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Remembrance of places past: a history of theories of space

1.1. Introduction

SPACE plays a role in all our behaviour. We live in it, move through it, explore it, defend it. We find it easy enough to point to bits of it: the room, the mantle of the heavens, the gap between two fingers, the place left behind when the piano finally gets moved. Yet, beyond this ostensive identification we find it extraordinarily difficult to come to grips with space. We could begin by asking a few common-sense questions. Is space simply a container, or receptacle, for the objects of the sensible world? Could these objects exist without space? Conversely, could space exist without objects? Is there really a void between two objects, or would closer inspection reveal tiny particles of air or other matter? These questions call to mind several related ones. Is space a feature of the physical universe, or is it a convenient figment of our minds? If the latter, how did it get there? Do we construct it from spaceless sensations or are we born with it? Of what use is it?

Philosophers, and particularly metaphysicians and epistemologists, have long sought answers to these questions. Aristotle, for example, held that the place of an object was the internal wall of its container. This derived from his view that the universe was a plenum - totally filled with matter - and that the outer surface of any object must be contiguous with some other matter; that is, the inner surface of its surround. This view of space survived for many centuries, in spite of strong criticisms and alternative proposals. In our review we shall not describe these early developments.* Rather, we shall pick up the story at the end of the seventeenth century, by which time the accumulated criticisms against the Aristotelian notion of space had led to its abandonment.

We have chosen to start with Newton, Leibniz, and Berkeley because it was in their writings that the problems of space were initially formulated in a way that is relevant to us. Before we turn to our history we should state our motives and intentions, and warn the reader of our biases. Our primary

* Jammer (1969) provides an historical survey of theories of space, while Efros (1917) discusses some of the more telling criticisms of Aristotle's views.

interests are historical and intellectual. Put simply, we want to avail ourselves of the ideas and arguments which others had brought to bear on the subject. More importantly we wanted to locate ourselves within this historical tradition. When we first began to entertain the notion that the hippocampus provided organisms with an *a priori* Euclidean spatial framework, we found little support or sympathy in the writings of contemporary psychology or neuroscience. On the contrary, as we shall see, most current writers hold that space as represented by the mind or brain is dependent on the relationship between objects or stimuli. History shows that this was not always the case. Moreover we think it affords some perspective on why the current scientific climate favours relative theories of psychological space.

Our bias, then, is against relative theories and our intention is to emphasize the weakness of this point of view, not so much to harry it out of existence as to undercut its claim to account for all of the phenomena. We aim not for victory but an honourable truce. In our view both the absolute and the relative theories of psychological space are needed and we suggest that the Constructor of Brains hedged his bets and incorporated both systems into his invention. The problem then for the neuroscientist becomes one of describing the properties of these different spatial systems, identifying them with specific areas of the brain, and describing the interactions amongst them.

Recurrent throughout this historical chapter are a series of antitheses: psychological v. physical space, absolute v. relative space, innate v. learned or constructed, Euclidean v. non-Euclidean. The theory of space espoused by a particular author can be viewed (roughly) as a set of choices between these alternatives. While most of the choices are relatively independent of each other, certain groupings seem to go together more easily than others. For example, a theory of relative psychological space is usually conceived as acquired or constructed rather than as an innate property of the mind. It might help the reader if, at this point, we make more precise the sense in which we are using these terms and to adumbrate what we see as the issues surrounding each antithesis.

(i) Psychological v. physical space. We shall use the term *psychological space* to refer to any space which is attributed to the mind* either as an intrinsic aspect or as an inevitable or highly probable product of the normal operation of the mind, and which would not exist if minds did not exist. Psychological spaces can take many forms. Included are concepts

* Throughout this chapter we shall freely use the term mind without precisely defining it. In our usage, it is not identical with consciousness nor does it necessarily imply consciousness. Nor does it simply mean the operation of the whole brain. Readers who feel uncomfortable with this term and prefer an unknown set of well-defined entities or processes to a well-defined set of unknown entities or processes can systematically substitute the clumsy phrase 'some operations or activities of some (unspecified) parts of the brain' for 'mind'.

which the mind constructs on the basis of reflections on experience, abstractions from sensations, organizing principles which impose unified perceptions upon otherwise diverse sensory inputs, organized sensory arrays which derive their structure from the nature of peripheral receptors, or a particular set of sensations transduced by a specialized (spatial) sense organ. The study of psychological spaces falls within the domain of the disciplines of psychology and physiology.

In contrast, *physical space* is any space attributed to the external world independent of the existence of minds. It describes a feature of the universe, even an inanimate, incognitant one. Physics is the discipline which addresses itself to the existence and properties of this space.*

Our concern in this book is primarily with psychological space. From our point of view, it little matters what the shape of physical space is or indeed whether space is a property of the physical universe at all. Our interest in physical space derives from two considerations: (a) historically, ideas about physical space have influenced thinking about psychological space, and (b) some theories of psychological space suggest that it is learned from or constructed on the basis of experience with the physical universe. Were this latter suggestion the case one might expect some correspondence between the properties of psychological space and those of physical space, and evidence of discordance between the two is *prima facie* evidence against such theories.

(ii) Absolute v. relative space. This distinction can be applied to psychological as well as to physical spaces. In our usage *absolute space* embodies the notion of a framework or container within which material objects can be located but which is conceived as existing independently of particular objects or objects in general. Objects are located relative to the places of the framework and only indirectly, via this framework, to other objects. Movement of a body (including the observer) changes its position within the framework but does not alter the framework or the relationship of other objects to the framework. In contrast, *relative space* designates a set of relations amongst objects or sensory inputs which in themselves are inherently non-spatial. Objects are located relative to other objects and relative space does not exist independent of the existence of objects. In order to ease the reader into the absolute/relative distinction in the realm of psychological space, let us do a little introspective experiment. Let us close our eyes and think about space. Several different types of space come readily to mind. To us, these spaces divide rather naturally into those which are felt to emanate from the observer and those which are independent of the observer. In this latter notion there is a sense of position within a framework

* Only mathematics is not tainted with sectarianism and tries to describe the properties of spaces irrespective of whether they are physical or psychological, or indeed exist at all in the sense we are using the term.

which also contains other objects. The framework may be local, such as a room or a building, or it may be more extensive, such as the city, the continent, or the universe. Persons and objects are located within these spaces but do not define them in any fundamental sense - remove any object and space is left behind. The space itself is immovable and continuous - there are no gaps in it. Although one can think of small parts of it, these are always recognized as portions of a whole. This notion of a connected, total space is what is meant by absolute space. Everything occurs within it, and it serves as the basic framework tying the universe together into a coherent whole.

In addition to this unitary environment, other notions of space come to mind. These are usually more restricted in scope and usually relate directly or indirectly to features of the observer's body. Thus an object is located to the left of me now, but to my right after I make an about-face. Higher order relative spaces can also be imagined. Object A is to the left of B, behind B, or between B and C. In these higher-order spatial relationships, objects are located with respect to each other in terms of their relation to the observer. Take a stroll and A ends up to the right of B or in front of it. In general, this type of relative space moves with the observer. Consequently changes in his position can alter the relations of objects in the schema.

A different type of relative spatial relation appears less bound to the observer: A is near to, around, in the neighbourhood of B. While these topologic relations are independent of the position of the observer, they are rather dependent on the context. Is Edinburgh near London? Yes, in a global context; no, in a British one. We suspect that examination of this context will reveal a full-blown concept of space and that seemingly simple topologic concepts covertly presuppose such spatial frameworks.

Finally there is the space occupied by things, the *extension* of a body or an object. This is clearly related to that body and travels with it.

All of these non-absolute spaces are logically separable, although they may be interrelated. They are all set within the unitary spatial framework we have called absolute space, and it is within this framework that they move relative to each other. These spaces all fall under the rubric of relative psychological space.

(iii) Innate v. learned or constructed. This obviously only applies to psychological space. By innate or *a priori* is meant that the structure and function of those parts of the brain involved in generating the space are specified by information in the organism's genes. The alternative is that their structure and function is determined by the specific experiences of the organism. We include in this class of *a posteriori* theories both those which postulate a direct influence of experience in organizing neural spatial structures and those which view space as a concept generated by non-

spatial cognitive operations of the brain. It should be pointed out that there are intermediate positions between the two extremes. One possibility close to the *a posteriori* side is that some parts of the structure are genetically determined, and others are dependent upon experience. This may be merely a restatement of the antithesis at the molecular level. Another possibility somewhere near the middle is the notion that genetic instructions might specify several alternative structural wiring diagrams, the one to survive being selected by the experience of the particular organism. Finally, it might be that the structure and function of those neural systems concerned with space are genetically specified but that particular experiences determine such things as the efficiency of the systems, how much reliance the organism will place on the information gathered in and generated by them, or how ready it is to act upon that information. These intermediate positions make differing claims about the extent and nature of the genetic endowment concerning psychological space, as we shall see later when we discuss particular theories representing some of these possibilities. Of course, all theories, *a priori* and *a posteriori* alike, accept that the specific contents of representations gathered within these spatial systems are derived from experience. The difference lies in what they say about how these representations are structured, and from whence this form of structuring, or framework, derives.

An *a priori* theory makes no claims about the nature of physical space but instead directs attention to questions of how psychological spaces evolved, what survival advantages they offer organisms, and how genetic instructions programme the development of the involved neural structures. Some *a posteriori* theories are interested in the nature of physical space while others are not. Consider a version of *a posteriori* psychological space which holds that it was learned on the basis of experience with physical space. This naive realist view would predict a close correspondence between the two and, therefore, as we have pointed out above, evidence of discrepancies will count against this model. A different theory is that psychological space could be constructed on the basis of experience with non-spatial aspects of the physical world such as objects or stimuli. As this position has considerable influence in the history of psychology we shall examine it carefully in this chapter to see how tenable it is. We shall be particularly interested in two of its assumptions: first that organisms can identify and re-identify particular objects or stimulus configurations without recourse to a pre-existing spatial framework, and second that organisms can select and group together those movements and only those movements which are successful in re-establishing an original sensory array which has changed. One, or perhaps both, of these abilities are the minimal requirements for the generation of a psychological space from spaceless data; the first because it is supposed to give a reliable set of items upon which one can begin to build a set of (spatial) relationships, and the second because it allows such spatial notions as distance to be extracted from non-spatial information about the animal's movements. Since it is the contention of those who support the theory of an innate psychological space that these abilities are not possible in the absence of such a space or of some equally powerful set of innate ideas, we shall probe deeply to test their credibility.

(iv) Euclidean v. non-Euclidean metric. While the question of metric can be applied to either physical or psychological space, we are primarily concerned with the latter. The demonstration in the middle of the nineteenth century that non-Euclidean geometries and spaces of more than three dimensions were mathematically coherent and comprehensible, if not necessarily visualizable, led to questions as to whether physical space had a true metric or whether it was a matter of convenience which metric was chosen, or even whether it had a metric at all. These doubts were naturally reflected by similar questions about the metric of psychological space. In this book we shall be sticking our necks out and taking the strong position that the metric of the cognitive map is Euclidean, although psychological spaces associated with other neural areas may not be so. In the final analysis the evidence on the metric of the map must come from behavioural studies on such spatial abilities of animals as homing and triangulation and from studies on the physiology of the spatial nuclei such as the hippocampus. In this chapter we shall content ourselves with pointing out that any evidence which suggests that physical space does not have a Euclidean metric or that physical space can be described equally well by a Euclidean or non-Euclidean metric, far from counting against a Euclidean metric for psychological space, leaves the latter as one of the only possible sources of Euclidean notions and suggests that the mind (or a part of it) has a strong affinity for the laws of Euclid.

In this review we start with Berkeley, Newton, and Leibniz, in whose writings we can discern the original formulations of several lines of thought which persist to the present. Equally importantly, these writers serve as a good introduction to the work of Kant whose theory of psychological space, with suitable modification, will be adopted in this book. While Newton, Leibniz, and Berkeley differed on the nature of physical space, they agreed that psychological space was relative and derived from experience. Kant, on the other hand, asserted that psychological space was absolute and *a priori.* In the rest of the chapter we trace the development of the different theories of psychological space along empiricist, nativist, and Kantian branches down to their current formulation by modern psychologists such as Hull, Gibson, and Piaget.

1.2. Newton, Leibniz, and Berkeley

1.2.1. NEWTON'S UNIVERSE

In a famous series of letters Clarke and Leibniz (cf. Alexander 1956) debated the merits of two radically opposed conceptions of the nature of space:

Clarke defended the validity of Newton's concept of absolute space, while Leibniz argued that only relative space existed. In the *Principia* Newton had spoken of these two types of space:

'Absolute space, in its own nature, without relation to anything external, remains always similar and immovable. Relative space is some movable dimension or measure of the absolute spaces; which our senses determine by its position to bodies' (Scholium to Definition VIII, Number II, Cajori 1934).

In conjunction with absolute time, absolute space provided the basis for the omnipresence of the deity. Perhaps more important, absolute space was thought by Newton to be central to his physical theories. Though it described the structure of the universe, absolute space was not immediately accessible to the senses. Thus,

'because the parts of space cannot be seen, or distinguished from one another by our senses, therefore in their stead we use sensible measures of them. For from positions and distances of things from any body considered as immovable, we define all places; and then with respect to such places, we estimate all motions, considering bodies as transferred from some of those places into others. And so, instead of absolute places and motions, we use relative ones; and that without any inconvenience in common affairs' (Scholium to Definition VIII, Number IV).

Notwithstanding its inaccessibility to the senses, Newton felt that the existence of absolute space could be inferred from its effects upon matter, in particular from certain forms of motion.

