is identical with Equation (4.21).

Although the development presented is completely theoretical, in the sense that no new experimental data are given, all derived equations will be validated using measured data obtained from the published literature, or by courtesy of a colleague. In this latter respect – the fastidious insistence upon testing theoretical results against measured data – the current work differs from many other theoretical studies on perception.

In the course of this book, I shall be discussing many of the sensory systems, not just a single modality. The feature that I invoke to unify the senses is the concept of "information." Although temperature receptors, mechanoreceptors, light receptors, ..., each transduce a particular form of energy into neural signals (action potentials), nonetheless, all receptors transmit information from the so-called "external world" to the central nervous system. So "information" is a universal currency in which we shall trade. Psychologists, in particular, often respond to the effect that *information* has already been weighed as a tool for exploring the senses, and has been found wanting. However, the manner in which I shall apply the theory of information here is very different from anything advanced in the 1950's and 1960's. One could, I suspect, dispense totally with the terms "information" and "information theory", and proceed directly from the statistical mechanical treatment of entropy as introduced by Ludwig Boltzmann toward the end of the nineteenth century. I felt, though, that Boltzmann's methods might seem too remote, and Shannon's information theoretical terminology would sound somewhat more familiar. So I have tried, where possible, to use familiar Shannonian terms such as "channel," "transmission of information," and "bit."

The ideas that I am going to present in this book arose many years ago when I first studied the philosophical work of George Berkeley, in particular "A Treatise Concerning the Principles of Human Knowledge." But I am afraid to *begin* this book with Berkeley, because many people would approach his work with preconceptions, which I am anxious to alter. So I shall state the assumptions fundamental

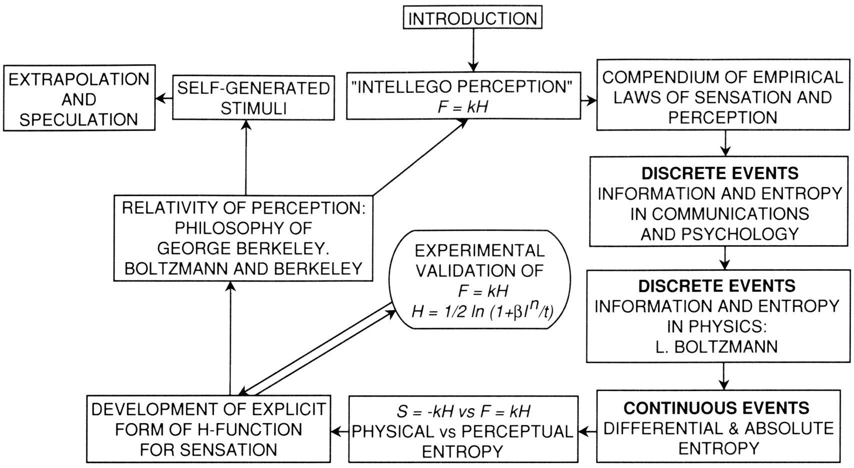

Figure 1.2 Flow diagram for this book. We begin on a philosophical note, but soon become technical. As we approach the end, we again become philosophical as we try to place the subject matter in perspective.

to my model of perception in the early chapters without describing explicitly how I came to formulate them. Then, later in the book, I shall confess my debt to the venerable philosopher, and show you the lineage of my thinking.

Philosophically, the current work is complementary to that put forward by the late David Marr (1982), who stated: " From a philosophical point of view, the approach that I describe is an extension of what have sometimes been called representational theories of mind. On the whole, it rejects the more recent excursions into the philosophy of perception, with their arguments about sense-data, the molecules of perception, and the validity of what the senses tell us; instead, this approach looks back to an older view, according to which the senses are for the most part concerned with telling one what is there." In this book by contrast, we shall, indeed, query the relationship between percepts and the mind that perceives. As we shall see, this will lead us to view the mind in a manner quite different from the usual. The philosophy will be discussed, however, only when we have glimpsed the rather extraordinary power of the new view of perception. Figure 1.2 may help to clarify the order of approach.