The theory of absolute space, as conceived by Newton, relied upon a particular notion of the universe, which saw it composed of matter and the absolute space containing that matter. God created matter in the form of solid, impenetrable particles, or atoms, and these atoms were embedded in space. Though small, atoms had both mass and extension and should, with suitable advances in optical techniques, eventually be visible to the eye. Atoms were separated from one another by void or empty space. In combination with each other they formed the objects or bodies of the sensible world. The movement of bodies and their interactions with one another constituted, for Newton, the science of dynamics, and it was within this context that the notion of absolute space became critical. Newton distinguished between absolute and relative motions in terms of the forces acting on bodies that cause motion. Thus,

'True motion is neither generated nor altered, but by some force impressed upon the body moved; but relative motion may be generated or altered without any force impressed upon the body. For it is sufficient only to impress some force on other bodies with which the former is compared, that by their giving way, the relation may be changed, in which the relative rest or motion of this other body did consist' (Scholium to Definition VIII, Number IV).

True, or absolute, motion could not be referred to other bodies, but rather must be referenced to some absolute framework. The classic case, discussed in detail by Newton, concerned centrifugal motion, as in the rotation of a pail of water. Here, the centrifugal force which pushes water up the sides of the rotating pail occurs independently of the relative motions of pail and water. Newton argued that this force can only be comprehended through the assumption of absolute motion, and that absolute motion demanded the notion of absolute space. Thus, we could not sense these absolute entities, but we could validate their existence through their effects.

1.2.2. LEIBNIZ'S UNIVERSE

Leibniz was a philosopher who, while accepting Newtonian physics, categorically rejected its metaphysical presuppositions. He could not accept Newton's atoms as the fundamental building blocks of the universe; he could not accept the notion of the void in which these atoms were supposed to float; he could not accept the mysterious forces through which one body reached across the void to influence another. Instead, he viewed all these as secondary manifestations derived from a more fundamental metaphysical system. Here there was no matter, no causal interaction, no time, no space; all that existed was an infinitude of simple non-corporeal substances living out their destiny in total isolation from one another. This deep metaphysical level Leibniz called the monadic realm, and its inhabitants he called *monads.*

In order to see how Leibniz derived the concept of space from the monads it will be necessary to discuss some of their properties. Here, we can give only the flavour of his ideas; the interested reader should refer either to Leibniz's own writings (cf. Parkinson (1973), or to the books by Russell (1937) and Rescher (1967). Unlike Newton's atoms, the monads had no mass nor did they have extension. They were idealized mathematical points possessing a rudimentary form of consciousness, which Leibniz likened to that of a deep dreamless sleep or coma. These monads existed in infinite numbers and taken together they constituted the universe. If it made any sense to ask the question: what is there between two monads?, the answer would be another monad. The defining characteristic of each monad was its continuously changing internal state. The successive states of a monad, past, present, and future, were predetermined by God at the creation of the universe. Each monad had its own built-in programme which, once set in motion, carried on inexorably throughout eternity. Leibniz specifically denied that there could be interactions of any sort between monads. The order exhibited by the world was due not to such interactions, but rather to the harmonious relationship amongst the programmes of the monads established at creation. At any given time the state of a single monad reflected the simultaneous states of all the other monads. To understand fully any one monad

it would be necessary to understand the entire universe. This notion of the relationship between the different monads can be put in another way, and compared with Newton's idea of causal interactions. Newton's cosmological musicians achieved their symphonic unity by listening to and playing along with each other. Leibniz's harmony arose out of the isolated efforts of his insensate musicians, each in command of a degraded version of the symphony, each playing his part to the music in his head.*

Each monad was unique in the sense that its internal programme reflected the whole from a particular point of view. None the less, there was some similarity between all of the monads, and some were more alike than others. Leibniz couched this relationship between monads in perceptual terms: a monad 'perceived' another more clearly if it had a similar programme, while dissimilar monads were 'fuzzy'. Thus, although in theory a monad reflected all the other monads, in practice its knowledge of some was better than of others. Furthermore, this 'perception' of one monad by another was not reciprocated by an equally clear perception in the opposite direction. The importance of this asymmetry will become apparent as we turn to Leibniz's theory of space.

How did Leibniz derive such concepts as extension, object, and space from this elegant but uncomfortably strange universe? He did so at two separate levels. In much of his writing he stuck to the metaphysical level and showed how certain properties of the monads and their relations could be equated more or less arbitrarily with extension, object, and space. In the correspondence with Clarke he ventured into the phenomenological domain and tried to give an account of the genesis of psychological space.

In the realm of the monads Leibniz viewed the emergence of extension as involving the same process by which mathematical points make up a line. Certain clusters of monads would have programmes which were so similar that from the point of view of most other monads they would be indiscernible. They would then appear as the repetition of the same monad; this defined extension. More complicated clusters of linked monads were 'perceived' as objects. Space was also derived from the 'perceptions' of monads. From the point of view of any particular monad, all of the other monads could be ordered in terms of their similarity to the perceiving monad. This set of ordered relations was the basis for space in the monadic realm. Leibniz equated 'A is a clearer monad than B' with 'A is closer than B'. The space derived in this way is relative to the point of view of the 'percipient', and because of the asymmetrical nature of intermonadic perception the distance between two monads would be viewed as different by each monad. In this way it was possible to maintain that every

* This analogy can be extended in the following way, to incorporate one of the major theological differences between Newton and Leibniz: for Newton the composer of the symphony had occasional recourse to altering the course of the music, making minor adjustments here and there; for Leibniz the composer was simply an observer, capable of seeing the symphony in its entirety, but not influencing it.

monad 'perceived' the universe in its unique fashion. In theory, this meant that every monad could be identified by its perception, and there would be no need of any spatio-temporal framework to assist in identifying or locating monads.

At a psychological level a similar process was assumed to be in operation. This is hardly surprising, since Leibniz viewed minds as a single monad dominating a complicated aggregate of monads. But minds did not directly perceive individual monads; rather, they were sensitive to monad clusters in the form of extended objects. The process by which space of the monadic realm was reflected in the mind was summarized by Leibniz:

'I will here show, how men come to form to themselves the notion of space. They consider that many things exist at once and they observe in them a certain order of coexistence, according to which the relation of one thing to another is more or less simple. This order, is their *situation* or distance. When it happens that one of those coexistent things changes its relation to a multitude of others, which do not change their relation among themselves; and that another thing, newly come, acquires the same relation to the others, as the former had; we then say, it is come into the place of the former . . . then we may say, that those which have such a relation to those fixed existents, as others had to them before, have now the *same place* which those others had. And that which comprehends all those places, is called *space.* Which shows, that in order to have an idea of place, and consequently of space, it is sufficient to consider these relations, and the rules of their changes, without needing to fancy any absolute reality out of the things whose situation we consider' *(Leibniz's Fifth Paper,* in Alexander 1956, p. 69).

For Leibniz, space was read off the relations between objects, but only after an intermediate step involving the construction of a network of places. Thus, places were dependent upon the presence of extended objects. This put Leibniz in the position of claiming the ontological priority of extension over space, a view common to all relative theories. It is in this sense that such theories hold that space cannot exist in the absence of objects.

1.2.3. BERKELEY'S UNIVERSE

Whereas Leibniz sought to explain the existence of bodies and absolute space on the basis of monads, Berkeley denied that they existed independent of minds and their contents, ideas. There were two types of ideas: sensations which were impressed on the mind from outside (in the final analysis by God), and images of these sensations which were conjured up by the mind itself. Typical sensations were the colour red, a round shape, a sharp edge, a loud hum. The difference between an externally impressed sensation and an internally generated image lay in the greater strength, orderliness, and coherence of the former. Other notions, such as the idea that solid, impenetrable bodies existed in an external world and gave rise to sensations in the mind, were denied by Berkeley. Instead, such bodies were constructed by abstraction from sensations and their combinations

and sequences. For example, when the mind repeatedly experienced one bundle of sensations followed by another sensation or sensations it conjured up the notion of bodies and causality, attributing power to the first sensations in producing the second:

'Thus, for example, having observed that when we perceive by sight, a certain round, luminous figure, we at the same time perceive by touch the idea or sensation called heat, we do from thence conclude the sun to be the cause of heat, and in like manner perceiving the motion and collision of bodies to be attended with sound, we are inclined to think the latter an effect of the former' *(Human Knowledge*, in Turbayne 1957, p. 38).

But neither causality nor bodies nor any of these derived ideas actually existed aside from our thoughts about them. Stop thinking of them and they disappear (unless, of course, someone else continues to think of them).* Our primary concern here is with space and related concepts such as distance, so we shall turn directly to Berkeley's account of how the mind builds up these secondary notions.

Berkeley first drew a distinction between the notion of space derived from tactile information (which for him included proprioceptive feedback during movement) and that derived from visual information. His notion of the primacy of tactile information, and hence *haptic space*, is important historically and recurs in later writers. It rested on observations that the radical changes in visual and auditory sensation produced by changes in distance were ruled out for tactile sensation. According to Berkeley the primary notions of bodies and space which we form on the basis of tactile sensations were due to the differential resistance produced by the same movements at different times:

'When I excite a motion in some part of my body, if it be free or without resistance, I say there is *space*; but if I find a resistance, then I say there is body; and in proportion as the resistance to motion is lesser or greater, I say the space is more or less *pure.* So that when I speak of pure or empty space, it is not to be supposed that the word 'space' stands for an idea distinct from or conceivable without body and motion - though indeed we are apt to think every noun substantive stands for a distinct idea that may be separated from all others; which has occasioned infinite mistakes. When, therefore, supposing all the world to be annihilated besides my own body, I say there still remains pure space, thereby nothing else is meant but only that I conceive it possible for the limbs of my body to be moved on all sides without the least resistance; but if that, too, were annihilated, then there could be no motion, and consequently no space' *(Human Knowledge,* in Turbayne 1957, p. 81).

These notions of proximal tactile space and tangible bodies served as the foundation onto which was grafted our notion of visual space. Prior to

* Sometimes Berkeley trivializes the problems generated by this difficulty by asserting that bodies do not disappear when we stop thinking about them since God perceives them. Here of course God begins covertly to take on some of the properties of external absolute space.

Berkeley it was thought that knowledge of the distance of an object depended on an innate connection to such phenomena as the amount of convergence of the eyes, the disparity of the rays entering the eye from an object, the number of intervening objects, and the distinctness of the object. As we shall see, this point of view was rehabilitated in the nineteenth century. Berkeley, however, showed how all of these were only contingently related to distance and thus must have been learned by association with tangible space:

'and I believe whoever will look narrowly into his own thoughts and examine what he means by saying he sees this or that thing at a distance, will agree with me that what he sees only suggests to his understanding that after having passed a certain distance, to be measured by the motion of his body, which is perceivable by touch, he shall come to perceive such and such tangible ideas which have usually been connected with such and such visible ideas' (*A New Theory of Vision*, in Luce and Jessop 1948, p. 188).

The role of visual space was predictive; it informed the mind beforehand what tactile sensations were contingent on which movements and what visual sensations to approach or avoid.

Thus, for Berkeley there were several types of relative space, depending on different modalities. These were connected to one another through associations derived from experience, with touch serving as the basis. In his early writings Berkeley suggested that the tactile sense actually gave one access to the physical universe. Later, he rejected this notion, claiming that he had only adopted it in order to facilitate acceptance of his radical ideas. A rigorous application of these ideas meant that no contact with an external universe, if one existed, was possible. These ideas naturally led Berkeley to reject completely the Newtonian concepts of rigid body and absolute space. Physics was the study, not of material bodies, but rather of the succession of sensations programmed in the mind by God. Berkeley's rejection of Newton's absolute inertial framework led him to search for alternative solutions to Newton's problems. Thus, for example, he concluded that centrifugal motion, which Newton cited as evidence for absolute motion and absolute space, was really movement relative to the outer shell of the universe, the stars.

1.2.4. A COMPARISON OF THE THEORIES

It would be useful at this point to pause and summarize the answers given by these three authors to the questions posed at the start of this chapter. We can also discuss the strong points of each of the theories, as this will serve to introduce the work of Kant, the writer who effectively combined these strong points into a single powerful theory of space.

(1) *Does physical space exist and what is its form?*
The answers given by our authors cover the entire spectrum. At one extreme stood Newton, who believed that physical space existed external to, and independent of, any and all conscious beings, that its form was absolute, and that, although it could not be experienced directly, its influence on physical bodies could be demonstrated. At the other extreme, Berkeley and Leibniz both denied the existence of physical space, but for different reasons: Berkeley as a corollary to his thesis that nothing existed outside of our thoughts, Leibniz because there was no role for space in the realm of his non-corporeal monads.

(2) *Does psychological space exist and what is its form and origin?*
Here, in contrast to their opposed positions on physical space, there is virtual agreement amongst our authors that psychological space exists and that its form is relative. Furthermore, they all felt that this relative psychological space was manufactured by the mind as a consequence of its experience with bodies or sensations. Three possible recipes for constructing a relative psychological space were suggested: (a) map out the regions of least resistance to bodily movements, call that space; calculate the amount of movement between sensations, call that distance (Berkeley); (b) notice which bodies do not change position relative to each other and use these as a reference frame to define places, and thence space (Leibniz); (c) pick some reference body which is assumed to be stable relative to absolute space, then calculate the positions and motions of other bodies relative to this *inertial* frame (Newton). The first two recipes stressed the primacy of the concept of body or sensation over that of space, while the last did not. This central disagreement between the models reflects the opposed order in which they derived the concepts of space, object, and extension; this opposition is inherent in the absolute/relative space dichotomy. For both Berkeley and Leibniz, extension had logical priority, leading to objects which then defined space. For Newton absolute physical space existed without objects or their extension, and relative psychological space was an approximation to this. Newton was left with a curious position on absolute space; it existed in the physical world, but not directly in the psychological realm. Yet,

'in philosophical disquisitions we ought to abstract from our senses, and consider things themselves, distinct from what are only sensible measures of them' (Scholium to Definition VIII, Number IV).

The ultimate validity of absolute space was physical rather than psychological, and Newton offered no simple formula for the translation from one realm to the other. The problem raised by this conception of absolute space formed part of the motivation behind Kant's work, as we shall see shortly.

The consequences of the different way in which psychological space was derived by these writers can be seen in later approaches to this problem.