Since my readers will have different educational backgrounds, I have introduced chapters dealing with more elementary material that may be familiar to some and not to others. I devote quite some space (about three chapters) to developing the rudiments of information theory, all of which can be skipped over by the reader who is knowledgeable in these matters. I have also devoted Chapter 3 to the description of various physiological and psychological experiments dealing with the special senses. These experiments are the ones on which we shall later test our theoretical structure; they are, so to speak, grist for the mill. Although the chapter that deals with experiments is intended primarily for the psychophysically naïve, there are facets of the classical analysis of experiments that are, in my experience, not familiar to all practising psychophysicists. The final chapter, dealing with extrapolations, extends far beyond the atomistic percepts associated with stimuli of the intensity type. Here we relax our requirement for mathematical rigor and give free vent to imagination.

Figure 1.2 is a flow diagram that guides us through the book. Notice that the flow of thought is cyclical, beginning with the selection (not derivation) of an equation, $F = kH$, and finally coming full cycle back to this same block, but now with philosophical basis for the equation. We might note also that the central block, dealing with experimental validation, occupies some five chapters (10 through 14 inclusive). Please notice, also, that the final two blocks on the left-hand side of the flow diagram should be approached in sequence. That is, they should be read *after* the remainder of the book has been digested.

Let me now state, as explicitly as I can, one of the main objectives of this book. Throughout the past century and a half, rather a large number of *empirical equations* have been formulated by psychologists and physiologists studying sensory phenomena. Empirical equations are equations based purely on measurement. They are convenient descriptions of data, but descriptions for which there has been no general explanation. One of the earliest of these empirical equations is Weber's law,

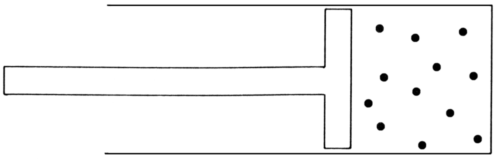

Figure 1.3 A quantity of gas contained within a cylinder. A piston serves to compress or decompress the gas, but no molecules can escape.

$\Delta I / I$ = constant.[1]Another is the Plateau-Brentano-Stevens power law, $F = kI^n$, etc. In this book, as well as in the various journal papers to which it refers, I shall *derive* these hitherto empirical laws from a small set of assumptions. In fact I shall try to derive, from the same set of assumptions, *all* the sensory laws relating three fundamental psychophysiological[2] variables. *Unification* of the laws of sensation is one of my primary objectives.

To the physicists among my readership, *unification* needs no further elaboration; the concept of unification of the fundamental physical forces, etc. is abundantly clear. However, I have found that to the biological and social scientists this term is far from familiar. So with the latter group in mind, let me try to demonstrate both the *meaning* and the *power* behind the process of unification. I shall proceed by using an analogy.

THE MEANING AND IMPORT OF UNIFICATION OF THE LAWS OF SCIENCE

I am choosing the analogy of the ideal gas law, that most readers will have encountered at some time in their elementary physics or chemistry courses. Let us consider the experiment represented by Figure 1.3. A quantity of gas is contained within a cylinder. The gas can be compressed by driving a piston inward, or rarefied by pulling the piston outwards. No molecules of gas can escape from the cylinder. The ideal gas law (or Boyle-Gay-Lussac law) states that

$$PV = nRT , \tag{1.1}$$

where P is the pressure of the gas, V is the volume it occupies, n is the number of moles of gas, R is the gas constant, and T the absolute temperature. Let us confine the discussion to a single mole of gas in order to simplify the equation.

Consider, now, three simple experiments that we can perform on the gas. Each experiment will involve studies on the three state variables P, V and T.