In particular, Berkeley and Leibniz spawned psychological models persisting to the present day. Though they agreed on the primacy of extension and the secondary nature of space, their derivation of extension differed. Berkeley derived it from movement, and his emphasis upon the role of movement remains a constant feature of *empiricist* theories. Leibniz, on the other hand, derived extension from a kind of monadic 'perception', and can thus be viewed as a forerunner of the *nativist* position, which assumes that spatial information is somehow extracted from sensations.

(3) *What is the relation between physical and psychological space?*
Berkeley excused himself on this one through denying the existence of physical space, but both Newton and Leibniz provided answers, albeit vaguely formulated ones. Newton simply asserted that relative psychological space, with its dependence on relative frameworks, was an approximation to absolute physical space. Leibniz's account of the relation between the two spaces was also vague, but more interesting in one of its implications. For him, psychological space was a translation into the phenomenal world of the underlying relationships between monads, based on their mutual perceptions in accordance with the pre-established harmony. An implication of this is that the contents of the mind can reflect the external world in spite of an absence of communication between the two.

(4) *What is the function of space?*
The general answer is that absolute space performs work, while relative space is little more than an epiphenomenon. The absolute space of Newton was an integral part of his universe and added something to our knowledge of that universe. In contrast, relative spaces of all kinds were derived from other knowledge and served as shorthand for, or generalizations from, that knowledge.

Each of the three theories we have discussed had at least one strong point in its favour. Newton's advocacy of absolute physical space rested on the role this concept played in his physics, and the empirical success of that physics. Berkeley's epistemological analysis cast grave doubts on the ability of conscious beings to know anything about the existence or nature of the external world. Finally, Leibniz provided one example of how notions applicable to the external world, such as space and objects, could be manufactured by conscious entities totally isolated from that world. It was these three ideas that Kant synthesized into his theory of space.

1.3 Kant

Throughout his life Kant grappled with the problem of the metaphysical foundations of Newtonian physics and Euclidean geometry, both of which seemed necessarily true of the physical world, but neither of which, he felt, could be grounded in sensation. Kant could not accept the gap left in the

Newtonian system between the notion of absolute space underpinning the physical laws, and the notion of relative space which organisms generate from their interaction with physical bodies. Induction seemed too weak a basis to sustain the notion of infinite, everlasting, absolute space. Furthermore, Kant was deeply impressed by the arguments of Berkeley and Hume that conscious minds could have no access whatever to the physical world (if it existed). His resolution of these problems, reached in the *Dissertation* of 1770 (cf. Handyside 1928) and the *Critique of pure reason* (1787),* was that space was indeed absolute, but that it was not a property of the physical world. Rather, it was an innate organizing principle of the mind, by which the sensations derived from the physical world were constructed into a conscious manifold. Space was a *way* of perceiving, not a thing to be perceived.

The steps by which Kant arrived at this solution are not crucial to our argument, and we shall only sketch in their outlines. The interested reader is referred to Handyside (1928) for some of Kant's earlier writings on space and to Garnett's (1939) discussion of these writings. Briefly, Kant's initial position on the nature of space was a compromise between Leibniz and Newton. From Leibniz he took a relative notion of space, but unlike Leibniz he derived this space from the interaction of substances through Newtonian forces.

'It is easily proved that there would be no space and no extension if substances had no force whereby they can act outside themselves. For without a force of this kind there is no connection, without this connection no order, and without this order no space' (*Thoughts on the true estimation of living forces,* in Handyside 1928, p. 10).

Note that while accepting Leibniz's relative space, Kant firmly rejected his notion of pre-established harmony. Only through interactions could relative space be derived. However, Kant's synthesis was essentially circular and clearly inadequate. Space was derived from the interaction of bodies through forces, but the very existence of bodies and forces seemed to presuppose space. Further, a reliance on forces as the wellspring of space failed to explain all of the latter's properties; in particular, it could not account for the three-dimensionality of space. At this time the only evidence that Kant could adduce for this property was the inability of the imagination to visualize spaces of other than three dimensions; here, he pointed towards one of the arguments he was to use later.

Following several other unsuccessful attempts to provide a relativist account of space, Kant shifted to a Newtonian position in which he accepted the necessity of a concept of absolute space:

'absolute space has a reality of its own, independent of the existence of all matter, and indeed as the first ground of the possibility of the compositeness of matter' (*On the first ground of the distinction of regions in space,* in Handyside 1928, p. 20).

* All references to the Critique are to the 1787 version, as translated and edited by N. Kemp Smith.

The major evidence Kant used in support of the necessity for a notion of absolute space concerned objects which were similar but incongruent, such as left and right hands, left and right screws. The parts of these objects and their internal relations had exactly the same description and yet they could not be superimposed on each other because the three-dimensional space they occupied was different. In other words, part of the description of a left hand involved a reference to the space in which it was set. If there were only one hand in the universe, it would be impossible to say whether it was a left or right hand without recourse to an absolute spatial framework. At this point Kant was still thinking about absolute space in the Newtonian way, as a property of the physical world. His shift to a psychological interpretation of absolute space was due to Leonhard Euler's influence. Euler suggested that space was purely psychological but that it was not derived, as previous writers had thought, from sensations originating in the external world, nor from minds reflecting on these sensations. Using this insight of Euler, together with his earlier arguments in favour of the necessity of absolute space, Kant formulated his mature theory of space.

In the *Dissertation* of 1770 and the *Critique of pure reason,* Kant developed a theory of knowledge in which the psychological notion of space played a fundamental part. It is necessary first to consider the general theory of knowledge before turning to the specific role of space. Kant began by classifying propositions in two different ways: the first in accordance with their origins, the second in accordance with the means available to validate them. In addition to knowledge which originated from the external world and could therefore be called *empirical,* or *a posteriori,* Kant identified a category of *a priori* knowledge, defining it as

'knowledge that is ... independent of experience and even of all impressions of the senses' (*Critique*, p. 42).

This knowledge took the form of

'rules which I must presuppose as being in me prior to objects being given to me'

and

'concepts to which all objects of experience necessarily conform, and with which they must agree' (*Critique*, p. 23).

The other way that Kant classified knowledge was based on the means by which the validity of propositions about the world could be verified. The first type of logical proposition, which he called *analytic,* consisted of a subject and a predicate, where the predicate was contained in the meaning of the subject. Definitions are the paradigm analytic propositions. The truth of analytic propositions is tested by unpacking the meaning of the terms in the subject and checking these against the predicate. In contrast, *synthetic* propositions were ones which conjoin a subject and a predicate,

neither of which implies the other; these can be verified with reference to the external world.

The obvious combinations of these two classes are *analytic a priori* and *synthetic a posteriori.* In the first, the predicate is contained in the meaning of the subject and thus can be validated by the mental process of unpacking the meaning of the subject; in the second, the validity of the relationship between subject and predicate must be sought in the external world. However, in addition to these two, Kant proposed a third combination, *synthetic a priori.* These were propositions in which the meaning of the subject did not imply the predicate but which could not be validated empirically; instead, this had to be done with reference to purely mental processes. One example Kant gave was the geometrical axiom that 'a straight line is the shortest distance between two points'.

Kant maintained that our notion of space is a *synthetic a priori* which, though not derived by the individual from the world, gave certain knowledge of that world. A little background on Kant's ideas of how the mind worked would help in understanding what he was saying here, for the concept of *synthetic a priori* knowledge is a highly controversial and important one. Kant took a moderate Berkeleyan position on the relation between minds and the external world. He did not follow the Berkeleyan road all the way to its solipsistic conclusion that nothing existed except the contents of consciousness, but settled with the position that, although the external world existed outside of our minds, we could never know anything about it as it was in itself. Knowledge was necessarily derived from consciousness, and the world which existed apart from consciousness was ultimately unknowable.

According to Kant the mind represented the external world in two different ways, each derived from a different mental faculty. The faculty of sensibility constructed representations (called intuitions) which consisted of particular events and objects set in their spatio-temporal context; the faculty of understanding listed each object under the abstract concepts of which it was an instance. Thus, the sensibility would represent a red ball as that particular ball next to the blue chair. In the understanding, it would be listed under redness, balls, etc.

Within the faculty of sensibility, Kant distinguished between two types of intuition: empirical intuitions, such as impenetrability, hardness, and colour which derived from the unknowable outer world, and pure intuitions such as extension which were wholly due to the structure of the sensibility itself. The former constituted the matter of the representation while the latter gave it its form. It was Kant's contention that space was a pure intuition in the sensibility as opposed to an empirical intuition or a concept in the understanding.

Following Euler's reasoning, he denied that space was a concept; it was not abstracted from several different instances of space, since these more limited patches of space were always conceived as parts of a single, infinite space. On the other hand, space was not an empirical intuition either, since it was a necessary precondition for objects to be perceived in the first place:

> 'Space is nothing but the form of all appearances of outer sense. It is the subjective condition of sensibility, under which alone outer intuition is possible for us. Since, then, the receptivity of the subject, its capacity to be affected by objects, must necessarily precede all intuitions of these objects, it can readily be understood how the form of all appearances can be given prior to all actual perceptions, and so exist in the mind *a priori,* and how, in a pure intuition, in which all objects must be determined, it can contain, prior to all experience, principles which determine the relations of these objects' *(Critique*, p. 71).

Particular objects in an intuition, or concepts in the understanding associated with these objects, did not have the same necessity about them as did space. A ball did not have to be red, nor did it have to be located in a particular place. On the other hand, a part of the house containing the room, a space for the room, a place of the ball, all these were necessary and could not be thought away:

> 'If we remove from our empirical concept of a body, one by one, every feature in it which is (merely) empirical, the colour, the hardness or softness, the weight, even the impenetrability, there still remains the space which the body (now entirely vanished) occupied and this cannot be removed' *(Critique,* p. 45).

The fact that space could not be annihilated and that it had to take a certain form constituted strong arguments for Kant's view. Further, his notion of space provided a solid epistemological basis for the postulates of Euclidean geometry and Newtonian physics, showing that these could be immediately and innately available to the mind and yet provide knowledge applicable to the external world.

Unfortunately, Kant did not provide an analysis of how this innate knowledge arose. He postulated that we can have no knowledge of the external world as it is in itself, and that the ultimate validity of the notion of absolute space derived solely from the fact that it was part of our mode of perceiving, an intuition. Yet, this space synthesized by the mind, this mode of perception, must have some correspondence to the physical world if it is to be useful to the organism. How could this come about? How, in other words, do *synthetic a priori* intuitions arise? Had Kant been a Darwinian he might have developed something like an evolutionary version of Leibniz's pre-established harmony; in fact, present-day writers concerned with the origins of psychological knowledge (e.g. Piaget 1971b) interpret Kant in this way. Let us briefly spell out what this might mean.

The external world has a structure which cannot be directly and totally perceived by any particular organism. Let us assume (with some modern physicists) that it is a sort of n-dimensional energy soup. Animals on all levels of the evolutionary scale develop perceptual and classificatory

systems which are sensitive to various aspects of this soup; these become their version of reality, or their *ambient.* One evolutionary development led to a set of systems which divided the soup sharply into discrete objects and provided a spatial framework for containing these objects. Ancillary notions such as causality and force were also developed to account for connected bits of the soup which could not be clustered into a single object.*

Kant emphasized the point that it is difficult for us to imagine how the world would appear in the absence of these particular intuitions. Yet, it might be argued, as Berkeley did, that this way of perceiving the world is not given *a priori* but must be learned anew by each member of the species. One major difference, then, between a Kantian theory and an empiricist one resides in the level at which learning about space occurs. Kant only makes sense if we assume that a species has 'learned' to partition the world into absolute space and the objects it contains, and that individual members of that species need not acquire this knowledge *de novo.* Empiricist theories, on the other hand, must assume that each individual learns about space and objects in its own way. While this confers the advantage of flexibility on the individual members of the species, it conflicts with the notion that concepts of space must obtain a necessary form.

There are three possible non-Kantian ways of circumventing this problem, and all of these have been tried at one time or another. First, one might deny that there are necessary ways of conceptualizing space; we shall see later that this claim has been made by the so-called *cultural relativists.* Second, one might suggest that we acquire notions of Euclidean space entirely from experience because we live in a roughly Euclidean world. If we lived in another type of universe we would have different notions about space. This, of course, is a strict empiricist model. Finally, one could assume that the concept of absolute space is not given *a priori,* but that perceptual and response systems are pre-structured in such a way as to determine that experience will lead to the formulation of this concept in each individual. A variety of such models have been proposed, differing in the nature and extent of this pre-structuring. These models are not empiricist, but neither are they strictly Kantian, in that they deny the pre-formed status of three-dimensional Euclidean space. We shall be discussing various versions of all these non-Kantian models in the remainder of this chapter.

Leaving these alternative views aside for the moment, we can see that, by allowing for evolution, an innate spatial mode of perception could be developed which would confer upon the perceiver accurate knowledge of certain aspects of the external world. As it is this neo-Kantian position

* As to the question of why this particular set of classificatory systems developed, rather than some other, we can provide no answer. For instance, it is not obvious why we perceive space as three-dimensional, though it is clear that we do.

which we shall be adopting in this book, it is worth restating two main features of the argument:

1. Three-dimensional Euclidean space is a form imposed on experience by the mind.
2. This unitary framework, conveying the notion of an all-embracing, continuous space, is a prerequisite to the experiencing of objects and their motions.

The history of attempts to explain space perception after Kant revolves around theories which denied one or both of these tenets. It is our contention that no theory denying these principles can succeed.

Viewed in the way described above, Kant can be construed, albeit in the face of his own vigorous denials, as providing the basis for dividing the study of the natural world into physics and psychology. Unforeseen by Kant, physics has been able to develop techniques and languages for the description of the external world itself. The role of psychology, then, is to describe the innate features of the minds of different organisms which have evolved to match certain aspects of that physical external universe, and the way in which the physical universe interacts with the mind to produce the phenomenal world.

1.4. After Kant: nativism versus empiricism

By concentrating upon absolute space, and ascribing it to the innate machinery of the mind, Kant had the effect of largely removing the evaluation of his theory of space perception from the experimental arena. It is not surprising, then, that over the course of the next century, during which time experimental approaches to psychological problems began to gather impetus, the influence of Kant's model waned. There were, of course, other reasons for this and for the concomitant return to an emphasis upon relative space; in particular there were radical changes in first mathematics, and then physics, which undercut Kant's arguments based on Euclidean geometry and Newtonian physics. Whatever the reasons, the shift in emphasis from an absolute to a relative theory of space has had the most profound effect upon research in psychology.

Kant's postulation of an *a priori* absolute framework did not, by itself, provide a complete explanation for all aspects of space perception. He was virtually unconcerned with a series of more mundane issues such as the nature of depth and distance perception, localization within the spatial framework, and so on. In attempting to come to grips with these problems, those that followed Kant opened up a set of new difficulties and the investigation of these eventually led to the formulation of entirely new models for space perception, the so-called *nativist* theories. Common to all these models was the assumption that some portion of our spatial knowledge is independent of specific experience.

On the other side, the empiricists were equally interested in these problems. Their basic assumption, of course, was that all forms of knowledge about space, including its very existence, must be acquired through experience. For some time after Kant empiricists laboured at refining the position set out by Berkeley. In the course of these refinements one can detect a shift away from any interest in the notion of unitary space, a shift which matched the one occurring within nativist theory. Thus, the nineteenth century was characterized by a major change in the emphases of theories of space perception; in effect it was decided that absolute space was not important and that relative space held the key to a complete understanding of the problem.

1.4.1. EARLY VIEWS

The perception of space includes knowledge about the size, location, and distribution of things in a unitary three-dimensional environment. Kant concentrated on the last problem, leaving the first few problems to subsequent writers. There are only two possible classes of explanation for these: either there is information in the mosaic of stimulation which inherently specifies certain features of space, or these features are contingently derived from experience.

We have already discussed Berkeley's model, which includes assertions about the derivation of distance, location, and the idea of space itself, from experience. This formed the basis for future empiricist models, some of which we shall discuss later. The major problem faced by these models is simply stated: how can an organism learn about space, in all its aspects, from scratch? It is encumbent upon empiricist theories to demonstrate two things: (1) no knowledge of space is available prior to experience; (2) there are empirically verifiable means by which such knowledge can be derived from experience.

The other class of theories, termed nativist, assumes that some spatial knowledge is available prior to specific experience. Kant fits into this category, as do several who followed him and accepted the idea that the framework of unitary space was innate. There was another class of nativists, however, who accepted innate spatial knowledge without crediting the idea of an intuition of unitary space. This constituted the major shift away from Kant noted already, and led to a totally different type of theory. It is unfortunate that Boring (1942), in his classical review, failed to recognize this schism, for he has obscured the important differences between models which posit an innate framework and those which do not.* The requirements of a successful nativist theory vary with the features of space perception it takes as given. In general, it must provide evidence that there are mechanisms capable of automatically extracting the required information

*Piaget, for instance, lumps Kant together with the later nativists and dismisses both for the same reasons (see p. 42n). Pastore (1974) has commented on this misinterpretation in Boring.

and that these do not depend upon specific experiences of the organism. In addition, if the theory leaves any aspects of space perception outside this innate umbrella, it must provide an explanation for how these are built up from what was innately available.

Both the early nativists and the empiricists working at the start of the nineteenth century were as yet unaware of a whole set of problems concerning space perception; these unfolded partly as experimental research burgeoned, in particular that concerned with visual space perception in humans.* Another factor contributing to the elaboration of new issues was the solution offered to the first problem attacked by the post-Kantian nativists, that of localization in three-dimensional space.

It will be recalled that Kant could offer no strong argument for the necessity of three-dimensional spatial intuition, nor did he discuss the problem of localization within that space. Lotze (1886) described the issue in this way:

'Let it be assumed that the soul once for all lies under the necessity of mentally presenting a certain manifold as in juxtaposition in space; How does it come to localize every individual impression at a definite place in the space intuited by it?' (pp. 51-2)

1.4.1(a). The nativist solution. Writing shortly after Kant, Muller offered a solution to the problem of three-dimensional localization, set within his essentially Kantian 'doctrine of specific nerve energies'. This doctrine held that when a nerve was stimulated the sensation elicited was a property of the nerve itself (or its termination in the central nervous system) and not of the physical nature of the stimulus. Thus, for example, a mechanical blow to the eye resulted in a visual sensation. In addition, however, nerves could signal some aspects of the physical world as well owing to their sensitivity to vibrations, chemicals, heat, and electricity. One of these qualities of the world in itself was extension, and the visual and tactile modalities were best suited, by virtue of their structure, to signal it:

'. . . inasmuch as the nerves of the senses are material bodies, and therefore participate in the properties of matter generally occupying space . . . they make known to the sensorium, by virtue of the changes thus produced in them by external causes, not merely their own condition, but also properties and changes of condition of external bodies ... All the senses are not equally adapted to impart the idea of 'extension' to the sensorium. The nerve of vision and the nerve of touch, being capable of an exact perception of this property in themselves, make us acquainted with it in external bodies ... The retina of the optic nerve has a structure especially adapted for this perception' (Muller in Herrnstein and Boring 1966, p. 33).

* Our emphasis upon human visual space perception is necessitated by this historical fact. Where possible we shall introduce evidence from other sources, as our argument is meant to apply across all species and modalities.

According to Muller both the three-dimensional structure of space and the distribution of objects in that space were specified by the spatial positions of retinal elements activated by visual inputs. That is, the peripheral visual apparatus was itself extended in three dimensions; perception of both absolute and relative space was a simple matter of 'reading' the set of activated nerves.

Lotze expanded on this notion of the 'spatial' information transmitted by nerves in addition to the quality of the sensation. He called this extra information the local sign of the stimulus and noted that without some such information the mind would merge two identical or similar sensations arising from different areas of the world.*

Both Lotze and Muller argued for the innate basis of the intuition of space. In this they agreed with Kant and differed from those nativists who followed; these latter rejected both this claim and the unitary space it presupposed. Given that positional localization was being ascribed to certain sensations, it seemed sensible to drop the idea of an *a priori* spatial framework and rely solely upon spatial sensation. At least this would return the study of space perception to the laboratory. This new type of nativism, as espoused by Hering (cf. Hurvich and Jameson 1964) and James (1890), for example, differed from both the *a priorism* of Kant and the empiricism of Berkeley. It assumed that our notions of space were no different from those of colour: simply features to be extracted from the ambient stimulating environment. What remained to be determined was the nature of the stimuli involved and the means by which information was derived from them.

Hering's version of the theory of local signs supposed that each retinal element, when stimulated, provided information about its location. There were three types of local sign, one pertaining to each dimension of space. The stimulation derived from an object, for instance, automatically conveyed information about the spatial attributes of that object. Similarly, relations between objects could be read off the pattern of retinal stimulation.** All nativists agreed that there were sensations corresponding to, and evoking feelings of, space. However, there was no concentrated effort to explain why or how these sensations came to elicit spatial feelings.*** A related but, from our point of view, more important failing of most nativist models concerned their lack of interest in the means by which a unitary spatial framework was generated out of these sensations. Following Hering, it was usually assumed that simply specifying the basic spatial sensations

* It is not clear exactly what form Lotze thought these local signs would take. He may have had in mind something like the topographic sensory maps of the body surface, retina, etc., which have subsequently been described.

** There is in all nativist models a strong strain of naive realism. Perceptions more or less mirror the physical world, which is directly perceived.

*** James admitted this failing of nativist theory when he stated that 'who calls a thing a first sensation he has no theory of its production' (James 1890, vol. 2, p. 280).

was all a theory of space perception had to do. This lack of concern reached its logical end-point with James (1890), who more or less denied the existence of any concept of unitary space:

'... if any known thing bears on its front the *appearance* of piecemeal construction and abstraction, it is this very notion of the infinite unitary space of the world. It is a *notion*, if ever there was one; and no intuition. Most of us apprehend it in the barest symbolic abridgement: and if perchance we ever do try to make it more adequate, we just add one image of sensible extension to another until we are tired. Most of us are obliged to turn around and drop the thought of space in front of us when we think of that behind' (vol. 2, p. 275).

This attitude towards unitary space shows how far nativism had travelled from its Kantian beginnings. Extended objects automatically elicited the perception of a three-dimensional universe. The unitary space which dominated Kant's thinking was an unnecessary notion.

Mach (1897) was an important exception to this trend; while agreeing that sensations conveyed spatial information he felt that these could only produce positional localization for the single *field* perceived in one instant, or fixation. Mach suggested that what can be given in immediate sensation is limited to information pertaining to relative, or *egocentric,* localization, the position of things relative to the observer, and to each other, at that moment in time. In order to appreciate the world as a coherent, interconnected universe he felt it necessary to consider the information provided by movements of the eye, head, and body. The individual *frames* of experience provided by sensation could be spatially ordered quite easily. However, how were these individual frames to be combined into a connected series? Mach was the first nativist to realize the importance of the fact that we do not experience the world as a set of frames loosely interwoven with the seams still showing. Rather, these are effortlessly integrated into an overall conceptual space. According to Mach, this problem is solved through the intervention of motor feedback processes which guarantee, for instance, that

'the whole optical space appears to us a continuity and not an aggregate of fields of vision . . . at the same time, the optical objects remain stationary . . . Thus we arrive at the practically valuable conception of our body as in motion in a fixed space' (pp. 63-4).

In attending to these questions Mach showed that specifying the means for a static three-dimensional localization would not be sufficient in accounting for space perception *in toto*. He was also the only early nativist to pay attention to the conception of a fixed space.* None the less, he did not specify how motor processes brought about the integration of separate visual fields and the concomitant conception of fixed space. Was this an

* It should be noted that Lotze (1886) also recognized the importance of information from motor processes in articulating the meaning of local signs, but he did nothing more than mention this fact.

unlearned mechanism or was it acquired? If the latter, and Mach seemed to lean in this direction, how was this learning accomplished? Finally, what form did the motor information take, and from where did it emanate? These questions, ignored for some time after Mach, still require answers, as we shall see later.

No further resolution of these issues was to come from the traditional nativist approach; further progress involved radical shifts in the theory, and these were not undertaken until the Gestaltists presented their new model. The temporary failure of nativism at the time was matched by similar problems in the empiricist camp, whose evolution after Kant we can now briefly review.

1.4.1(b) The empiricist solution. An emphasis upon objects and their localization, combined with a relative lack of concern with the concept of unitary space, also characterized empiricist theory in the nineteenth century. Empiricists disagreed with a fundamental assumption of nativist theory: that sensations contained inherently spatial information. Here, Kant and the empiricists found common ground: sensations were spaceless in content. Berkeley's empirical model laid the basis for a number of similar ones, involving refinements of the mechanisms by which associations formed between a succession of sensations could generate the concepts of extension and space.

After Kant empiricist theory developed quite slowly, perhaps because of the support derived by the Kantian position from the success of Euclidean geometry and Newtonian physics. Reid (1785) modified Berkeley's position while accepting his main argument that space is an empirically derived concept. He held that Berkeley's emphasis on tangible space was overstated, and attempted to show how tangible and visible space must be independent but necessarily interrelated. Thus

'The correspondence between them is not arbitrary, like that between words and the thing they signify, as Berkeley thought; but it results necessarily from the nature of the two senses' (p. 286).

That is, Berkeley held the strong empiricist position that any correspondence between visual and tactile space was a function of experience in matching the two: Reid, on the other hand, held that the two necessarily reflect one another. However, he did not specify what lay at the basis of this fixed correspondence, nor how these two types of space gave rise to the concept of unitary space. Much the same position was adopted by a number of his contemporaries, including Stewart (1818).

Some decades later a number of British Associationists continued this empiricist tradition. Spencer (1855), for example, argued rather forcefully against the Kantian model, raising objections to be encountered subsequently in the work of Poincaré (1913). Spencer first argued that the fact that we cannot contemplate the annihilation of space does not confer upon space the unique status claimed for it by Kant. Instead, he suggested that, if we view space as 'an ability to contain bodies', then it is perfectly logical that we have acquired the knowledge that this ability cannot be annihilated. He went on to argue that this notion accounts for the fact that

'... every conception of space which can be formed by a single mental act is limited to such portion of space as we can have experience of at one time' (p. 54).

That is, we cannot consciously hold an image of space which goes beyond the powers of our sensing apparatus. We cannot see both in front of and behind ourselves; thus we cannot conceive of a completely unified space.

As for how space concepts do arise, Spencer continued where Berkeley left off.

'... whether visual or tactual, every perception of the space-attributes of body is decomposable into perceptions of relative position . . . all perceptions of relative position are decomposable into perceptions of the relative position of subject and object; and ... these relations of position are knowable only through motion' (p. 233)

This is as direct a statement of the rigidly egocentric concerns of empiricist theory as one can find, and it accurately sums up the situation which produced a total neglect of the notion of absolute space. Spencer attempted to show how the concept of position devoid of body, and thence the concept of space, were developed through experience and the processes of association. This was similar to the mechanism suggested by Berkeley, and we shall not repeat it here.