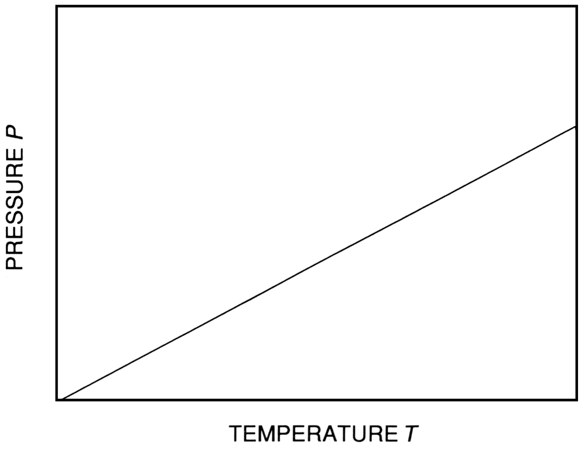

Figure 1.4 Charles' Law for an ideal gas. Pressure varies as absolute temperature when volume is held constant.

In the first experiment we maintain the volume of the gas at a constant value (by fixing the piston in place), and we study the manner in which pressure changes with temperature. From Equation (1.1) we obtain

$$P \propto T\,, \tag{1.2}$$

pressure varies directly with temperature (Figure 1.4), which we recognize as Charles' law.

In the second experiment, we hold the temperature of the gas at a constant value, and we study how pressure changes with volume. From Equation (1.1),

$$P \propto 1/V\,, \tag{1.3}$$

pressure varies inversely with volume, which we recognize as Boyle's law.

In the third experiment, we again hold volume constant, but now we proceed somewhat differently. Recalling that $n = 1$, we differentiate Equation (1.1) with respect to P :

$$\frac{dT}{dP} = \frac{V}{R}\,.$$

Representing the differentials, dP and dT by their respective finite differences,

$$\Delta T = \frac{V}{R}\Delta P\,.$$

Finally, dividing by T, we obtain

$$\frac{\Delta T}{T} = \left(\frac{V}{R}\Delta P\right)\frac{1}{T}$$

or

$$\frac{\Delta T}{T} \propto \frac{1}{T}\,. \tag{1.4}$$

That is, suppose that we conduct an experiment in which volume is held constant and pressure is changed by a small, but always constant amount, ΔP. Then the fractional change in temperature, $\Delta T/T$, will, by Equation (1.4), vary inversely with T, as shown in Figure 1.5.

Three experiments: three variables. The reason for selecting these particular experiments is that they can be considered as analogs of certain well-known psychophysical experiments: the demonstration of the "law of sensation," of the principle of adaptation, and of the Weber fraction respectively. We shall deal with the psychophysical experiments in Chapter 3, but, for the moment, let us fix our attention on the analogs. They illustrate some valuable lessons.

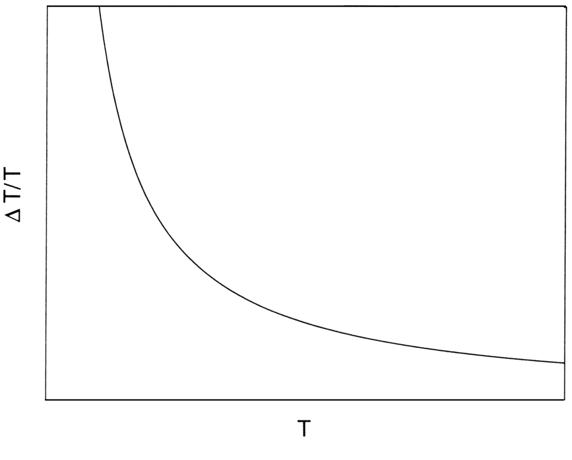

Figure 1.5 The volume of an ideal gas is held constant. When pressure is changed by a fixed amount, ΔP, the fractional change in temperature, $\Delta T/T$, varies inversely with temperature, T.