At about this time radical developments in geometry provided new impetus for empiricist theory. As we have seen from our study of Kant, geometry held a special place amongst the sciences. It was the paradigm science, a purely relational system which nevertheless faithfully and necessarily reflected the structure of the physical world. All of this changed in the middle of the nineteenth century with the discovery (invention) of non-Euclidean geometries by Riemann, Lobachevski, Bolyai, and others. These geometries were based on modifications in one of Euclid's original postulates, the so-called parallel postulate. This stated that through a point outside a line only one other line could be drawn parallel to the original line. This postulate had always been viewed with suspicion; it lacked the intuitive 'self-evidentness' of the other postulates and axioms and relied on such unobservables as the relationship between lines at infinity. During

* It is worth emphasizing the recurrence of the idea that our concepts of space are completely dependent upon sense-data limits. As we have seen, James stressed this point as well, showing that there was little disagreement here between empiricists and nativists. Much the same position was also adopted by Poincaré. We would agree that organisms do not 'see' absolute space; cognitive maps are not pictures of the universe, they are schemata from which any portion of space can be constructed. The fact that we cannot *perceive* unified space does not mean we cannot *conceive* it; the latter potentiality derives from the possession of a structure which can be used to construct spaces that stretch endlessly in all dimensions.

attempts to derive it from the other more intuitively obvious postulates, or to dispense with it altogether, it was noticed that other geometries, with total internal consistency, were possible. In these there were no parallel lines or even an infinitude of parallel lines. This discovery called into question the *a priori* status of Euclidean geometry and its assumed relationship to the physical world. No longer could it be maintained, as Kant had, that Euclidean geometry

'... carries with it apodictic certainty; that is to say, absolute necessity, not based upon experience, and consequently a pure product of reason' (Prolegomena, Section 6).

Helmholtz was among the first to incorporate directly the new findings of mathematics into his theory of psychological space. Thus, he entitled one of his papers on the subject *Space can be transcendental without the axioms being transcendental* (cf. Warren and Warren 1968). While accepting the idea that the psychological spatial framework was innately given,* Helmholtz denied that the metric of this framework was inherently Euclidean. If, following Kant, one continued to insist upon the Euclidean nature of this framework, then one was in danger of being at variance with the physical world, should that world be best described, for example, by Riemannian geometry.

Helmholtz felt that the particular metric to be applied to our concepts of space had to be acquired through experience, though he did not specify how this would occur. Similarly, the meaning of local signs was also learned. Thus, Helmholtz was placed in the empiricist camp. He categorically rejected the nativist views of his contemporary, Hering, because such

'theories are always obliged to assume that actually existing *sensations* can be squelched by an experience showing them to be unfounded' (1910 p. 556).

That is, Helmholtz felt that if it was necessary to invoke experience to explain some spatial perceptions it was most parsimonious to explain all perceptions in this way; there was no need to talk about innately spatial sensations.** There was, of course, a fatal flaw in Helmholtz's theory, from

* Helmholtz did not discuss this issue at any length; at one point, however, he suggested that the psychological concept of unitary space is innately derived from the sense of touch. James (1890), taking note of this, dismissed Helmholtz in the following way: 'Of course the eye-man has a right to fall back on the skin-man for help at a pinch. But doesn't this mean that he is a mere eye-man and not a complete psychologist' (p. 279).

** A corollary of this view was also promulgated by Helmholtz when he stated that whatever 'can be overcome by factors of experience, we must consider as being itself the product of experience and training' (p. 13) This view led empiricists to concentrate upon demonstrating the ways in which different experiences could influence various perceptual functions. The demonstration of the effects of wearing prisms, begun with Stratton's (1897) work, is a prime example of this. It was held by empiricists that the study of adaptation would tell us something about the origins of space perception, by recreating the 'naive' state. This entire methodology, of course, suffers from a confusion between modification and generation, as Pastore (1960) and others have pointed out. The fact that certain experiences can affect space perception does not tell us anything about the origins of space perception itself. For this reason we shall not have much to say about studies exploiting this type of reasoning.

the empiricist point of view, in that he allowed an innate spatial intuition to creep in by the back door of touch.

A somewhat stronger empirical position was adopted by Wundt (1894). He argued that neither the sensations of touch and movement, nor those of vision were sufficient in themselves to account for space. Thus, he described the basic empiricist and nativist models as follows:

'It has often been thought possible to set up a theory in terms of movement and movement-sensations alone, and either entirely to neglect the local sensation qualities of the retina and skin, or to regard them as functioning in entire independence of movement, and as being, like the latter, sufficient in themselves for an adequate explanation of the facts . . . Experience shows that *these* two influences are so intimately connected that neither of them is operative without the other' (p. 168).

Instead, Wundt held what he described as a theory of 'complex local signs'. This theory

'. . . regards the extensive idea as the mental resultant of intensively graduated local signs of the movement-sensation and qualitatively graduated local signs of the sensory surface. Space perception depends on the uniform association of these two sensation series' (p. 169).

These sensation series were developed through experience, and the perception of space, therefore, was a function neither of the innate structure of the mind, nor of particular properties of the sensations themselves. The catch in this, of course, is the phrase 'uniform association'. Wundt did not explain where this came from, nor how it functioned. If this association was automatic, then Wundt imported non-empirical notions into his model without openly saying so. He provides a good example of how difficult it is to be a thorough-going empiricist.*

1.4.1(c). Early views reviewed. In the course of elaborating these early versions of nativism and empiricism, investigators uncovered a host of new problems. Most of these revolved around the distinction between sensation and perception. Within both theoretical approaches the perception of space was seen as dependent upon some transformation of the former into the latter. Both demanded some measure of uniformity in this transition; unfortunately, this uniformity was lacking in a wide variety of situations.

Nativism suffered most from this discrepancy. Assuming, as it did, some fixed relationship between sensation and perception, this approach ran aground when confronted with the so-called *perceptual constancies.* This

* James (1890) had the following to say about Wundt's theory: 'Wundt's theory is the flimsiest thing in the world. It starts by an untrue assumption and then corrects it by an unmeaning phrase. Retinal sensations are spatial: and were they not, no amount of 'synthesis' with equally spaceless motor sensations could intelligibly make them so' (p. 277-8).

category of phenomena demonstrated that sensation (as received at the sensory surface, the proximal stimulus) could vary without any change in perception. The simplest of such phenomena, that of retinal localization invariance, shows that a form looks the same regardless of where on the retina it falls. This, in itself, can be handled by certain versions of early nativist theory. However, perceptual size invariance presents an insuperable problem. The distance of an object can vary (and thus the proximal stimulation must vary) without any change in perceived size. In order to account for this, and similar findings, nativism had to continually resort to the role of experience in explaining perception. This, as Helmholtz pointed out, was both uneconomical and unsatisfactory, and it led to the abandonment of the Hering-type nativist model.

Empiricism, on the other hand, could at least hope to explain these phenomena in terms of learning; it is required only that it be demonstrated that such constancies are acquired rather than innate. Thus, since size constancy is intimately connected with the perception of distance, it is necessary to show how the perception of distance develops through experience. However, there was another class of phenomena which embarrassed empiricists: the illusions. Here, perceptions did not correlate with sensations in the expected way, according to everything experience ought to have taught the organism. In attempting to explain both the constancies and illusions empiricism was forced to rely on such things as unobservable sensations and 'unconscious inferences' from these. This was not a particularly satisfying state of affairs.

At the start of the twentieth century there were, as James (1890) pointed out, only three possible theories of space perception:

'Either (1) there is no spatial *quality* of sensation at all, and space is a mere symbol of succession; or (2) there is an *extensive quality* given immediately in certain particular sensations; or, finally (3) there is a *quality produced* out of the inward resources of the mind, to envelop sensations which, as given originally, are not spatial, but which, on being cast into the spatial form, become united and orderly' (p. 271-2).

However, James dismissed the Kantian position,* while neither the empiricists nor the nativists had provided anything like a solution to the problems of space perception.

* James called the Kantian view 'mythological' because he was 'conscious of no such Kantian machine-shop in my mind' and he had 'no introspective experience of mentally- producing or creating space' (p. 275). It is interesting that McDougall (1923), reviewing the same material, came to a rather different conclusion: 'spatial perception, as enjoyed by ourselves and the higher animals, is an extremely complex function, the capacity for which is not built up by each of us *de novo*, but is laid down in our innate constitution' (p. 245). In direct response to James he stated that 'the processes that go on in our heads can never be revealed in all their vast complexity to the introspective glance of any psychologist - not even of a William James' (p. 248). Pylyshyn (1973) and others have commented on the importance of representations which cannot be open to conscious experience.

1.4.2. LATER VIEWS

The difficulties faced by early empiricist and nativist models indicated that new departures were needed. These were provided on the one hand by Poincaré and on the other by Gestalt theory. The former attempted a thorough going empiricist model which would eschew such things as unconscious inferences and which would provide explanations for the development of space perception through experience. The latter reformulated the basis of nativist theory, denying the elementarism of Hering and re-incorporating the idea of a spatial framework, though in a limited way. Both of these new approaches owed something to the contemporary developments in mathematics and physics, in particular the new ideas concerning the relationship of geometry to the physical world and the concept of the *field* developed in relativity physics.

1.4.2(a). Poincaré's model. Henri Poincaré (1913) proposed a model for the development of space perception, within a broadly empiricist context, which has served as a point of departure for all subsequent empiricist approaches, including those applied to humans and infra-humans. Writing from the standpoint of a mathematician and philosopher of science, he represented an almost total return to the Berkeleyan view of space. Poincaré agreed with Kant that the notion of geometrical space was not part of the objects of sense themselves; he held it to be a matter of convenience which geometry one chose. However, the space of Kant's introspection was continuous, infinite, three-dimensional, homogeneous, and isotropic, while the space of Poincaré's introspection, which he labelled *representative* space, lacked all of these qualities. Discussing examples from visual, tactile, and motor space, Poincaré suggested that the space given in perceptual experience was much more restricted and egocentric than that suggested by the Kantian model. Thus, according to Poincaré

> 'absolute space is nonsense, and it is necessary for us to begin by referring space to a system of axes invariably bound to our body' (p. 257).

Many of Poincaré's ideas about space rested on notions of the active role of the motor system in the development of perception: an organism incapable of movement could not perceive space. Our minds constructed the space of Euclidean geometry as a convenient fit to experience 'by studying the laws by which . . . sensations succeed one another' (p. 71). These sensations were derived from either real or imagined movements, relative to things in the external world.

Poincaré distinguished between two types of external changes in things: those of *position* and those of *state*. While the former could be 'corrected'

by some internal change, the latter could not.* These internal changes were the source of the sensations underlying the notion of space. Thus, to localize an object in space 'simply means that we represent to ourselves the movements that must take place to reach that object' (p. 70). Similarly, and with direct reference to the internal correction of an external change, the displacement of an object could be assessed by the organism through such movements as were necessary to bring the perception of that object back to its former state; that is, by reinstating the original view of the object. Directions of movement were not given, but

> 'the sensations which correspond to movements in the same direction are connected in my mind by a simple association of ideas' (p. 69).

Poincaré was aware that this association might be

> 'extremely complex, for the contraction of the same muscle may correspond, according to the position of the limbs, to very different movements of direction' (p. 69).

It was largely through the agency of the *displacement group* that Poincaré envisioned these associations as occurring. Derived from the mathematical theory of groups, a displacement group was defined as that set of internal changes capable of correcting for the same external change. Each of the movements (real or merely represented in thought) in such a group would be practically indistinguishable in its effects from all the others. The essential feature of the displacement group was its property of associating those movement patterns which were equivalent in their ability to reinstate a previous situation. By virtue of this association quite different spatial displacements would be connected in the mind, providing the basis for spatial concepts.**

It is essential to ask what Poincaré meant by 'correcting for an external change', as this ability, simply assumed in his model, is central to the displacement group and the construction of space. Poincaré suggested that displacements are considered as equivalent when they enable the observer to *regain the original view of an object.* Thus, correction involves reestablishing a subject-object relationship exactly equivalent to that which existed prior to the external change. If this is not possible through any displacement then the observer judges that the object has undergone a change of state. If it is possible, one can calculate the movement required

* Poincaré used this concept to separate object motion from form change. But, as Johansson (1964) pointed out, this left him unable to account for the simultaneity of the two, e.g. the spatial qualities of a fire or a moving animal.

** This theoretical position was adopted by Hull (1934a) in his discussion of the development of spatial behaviour in rats, as we shall see shortly (pp. 50-2). Its central feature is that many paths from any place A to any other place B will be connected together because the organism has had considerable experience with the equivalence of these paths in its exploratory movements. According to both Poincaré and Hull, this connection among equivalent paths occurs automatically, while Piaget (see pp. 41-5) held that it had to be learned.

to achieve it and thereby assess the movement of the object. However, the ability to regain the original view seems to presuppose some primitive means of definitively identifying objects. Poincaré provides no explanation for this capacity, nor any hint that it is learned rather than innate. This being the case, the construction of displacement groups rests on *a prioristic* foundations, though the *a priori*s are not the ones Kant chose. For instance, when a movement (real or represented*) which is assumed to lead to the reinstatement of an original situation does not do so, we do not conclude that the displacement group, and the notion of space it embodies, have been incorrectly constructed. Thus

'If experience succeeds, we say that it teaches us about space; if it does not succeed, we hie to exterior objects which we accuse of having moved' (p. 271).

Success, of course, is measured in terms of re-identifying the original view of the object. What this means, basically, is that Poincaré cannot distinguish between objective and subjective motion, nor construct space, without recourse to something like innate ideas, an uncomfortable position for any empiricist.

When Poincaré moved to a discussion of the necessity of three dimensional space he further undercut his empiricist position. Thus

'... when it is said that our sensations are "extended" only one thing can be meant, that is that they are always associated with the idea of certain muscular sensations, corresponding to the movements which enable us to reach the object which causes them ...' (p. 274)

and these associations

'... are the fruit of a long personal experience and of the *still longer experience of the race*' (p. 274, our italics).

Poincaré admits that such associations as the latter would constitute *a priori* intuitions, but argues that the presence of these associations does not mean that it would be impossible for us to conceptualize space in other ways, only that it would be difficult to do so.

We must admit that we find Poincaré rather confusing by this stage. While calling himself an empiricist (and being so labelled by most others) he makes use of several *a priori* notions. While seemingly concerned with the problem of the necessity of certain forms of spatial perception he constantly argues for the conventionality not only of geometry but also of psychological concepts; we represent space in the way we do because it is convenient, not because it is right. None the less, Poincaré represents an important benchmark in empiricist theory. With the notable exception of Piaget (see pp. 41-5), subsequent writers were rarely concerned with the

* By equating real and intended movements Poincaré was giving an implicit answer to the question of the nature of the information provided by motor processes in the elaboration of space; it comes not from the muscles themselves, but from some higher centre which programmes movements. We shall have more to say on this later.

epistemological questions that had traditionally formed part of any theory of space. He provided not only the nucleus of all future empiricist approaches, but also the set of problems to which such solutions would be applied. His assumptions concerning the development of the concept of metrical three-dimensional space have had a particular impact. Starting with empirical data from the physical world of sensations and movements this concept was constructed through a series of transformations, beginning with the simplest, and least specified, of geometries and leading to the most rigid. This entire process was fuelled by the mathematical properties of the *group of displacements,* which were a necessary *a priori* system. According to Poincaré this sequence was demanded by the facts; there could be no metrical information directly available in the stimulating array because there was no intrinsic metric in the physical world. Sense data present only heterogeneous spaces; experience must construct the rigid, metric framework of connected space. These assumptions, and particularly the one concerning the sequence of acquisitions leading to metrized spatial constructs, have formed part of virtually every model of space perception in this century, be it empiricist or nativist.

1.4.2(b). Gestalt theory. As espoused by Hering, James, and others nativism was a flawed theory, as we have seen. Sensations were inherently spatial, but they were also fixed in some way to the structure of the receptors, or their termination sites in the central nervous system. This combination of sense elements and fixed connections fell apart in the face of the perceptual constancies and led empiricists to deny the validity of the entire nativist approach. However, Gestalt theory, by making a few basic alterations in the nativist position, managed to salvage a reasonable theory which could at least cope with some of the previously unacceptable facts. Gestalt theory is associated with several writers, in particular Wertheimer, Kohler, and Koffka; though they did not agree on everything, there was a basic consensus on most of the fundamental issues. Gestaltists could not accept the tendency to reduce psychological processes to discrete and localizable physiological mechanisms; this formulation had torpedoed earlier nativists. On the other hand, the Gestaltists did not wish to return to the dualistic notion that mind could never be accounted for in physical terms. Gestalt theory derived its basic concepts from the new ideas generated in physics. Relativity physics, and the notion of the *field,* offered a potential means of conceptualizing perceptual mechanisms that would be both physiological and non-atomistic.

The central nervous system is extended in space and can give rise to patterns of simultaneous activity which have a spatial quality. According to Kohler (1947):

'Experienced order in space is always structurally identical with a functional order in the distribution of underlying brain processes' (p. 39).

Such a distribution of neural processes was labelled a *physiological field.* The part activities comprising such a field had no phenomenal meaning in isolation. Rather, the entire pattern of neural activity served as an isomorph for some molar psychological entity such as a thought or a percept. Further, there was no exact localization of these fields within the brain; what was important was the pattern of the activity, not its location.

In order to understand how physiological fields mediated psychological processes, it is necessary to provide a few further details of the basic Gestalt model. In his monumental treatise summarizing the theory, Koffka (1935) described several different 'fields'. The *geographical field* was the external physical world, that which provides the stimulating environment for all organisms. The *behavioural field,* on the other hand, was the environment as the organism presumably perceived it, a world full of things with meanings, exerting forces, and capable of eliciting certain responses. The former was objective, value free, and the same for all organisms located in the same place. The latter was subjective and unique to each organism.

The idea that all behaviour could be accounted for in terms of the behavioural field was rejected, for this would deny the role of the structure of the organism itself. Rather, the proper level at which to explain behaviour was the physiological field, that system of isomorphs which both represents the behavioural field and takes into account the biological structure. Here the central concept of *organization* was introduced. The nervous system constrains and organizes the possible physiological fields according to its properties, while at the same time the simultaneous inputs interact with one another to produce an integral whole. A number of organizational rules were adduced to explain why a physiological field segmented as it did, and why forms took the shape that they did. To a large extent these rules have become part of the accepted lore of form perception.

However, the concentration upon the physiological field, and the interactions which organized its distribution, compelled Gestalt theory to concentrate entirely upon form perception. Organization led to the segregation of any field into discrete 'things', the nature of which were determined by such features as articulation, continuation, good shape, and so on. These 'things' did depend, for their constitution, upon the existence of a framework, but here the Gestalt model was not using framework in the same three-dimensional sense as did Kant. Rather, Gestalt theory utilized a framework provided by the notions of horizontal and vertical. Koffka's book devoted only a few pages to the entire problem of the organization of three-dimensional space and said nothing at all about the concept of unitary space. In fact, it is possible that Gestalt theory would deny the validity of psychological unitary space in its entirety, much as James did. According to Koffka 'behavioural space is not Euclidean' (Koffka 1935, p. 275).

This accords with the data provided by relativity physics, but Koffka did not go on to deal with whatever geometrical properties behavioural space does have.

These considerations, by themselves, should not have prevented Gestalt theory from developing a physiological mechanism for objective space. There are, however, several other reasons why this might have happened. First, Gestalt theory was, as we have seen, strongly influenced by the prevailing emphasis upon relativity and the concomitant notion of the conventionality of geometry. There seemed no need to account for any particular metric in perceived space. Instead, the emphasis was placed upon the anisotropy of both the geographical and behavioural environments. Second, the basic structural form of Gestalt theory might have itself precluded any successful analysis of unitary space. Having denied the concept of an *a priori* objective space, and juxtaposed this with the idea of physiological fields as integral wholes, there seems no way that Gestalt theory could generate unitary space from individual fields. To do so would be to contravene the basic whole-part principles embodied in the theory. Either unitary space was there or it was not, it could not be constructed. This, of course, is a corollary of the often noted inability of Gestalt theory to cope with learning.

The outcome of all this was seen most clearly in Lewin's (1936) book on *Topological psychology,* where he attempted to deal with behaviour in space according to Gestalt principles. Thus

> 'psychology does not deal with one single connected space which represents the totality of its world' (p. 68).

Instead, Lewin concentrated on the dynamic properties of *life space,* equivalent to what Koffka called the behavioural field, and what most writers now term *personal space.* This space is described most adequately, according to Lewin, in terms of topological geometry, which is a system for defining spaces and spatial relations without measurement. It deals with connectedness, whole-part relations, boundaries, and so on. By itself, topology could not incorporate notions of distance or direction; Lewin therefore added some components of vector geometry which enabled him to discuss directional forces within the life space.* This conceptualization does allow for a discussion of some of the dynamic forces constituting a behavioural field, and it is these motivational variables that Lewin concentrated upon.**

* Lewin termed the space generated by this combination of topological space and vectorial geometry *hodological space*; this derives from the Greek word *hodos,* which means path. Thus, Lewin was interested in specific paths, or routes, through behavioural space.

** Lewin never actually formalized the mathematics he was to use. According to Kaplan: 'The actual application of topology to psychology remained for Lewin a program and a hope' (1956, p. 1307).

Lewin's insistence that psychological space is concerned with, and organized by, the meaning of things within the behavioural field has carried over directly to contemporary approaches to mental mapping, accounting for its bias in this direction (see pp. 75-80).

As useful as such an approach might be for exploring certain features of spatial behaviour, it is clear that its usefulness is limited to egocentric space. There seems to be no way that Gestalt theory can provide a basis for objective spatial representation. Added to these difficulties in coping with unitary space, we should briefly mention the problems associated with the physiological field and the idea of non-localization. The so-called 'law of mass action' assumed that the debilitating effects of brain damage depended more on the extent than on the locus of the damage; this was a necessary adjunct to the field theory. Though given some early support in Lashley's work (see e.g. Beach *et al.* 1960), it now seems clear that some form of discrete localization of function must be allowed (see Hebb 1949, pp. 12-16, for some discussion of this issue). The Gestalt programme, then, could not survive intact. Its emphasis on organizational properties was important, however, because it showed one way in which perception could be detached from the elements of sensation. Its total inability to handle metrical three-dimensional space meant that it could never provide a complete accounting for space perception.

1.4.2(c). Later views reviewed-briefly. Neither Poincaré nor the Gestaltists, in their reformulations of empiricism and nativism respectively, provided satisfactory theories, but they did lay the groundwork for further progress. Poincaré identified the starting point (the notion of the displacement group) from which successively more subtle concepts of the geometry of space could potentially be elaborated. His failure to show how this could be done opened the door for a more thoroughly empiricist approach, and that has been provided by Piaget and his co-workers.

The failure of the Gestalt programme was of a different order. In the course of its progress numerous experimental facts of perception were generated, and these constituted new problems for any future theory. The particular solutions offered by Gestalt theory could not work, but they did indicate that, within any nativist theory, inherently spatial sensations had to be extensively transformed before they could account for perception. This notion of transformations, combined with an entirely new idea concerning the source of spatial information from the environment, characterized J. J. Gibson's (1950, 1966) influential model.*

1.4.3. PRESENT VIEWS

We have seen that Poincaré's model failed to provide a resolutely empirical

* With Piaget and Gibson we shall bring our story up to the present. There have been other approaches, but these two are representative, embodying the empiricist or nativist presuppositions of all approaches. Thus, models such as transactionalism (e.g. Awes 1953, Ittelson 1960) or the sensory-tonic, organismic approach (cf. Wapner, Cirillo, and Baker 1971, for a review and some early references) place egocentric space before unitary space and are variations on the themes we have been exploring in this chapter. Though interesting in their own right, such approaches need not be considered separately in the context of our review.

explanation for the generation of spatial concepts. Further, it appears that any nativist model which denies the *a priority* of metric unitary space must incorporate an empirical explanation for the development of this concept, beginning with the inherent space provided by the structure of the organism and the automatic transformations worked on the sense data. Both Poincaré and, as we shall see, Gibson, starting from rather different theoretical foundations, settled on the agency of the mathematical group as crucial to the elaboration of space perception. For Poincaré this group consisted in the sets of movements which effected the same displacement in space. Their automatic association was seemingly inherent. For Gibson the group consisted in the set of transformations worked on sensory inputs, such that invariants were extracted from these data. Again, these processes were inherent.

Beginning where Poincaré left off, Piaget and his colleagues have proposed an elaborate scheme which attempts a thoroughgoing empiricist analysis of the ontogeny of space perception (Piaget 1955, Piaget and Inhelder 1956, Piaget, Inhelder, and Szeminska 1960). Theirs is a theory dealing with the epistemology of space *representation*, rather than perception. It is neither empiricist nor nativist; rather, it is best described as *structuralist*. Yet Piaget insists that spatial representations are acquired from experience and presents a scheme for this development which would, if correct, fulfil the programme of generating spatial concepts without *a priori* knowledge of unitary space. As such, it represents a view of psychological space antithetical to the position we adopt here, and must be closely considered.

While Piaget has concentrated upon the development of human spatial representation, the empirical approach of Poincaré has also influenced experimental psychologists working with infra-humans. In particular, Hull adopted this approach in his attempts to account for maze learning in rats. By briefly reviewing his model we can introduce the general problem of the study of space perception in infra-humans, with which much of the remainder of this book is concerned. Here, we can consider the early work on the nature of the rat's spatial abilities, and the kinds of explanatory models it elicited.

1.4.3(a). Piaget. Piaget's commitment to an essentially empiricist position is clear:

'it would be a complete mistake to imagine that human beings have some innate or psychologically precocious knowledge of the spatial surround organised in a two- or three-dimensional reference frame . . . Far from constituting the starting point of spatial awareness, the frame of reference is in fact the culminating point of the entire psychological development of Euclidean space' (Piaget and Inhelder 1956, p. 416).

On the other hand, Piaget is by no means the type of empiricist who considers organisms as merely passive receivers of information from the external world. Rather, Piaget holds that the experience which is essential to the development of intellectual concepts must itself be acted upon and organized by the subject. Thus, his is a constructivist model within which the structure of the organism interacts with the structure of the external world in a constant dialogue, the end-product being an increasingly refined version of the real world. Underlying the dialogue between organism and environment are two fundamental processes: assimilation and accommodation. The former refers to the way in which some specific action, in the course of reproducing itself, incorporates new external objects to its scheme. Thus, it is a form of generalization. The latter refers to the complementary process of modification of assimilation schemes in the course of incorporating a variety of new objects.

Piaget is concerned with the basic epistemological questions that we have already focused upon in our discussion of Kant. Acknowledging that there appears to be a certain predetermined aspect to the structures of intelligence, including those concerning space, he inquires into the seeming necessity of these structures. Either they are preformed in the sense described by Kant, or they are in some way constructed. Piaget opts for the latter position, and his theory is then largely concerned with showing how necessary mental structures might be constructed in the course of experience.*

Piaget starts by pointing out that mental structures cannot 'arise out of nothing' (1971a, p. 62). There must be

'... certain givens from which the construction of logical structures takes off, but these "data" are not primordial in any absolute sense ... nor do they "contain" what is, in the course of construction, "derived" from and "based" on them' (1971a, p. 62).

That is, the very first assimilations and accommodations can only take place against the background of some prior structures, and these must be inherent in the organism. For Piaget, what is given by heredity is a set of sensori-motor co-ordinations, or movement patterns, such as sucking and grasping in the human infant. These form the starting point in the endless chain of assimilation and accommodation, leading eventually to mature views of reality.

* Piaget rejects the strict Kantian model for a number of related reasons. At one level he seems to feel that construction is a much more powerful tool than pre-formation, in the sense that the former opens up 'the possibility of individual acquisitions' (1971b, p. 226). Of course, such individual acquisitions are quite beside the point with regard to structures which must obtain a necessary form in the end. At another level he rightly points out that pre-formation merely shifts the explanatory load from the individual to the species. It still remains a problem to explain how pre-formed structures came into being. Finally, Piaget rejects Kantian *a priorism* by lumping it with Gestalt ideas on the innate basis of forms, a theory which, he points out, cannot assimilate external experience at all. However, there is no justification for tarring Kant with this brush, just as Piaget is wrong in assuming that the later nativists, such as Hering, were avowed Kantians.