(a) Unification

The first thing to observe is that the single, parent equation, $PV = RT$ ($n = 1$), embraces all three types of experiment: $P \propto T$, $P \propto 1/V$, and $\Delta T/T \propto 1/T$. Knowledge of the parent equation permits us to derive each of the three daughter equations, and, hence, to predict the results of each of the three types of experiment. Not only does it predict the results of the three selected experiments but, presumably, of all the experiments ever performed, and of all the experiments that ever *will* be performed (within certain limits) involving the variables P, V and T. That is, the parent or master equation is a great unifying concept.

(b) Physical insight

The equation $PV = RT$ might have carried out its unifying function even if it had remained an empirical equation: a rule that just happened to work. However, with the advent of the branch of physics called *kinetic theory*, it became possible to *derive* this equation from the assumed kinetic properties of molecules. The emergence of $PV = RT$ from the kinetic theory of molecules enhanced confidence in the molecular model of matter that was still debated at the beginning of the twentieth century. Thus, the ability to derive a master or unifying equation from a mathematical model of a physical system builds confidence in the veracity of the model.

(c) Conservation laws

The derivation of $PV = RT$ from kinetic theory was even more remarkable because of an extraordinary feature of this derivation. The derivation does not in any way require knowledge of the intermolecular forces or even of the volume occupied by a molecule. It requires only laws of the conservation or balance type; namely the conservation of mass (or particles) in a closed chamber, and the conservation of energy in an elastic collision when the gas is in thermal equilibrium. These conservation laws, coupled with the Newtonian concept of force as rate of change of momentum, and the principle of equipartition of energy, permit the derivation[3] of $PV = RT$. Detailed knowledge of the intermolecular forces is not needed for the argument.

LAWS OF CONSERVATION AND LAWS OF MECHANISM

When the nature of the forces between molecules became known, our understanding of gas dynamics was, of course, enhanced. Our model of the gaseous state would not be complete if it did not contain provision for both elements: *conservation* or balance laws and *mechanistic* laws governing forces. These two types of law are complementary; they work together. There is absolutely no antagonism between them.

To underscore the complementary nature of laws of conservation and of mechanism, I offer a further example. Suppose that some chemical reaction is depicted as follows:

$$\text{Reagents} \rightarrow \text{Products.}$$

Without knowing any details of the mechanism of the reaction, we can invoke the law of conservation of mass, which states that (in the absence of nuclear reactions)

$$\text{total mass of reagents} = \text{total mass of products.}$$

If, at a later time, we come to understand the mechanism or explicit form of the reaction, we can write, say,

$$A + B \rightarrow C + D$$
$$\text{reagents} \rightarrow \text{products.}$$

We shall then understand the reaction explicitly, in terms of specified molecular components, but we shall not, in the process, have invalidated the law of conservation of mass. The law of conservation *required* a corresponding law of mechanism to complete the picture; the two laws work together.

Why am I dwelling on the relationship between these two types of law? This will become clearer as we move forward. We shall derive, in later chapters, a master or parent equation for the process of sensation. This master or parent law, from which we shall derive, and therefore unify, many of the laws of sensation and perception, is a law of the conservation type. It states, effectively, that the information content of a stimulus is relayed, with negligible loss, to the sensory receptor and thence to the brain. That is, it is an equation of information balance. It must be understood clearly that this law of conservation,

information of stimulus = information relayed to brain

does not in any way concern mechanism. That is, one must still work toward understanding the mechanism of operation of the sensory receptors; but such mechanisms *complement* and do not replace the principle of information balance. Enough said.

NOTES

1. Don't worry if these laws are unfamiliar. They will be defined in due course.
2. Neologism: *Psychophysical* + *Physiological* = *Psychophysiological*
3. Need I say that a few details have been omitted?

REFERENCES

George Berkeley, *Philosophical Works*. 1975. Introduction and Notes by M.R. Ayers. Dent, London.
Marr, David. 1982. *Vision*, Freeman, San Francisco.