It is important to remember that for Piaget these earliest inborn structures contain only the seeds of later structures, and nothing more, for it is this distinction which separates his model from one of totally pre-formed structures.

How, then, does Piaget envision the construction of spatial concepts, starting only with a limited set of sensori-motor schemes? According to him

'... at birth there is no concept of space except the perception of light and the accommodation inherent in that perception. All the rest- perception of shapes, of sizes, distances, positions,etc.- is elaborated little by little at the same time as the objects themselves. Space, therefore, is not at all perceived as a container but rather as that which it contains, that is, objects themselves; and, if space becomes in a sense a container, it is to the extent that the relationships which constitute the objectification of bodies succeed in becoming intercoordinated until they form a coherent whole. The concept of space is understood only as a function of the construction of objects . . . only the degree of objectification that the child attributes to things informs us of the degree of externality he accords to space' (1955, p. 98-99).

Here, Piaget asserts his commitment to a relative theory of space, derived from the relations between objects. But, the development of spatial concepts from object relations does not happen automatically, as Leibniz might have asserted. Thus,

'The "intuition" of space is not a "reading" or apprehension of the properties of objects, but from the very beginning, an action performed on them ... Action is first manifest in the form of sensori-motor activity regulating perception ... Poincaré had some inkling of this when he envisaged movements as the source of basic spatial concepts' (Piaget and Inhelder 1956, p. 449).

The very first concepts concerning space, then, are generated through actions directed at objects. Central to Piaget's argument, as it was to Poincaré's, is the concept of the *group*, about which Piaget has the following to say:

'A group is a closed circle of operations that return to the point of departure through an operation of the group as a whole . . . Like Poincaré, we shall not hesitate to speak of groups to designate the child's behavior patterns to the extent that they can be reversed or corrected to bring them back to the initial point. The only objection to Poincaré's description is that he considered such groups as capable of being immediately extended in adequate perceptions or images, whereas in fact they remain in the practical state for a long time before giving rise to mental constructions' (Piaget 1955, p. 105-6).

As with Poincaré, the group of displacements confers upon the organism the ability to return to its starting point. But, whereas Poincaré assumed implicitly that this ability rested upon some innate mechanism guaranteeing object identification and explicitly that the reversibility it implied was intellectually apprehended by the organism, Piaget asserts that reversible groups must themselves be constructed during development and that, once developed, they remain solely practical for some time. In so doing, Piaget avoids several of the problems associated with Poincaré's model. By assuming the *a priority* of groups, in the absense of an *a priori* spatial intuition, Poincaré was forced to assume some primitive ability to identify objects. Piaget can deny the *a priority* of both groups and space, and therefore allow for the development of processes generating the object concept and object identification upon which spatial concepts can be based. The consequence of this position, of course, is that the development of any secure ideas about space must be preceded by the concept of the permanent object, as stressed by Piaget himself. This is something which can be tested experimentally; we shall see shortly that the evidence on this point remains equivocal.

In denying that the earliest spatial notions are anything more than practical Piaget draws a distinction between spatial *behaviour* and spatial *representation.* An organism might behave as though it were in possession of certain spatial principles without being aware of the concepts inherent in these principles. For instance, reversibility in action would not imply the intellectual mastering of the *idea* of reversibility. This is a notion with which we concur, and to which we can only add that organisms might well be in possession of practical Euclidean schemes and a unitary spatial framework without being consciously aware of them. Here again, experimental evidence can be brought to bear on the question of just what kind of practical spatial knowledge is inherent in the sensori-motor schemes given to the neonate upon maturation of its nervous system.

Piaget, of course, specifically denies that the various practical spaces, at the service of reversible groups, can be taken as an ensemble adding up to something like unitary space. Rather, these spaces are separate and

'... there is no specifically geometric and kinematic representation that would make it possible to place them in a common environment' (1955. p. 113).

It is this common environment which must be generated through experience and which underlies any representations of multi-modal unitary space we subsequently possess.

To summarize: Piaget attributes to the organism certain forms of innate knowledge, embodied in action systems such as those controlling the sucking and grasping reflexes. Such knowledge is purely practical and not represented as yet in thought. None the less, it controls the organism's access to the external world. By 'watching' its own behaviour the young child derives certain fundamental principles, such as the reversibility of groups; these are built up through the matched processes of assimilation and accommodation. Using these as the foundation, other concepts, including that of the object and the spatial field, are established, and these in turn lead to the elaboration of more refined spatial concepts.

Piaget's model makes a variety of predictions about the course of the development of spatial representation. Two classes of predictions are of particular interest to us: (1) those concerned with the relationship between the development of the spatial field and the concept of object; (2) those concerned with the particular sequence of acquisitions of spatial notions, beginning with topological concepts and leading through projective ones to metrical Euclidean space.* Of course, in general, the statements Piaget makes about the time of onset of these various concepts are of interest in the evaluation of his theory. Evidence concerning the first category comes from studies of such things as the ontogeny of the object concept, the ontogeny of shape and size constancy, and the use of spatial frameworks. Evidence concerning the second category comes primarily from studies of the apprehension of the different geometrical features of objects. Here, Piaget's object-oriented bias has clearly restricted his investigations.

In all these cases Piaget's model, for its verification, requires evidence that concepts develop slowly and in a particular sequence. Rather than review the evidence immediately we shall drop our discussion of Piaget momentarily and move on to Gibson. As we shall see, his model ultimately makes some of the same predictions as does Piaget's, in particular concerning the primacy of topological notions of space. We shall return to the question of the ontogeny of spatial perception and representation shortly (pp. 52-5).

1.4.3(b). Gibson. J.J.Gibson (1950), in his landmark book *The perception of the visual world,* provided a new approach to the study of space perception. He attempted to reformulate the basic problems of space perception so as to furnish some explanation for the concept of unitary space, which he considered central to any understanding of space.

His fundamental commitment to a nativist, rather than empiricist, position is clear:

'there is always some variable in stimulation (however difficult it may be to discover and isolate) which corresponds to a property of the spatial world' (p. 8).

However, Gibson's brand of nativism is a far cry from that suggested by previous writers. First, he made it clear that the standard 'sensation yields perception' story was totally inadequate, noting again that while sensations are continuously varying, perceptions can remain remarkably constant. His rough equivalents to these time-(dis)honoured concepts involved the reintroduction of the distinction between the visual field and the visual world previously suggested by Mach. According to Gibson, the visual field 'is the

* Piaget makes much of the fact that this sequence reverses the historical order of their discovery by mathematicians, implying that the most primitive (child-like) was the hardest to find. Science had to peel off more and more layers of culturally imposed onionskin before reaching the basic mathematical concepts underlying all the others.

experience on which the doctrine of visual sensations is based' (1950, p. 27), while the visual world 'is the familiar, ordinary scene of daily life' (1950, p. 26). Further

'The field is bounded; the world is unbounded. The field is unstable; the world is stable. The field is composed of adjacent areas, or figures; the world is composed of surfaces, edges, and depths, or solid objects and interspaces. The field is fluid in size and shape; the world is rigid in size and shape' (1963, p. 3).

Thus, Gibson distinguished between the visual field which formed the central focus for most previous nativists and which was clearly non-Euclidean, and the visual world of unitary, stable, metrical space. Further, he took the radical stance that 'perception' pertains to the visual world. There is no other way, he suggested, to account for the facts of perceptual invariance. Objects remain the same size and shape though they move relative to the observer (and the stimulation derived from them changes), while the phenomenal world retains its stability and unity throughout.

How, according to Gibson, does the observer extract a stable visual world from the unstable visual fields, or retinal images, gathered from the ambient environment? Gibson's solution focused on the transformations the retinal image undergoes from moment to moment. These transformations form continuous series* which leave certain features of the retinal image unchanged. That is, there are portions of the field which do not vary from one fixation of the eye to the next. These higher-order invariant features 'may be the mediators of a stable visual world' (1950, p. 154). On the other hand, those features which do vary would mediate motion perception. It is important to identify the features of the ambient environment which might provide the necessary invariance. Gibson based his model upon the recognition that contours and texture gradients, features of surfaces rather than objects *per se,* formed the appropriate distal sources for a continuous series of transformations. The visual world, then, was based not on a succession of discrete images of a set of objects, as in a moving-picture sequence, but rather on a 'continuous but changing image' (1950, p. 158). The contours and textures in that image, with the transformations which could hold certain features invariant, remained constant, while the overall image could incorporate change. This invariant framework then embodied the objective space to which Gibson applied the term visual world. It was stable, boundless, and rigid. But, what about the geometrical properties of this world?

The transformations worked upon the retinal image could not hold any putative Euclidean properties of the physical world invariant, for the image itself was non-Euclidean. According to Gibson, only the topological

* This series of transformations, of course has all the properties of a mathematical group. Thus, the concept so important to the empiricism of Poincaré and to the Piagetian model takes up a central role in Gibson's version of nativism.

properties of the image retain invariance, and it is this invariance which must form the basis for whatever objective world we perceive and its dimensions. Thus, while Gibson seems to have provided a workable model for the integration of a coherent space, he accomplished this at the price of starting with a non-metrical, or topological, space. His model, if it is to be complete, demands some mechanism for generating from this continuous topological world a metrically specifiable world.

Gibson rejects the traditional (empiricist) distinction between exteroceptive and proprioceptive sources of information. This distinction, as many have noted (cf. Mace and Pittenger 1975), is raised in the service of models which argue that some separate access to motor plans is needed by the organism if it is to distinguish between objective and subjective movement. How else to tell, these models imply, whether the observer or the world has moved? But Gibson argues that this is rarely required because there is an invariant framework against which motion can be assessed. If the observer moves, the entire field should move in register. The fact that, under this condition, in a motionless world the environment appears stable indicates that there must be a series of adjustments accounting for the effects of eye, head, and/or body movements. On the other hand, the objective movement of anything in the visual field would be detected by its independent change (variance) relative to the remainder of the field. It is easy to derive from all of these factors the basis for various perceptual constancies.

In two recent articles Gyr (1972, 1975) has questioned the adequacy of this formulation. His objection is that Gibson has not successfully integrated exteroceptive and proprioceptive information, which would provide a surer basis for distinguishing objective from subjective movement as well as account for the fact that organisms do use motor feedback (or reafferent) information. While Gibson agrees that there are no passive observers, in that eye, head, and body movements are essential to perception, he does not accept that proprioceptive inputs are necessary to veridical perception.*

Keeping the two sources of input separate possibly enables the Gibsons to account for a stable continuous world where the source of motion can be identified. But this world is not metricized, and no suggestions are made as to how it could be done through development, though it is clearly a requirement of the model. One way out of this dilemma is to concede that

* Among the reasons for keeping exteroception and proprioception separate might be the problem raised by the need to co-ordinate the transformation of the two types of input such that they specify the same geometrical information. This problem becomes acute when one turns to the development of metric space during the growth of an organism; proprioceptive feed-back could vary with body growth, and these variations would have to be continuously re-mapped onto the visual transformations all the while that topological space is slowly giving rise to metrical space. A daunting problem. E. Gibson (1969) has alluded to this difficulty when she raised the possibility that the dimensions of objective space might vary with age.

movement processes automatically transform and metricize the visual fields, yielding the stable visual world. As this would be tantamount to accepting Kant's *a priori* intuition Gibson cannot make this step.

Little formalization of the mathematics involved in the transformations required by the model has been provided. In particular, one would like to see a formal treatment of the transition from topological to metrical space, as this would bear on Piaget's model as well. While this particular aspect of the model has been largely ignored, several investigators have explored Gibson's claim that visual input alone can specify the visual world.

In one of the first of these investigations Johansson (1964) attempted to resolve the problem of size-distance invariance. It is clear that, taken in isolation, the retinal image is ambiguous with regard to size and distance: two objects at different distances could produce the same retinal image. Yet our perceptions somehow are veridical with respect to these features, as they must be if motion is to be perceived. Johansson showed that

> 'Perception of motion in depth from a proximal pattern changing in two dimensions has ... proved to be rather inevitable, and thus a spontaneous consequence of stimulation in most cases' (p. 202).

He concluded that a change in two dimensions of the proximal (retinal) image automatically specifies three-dimensionality, and that this is basic to the accurate perception of size and distance. The model he proposed for this, involving vector subtraction, has been superseded by later work showing it to be insufficient. Eriksson (1973) pointed out that, while certain features of three-dimensionality might be obtained from changes in the optic array, these are not sufficient to disentangle the size-distance problem. His analysis applied both to the case of the stationary observer and the moving observer, and took into account changes in the texture gradients emphasized by Gibson.

In a subsequent paper Eriksson (1974) attempted to disentangle the contributions to perception provided by optical and movement information. He suggested that

> 'the visual system is able to provide the organism with distance information which is relative, and slant information which is absolute' (p. 233). *

However, information about absolute distances cannot be obtained solely from the visual input. Here, some contribution concerning the movements of the body, in terms of amplitude, direction, and acceleration, is required. Such information would allow the organism to calculate absolute distances; only then could the size-distance problems be resolved. Eriksson concluded that

> 'a living organism in a normal, redundant environment obtains veridical space information from the interaction of two systems: (a) the optical system generating object constancy and relative distance information, (b) the body-state system generating veridical distance and size information on the basis of movement parallax' (pp. 234-5).

* Eriksson points out that this means that visual input alone can account for shape constancy.

While Eriksson seems to imply that these mechanisms are innate, he allows that experience might generate other means of accomplishing the same function as movement parallax. However, he rightly points out that experience could not lead the organism to these alternative sources of information without the prior action of a system capable of performing the necessary processes. Thus, he denies that veridical perception can be acquired entirely through experience, even with innately meaningful sensations. That would be putting the chicken before the egg.

From the point of view of Gibson's model, these considerations suggest that Gyr's criticisms are well founded. Without some necessary contribution from both visual and motor processes veridical perception would seem to be impossible. Such a fixed linkage between the two would take one a long way down the path to a pre-existent framework, and it remains only to determine the exact nature and metrical properties of this framework. Eriksson implies that it must be Euclidean, but offers no proof for this. We shall not comment on this problem here, but shall formulate some reasons for postulating a Euclidean framework later. Thus, at the very least, Gibson's model must be modified to account for a necessary interaction between optical and motor information. This does not, of course, invalidate many of the important points Gibson has made; his recognition of the role of texture gradients is particularly important. It enables one to separate out those features of the environment specifying objects from those specifying the ground. From what we know of the processes involved in figure-ground separation this must surely be innate and amongst the first of the transformations worked on the optical data. In conjunction with recent speculation about 'two visual systems' (cf. Trevarthen 1968, E. Gibson 1970) it offers a possible explanation for shape constancy that is separate from that accounting for the veridicality of unitary space. Thus, the specification of the form and features of objects might take place independently of, and parallel to, the specification of that object's movements and location in absolute space. Of course, though shape might be treated in this way, size constancy would require the latter information. Only after data concerned with textures and contours had been integrated with information about movements could the veridical perception of absolute space, and its contents, be achieved.

1.4.3(c). Space perception in animals. Before turning to a brief discussion of the development of spatial concepts we should examine the ways in which the problem has been treated in the animal literature. To some extent this will involve a return to models we have already discarded, but it is a necessary one; much of the evidence pertinent to our theory comes from work with rats and we need to demonstrate that the principles deduced from work with humans apply to this species as well.

Hull (1943) utilized the empirical model established by Poincaré in his attempts to provide an explanation for spatial behaviour in rats. The need to say something about such behaviour arose out of the study of maze learning. Early investigations into the nature of maze learning were motivated primarily by an interest in the way in which such habits were acquired and maintained: which sensory inputs were essential, which not.* Notwithstanding this emphasis, these studies provided important insights into the basis of the rat's spatial abilities. The initial experiments (e.g. Small 1901, Watson 1907) were misinterpreted to suggest that maze habits were learned as a chain of proprioceptively guided responses; that is, as a stimulus-response (S-R) routine leading automatically to the goalbox. However, subsequent research demonstrated that complex mazes could not be learned on the basis of proprioception alone (e.g. Dashiell and Helms 1925, Dennis 1931, Honzik 1936), though simple repetitive sequences such as LRLRLR might be (Hunter 1940). Most workers rapidly agreed that vision was particularly important, expecially in those mazes which were open to a heterogeneous environment (Honzik 1936). Extra-maze cues were shown to be important by rotating the maze relative to the environment; such rotation invariably disrupted the maze habit (e.g. Watson 1907). However, there was no specification of how these extramaze cues exerted their powerful influence.

All this work was done on *spatial* mazes, that is, mazes in which different responses were required in different parts of space, as well as in different segments of time. One of the attempts to test the ability of rats to learn mazes proprioceptively involved the use of the *temporal* maze; here, the rat runs around the same parts of space and must distribute his differential responses solely in the temporal domain. Thus, after turning left on the first circuit through the maze the rat must turn right at the same point on a subsequent circuit. Hunter (1920) found that rats were incapable of learning a RRLLRRLL sequence in the temporal maze and concluded that:

'Work on the temporal maze indicates that it is all but impossible to set up a mere temporal sequence of kinesthetic processes with the rat. Running the spatial maze therefore must require cues which have space location as well as temporal position. In other words, the rat must recognize in terms of space where he is in the maze' (p. 16).

Results such as these suggested to most investigators that the rat had some sort of place orientation or directional set. Thus, Dashiell (1930), on the basis of work done in a maze containing many paths to the same goal, suggested that:

* Munn (1950) reviews these studies in detail. Here, we concentrate on the contribution this work has made to an understanding of space perception (see also pp. 286-90).

'learning consists in the establishing not of a definite *pattern of specific* turns, but of some more *general orientation* function. This general function enables it to pursue new pathways from time to time, the while remaining successfully oriented in the direction of the objective' (p. 19).

The notion that rats develop a direction orientation referring to the location of the goal is central to any analysis of maze learning; different psychologists approached this phenomenon in vastly different ways, adding to a fundamental split in psychological theory which remains today. Tolman (1932, 1948) proposed that rats form *cognitive maps* of environments:

'we believe that in the course of learning something like a field map of the environment gets established in the rat's brain ... and it is this tentative map, indicating routes and paths and environmental relationships, which finally determines what responses, if any, the animal will finally release' (1948, p. 192).

These cognitive maps were essential to the ability to respond flexibly in the maze situation, the animal emitting whatever responses were necessary to get to the goal. Implicit in Tolman's model is the assumption that the animal does not learn about space through the association of movements, but rather that the animal's spatial abilities rest on the construction of maps which represent the spatial relationships between the various things experienced in the environment.*

Faced with the same evidence, and well on the way to developing his general theory, Hull (1934a,b) proposed the concept of the *habit-family hierarchy.* He stated that:

'a family of habits may be defined in general as a group of two or more habit sequences, all of which may be initiated by a particular stimulus and terminated by a particular reaction' (1934a p. 39).

Thus, alternative solutions to the same maze problem, accounted for in terms of cognitive maps by Tolman, were dealt with in a strict S-R fashion by Hull. The rat learns not only about those routes which he actually traversed, but also those which, though different, start from the same point and end up at the same goal. According to Hull, this is accomplished because:

'hierarchies based primarily on locomotion are set up early in life, presumably as the result of locomotion in free space, with the result that the animal at the beginning of a maze experiment is already in possession of a vast repertoire of equivalent but fairly distinct locomotor habits, any one of which, in free space, would mediate a transition of his body from the starting point to the goal' (1934a, p. 41).

* It is unlikely that Tolman ever felt that such maps might be more than good metaphors, able to account for certain interesting forms of behaviour, but surely not existing within the brain, as we propose here.

The similarity of this explanation to that proposed by Poincaré is clear; organisms learn about space through the association of movements which, though different, all take the animal from one place to another. Hull's habit-family hierarchy is yet another application of the idea of mathematical groups and carries with it the same problems associated with Poincaré's model.

The weight of evidence concerning maze learning favoured Tolman's view that animals learn something about places in the environment. Woodworth (1938), writing during this period, summarized the situation as follows:

'Since neither chain reflex nor motor pattern accounts for the rat's behaviour in the maze, we ask once more what it is that the animal learns. The most obvious answer, which has been given repeatedly by investigators in describing the rat's concrete behavior, though avoided in their theories, is simply that the rat learns the place' (p. 135).

Thus, the investigation of maze behaviour in rats suggested that spatial behaviour could not be explained through the invocation of simple S-R habits. Something like a cognitive map, providing an overall framework and specifying places in the environment, is needed. However, Tolman said very little about the properties of such maps, or about the way in which they might have developed. Do rats learn to build maps? Or, is this ability given prior to experience?

1.4.4. THE ONTOGENY OF NOTIONS CONCERNING SPACE

We have seen, in work with both humans and rats, a clear need to discuss space perception in terms of a unitary framework stabilizing a three-dimensional world. We have argued that this framework is part of the innate machinery of the organism, and that it could not be developed entirely through experience, nor from experience with inputs specifying only relative spaces. This implies that the framework must be present at birth, or as soon as the necessary neural structures achieve mature function. While there has been considerable work on the ontogeny of space perception, virtually all of it has proceeded within the context of relative theories of space perception. Consequently, there is little evidence which speaks directly to the question of the ontogeny of the notion of absolute space. The nature-nurture issue, as applied to this field, has been concerned with the role of experience in the development of capacities such as localization which are functions of egocentric, rather than non-egocentric, space. Similarly, most of the work with children has concentrated upon such things as the development of left-right or up-down concepts, the use of arbitrary reference systems (e.g. the North-South axis), and the coordination of perspectives. None of this work can provide a clear answer to the question of whether or not an innate spatial framework specifying

metric three-dimensional space exists. While it has traditionally been assumed that this latter capacity only arises after the acquisition of a variety of relative spatial notions, there is, in fact, no evidence to compel this view.

Work with infra-humans (cf. Zuckerman and Rock 1957, Pastore 1960, Epstein 1964, Fantz 1965, for reviews) has generally confirmed that localization and depth perception are innately determined, though learning can provide alternative means for achieving these functions. Thus, Fantz concluded that 'perception is innate in the neonate but largely learned in the adult' (p. 400). He assumed that such learning involves finding out which dimensions of the environment to attend to, and that this principle holds for all species. Such learning of selective attention processes can only occur, as Eriksson (1974, see pp. 48-9) pointed out, if there is an innate mechanism specifying the appropriate information base in the first instance. Unfortunately, there is no body of evidence directed at the problem of 'place-orientation' abilities or other capacities dependent upon cognitive maps.

Curiously enough, though the methodological problems of working with humans are usually greater than those encountered with infra-humans, more progress has been made in determining the complex spatial abilities of children. Whereas James (1890) assumed that the infant confronted a world of 'buzzing confusion', work within the past decade has demonstrated that there is considerable structure to the infant's world.

The prime proponent of the view that unitary space only develops after long experience is, as we have seen, Piaget. He assumes that notions of space are dependent upon those of the object, and that something like a unitary space develops only after a series of acquisitions concerning heterogeneous relative spaces. Further, metric space is assumed to develop only after the mastery of topological space, perhaps as late as 11 years after birth in humans. It is important to stress Piaget's distinction between perception and representation; the former refers to practical knowledge, demonstrable only in actions; the latter refers to cognitive structures. Piaget is interested primarily in the latter, and thus concentrates upon the verbalizations of his (necessarily) older subjects. From our point of view it is unnecessary to insist upon innate representations in the sense defined by Piaget. It matters not whether the infant is aware of its capacities; their presence will organize its behaviour and, more important, its potential for representations. It is clear that there is no particular correlation between the ability to talk about space and the capacity to behave appropriately in it (e.g. Asso and Wyke 1970); thus any approach which relies upon verbalizations is bound to be seriously misleading.

In contrast to Piaget's views, most other contemporary workers have concluded that infants rapidly come to perceive a world of permanent objects embedded in three-dimensional continuous space (cf. Bower 1971, 1975, Hershenson 1967, Bond 1972, Harris, Cassel, and Bamborough 1974, Yonas and Pick 1975). Bower, for instance, suggests that young infants (up to 16 weeks)

> 'ignore features to such an extent that I would suggest they respond not to objects but to movements. Similarly, I would suggest that they respond not to stationary objects but to places' (1971, p. 37).

Thus, Bower is asserting that places precede objects, in direct opposition to Piaget's view.

In what is primarily a theoretical and methodological review, Yonas and Pick (1975) come to the conclusion that infants possess something like a three-dimensional mapping system providing them with

> 'a knowledge of spatial layout in three dimensions which is something like an adult's knowledge of spatial layout of his nearby environment' (p. 24).

Their review of the available data from studies of space perception in infants supports this conclusion. However, as they point out, the crucial experiments, involving such things as detour behaviour, have not yet been done. We agree with their suggestion that experiments designed to distinguish between 'place' and 'response' learning, similar to those done in rats (see pp. 71-4), should provide conclusive evidence on this question.*

While permitting the conclusion that an innate framework exists, most investigators do not take the additional step of ascribing to this framework any particular metric. It will be recalled that both Piaget and Gibson hold that spatial knowedge advances from topological (non-metrical) to Euclidean notions.

Piaget's strongest evidence consists of those studies showing that the topological features of objects are responded to before metrical ones (cf. Piaget and Inhelder 1956). However, most attempts at systematic confirmation of this sequence have failed (e.g. Laurendeau and Pinard 1970, Lovell 1959, Fisher 1965, Cousins and Abravanel 1971, Dodwell 1963). Reviewing these data, Dodwell concluded that there is 'no clear-cut progression from one type of thinking about space to another' (p.161). Thus, the topology-to-Euclidean development demanded by Piaget's theory seems not to occur, at least as far as the perception of the spatial properties

* Three recent studies provide some data on this question. Bremner and Bryant (1976) tested infants on place v. response performance and found that behaviour in 9-month-olds was primarily based on responses. Acredolo (1977), on the other hand, demonstrated that place behaviour was as frequent as response behaviour in 3-year-olds, and dominated in the 4- and 5-year-olds, becoming progressively more independent of particular landmarks. Finally, Fishbein (1976) has placed into opposition the possibilities that children use a spatial framework emphasizing the relations between objects or one which emphasizes the potential locations which objects might occupy. This study provides a direct assessment of the use of 'relative' or 'absolute' frameworks. Fishbein found that all of his children, aged between 6 and 11, were using an absolute framework, and that there was no change in this ability over the time period studied. These data contradict Piaget's assumption that the absolute framework cannot develop until about 10 years of age. See pp. 9l-2 for some further discussion of this problem.

of objects is concerned. When we move to space, as distinct from objects, we run out of data. Aside from evidence concerning depth perception and localization, little information is available. Several recent studies have shown that quite young children (4 years old) can read and interpret maps accurately without prior exposure or training (Muir and Blaut 1969-70, Blaut, McCleary, and Blaut 1970, see p. 79). These data are inexplicable within Piaget's scheme, but they do not prove the innateness of a Euclidean metric.

Our brief examination of the developmental literature is consistent with the conclusion that the ability to organize perceptions in a rigid, three dimensional space is available quite early, probably prior to any specific learning experiences. This is not to say that infants are 'aware' of it, as we have pointed out above. The representation in conscious thought of such notions of space might well follow the time course suggested by Piaget, or other similar models. In that case, the observed sequence of acquisitions would reflect the ease with which the child can symbolize its own perceptions and behaviour, not the order in which these become available as organizing frameworks for experience.

1.4.5. CONCLUSIONS

A unitary spatial framework, considered essential to the interpretation of a wide variety of abilities, seems to be present innately and available to organisms of numerous species as soon as they can move. Neither a strictly empiricist approach, nor a nativist one denying the *a priority* of such a unitary space, is consistent with both data and logic. This conclusion has several implications: (1) it ought to be possible to discover the neural correlates of unitary space perception, in as much as this 'concept' is not built up from others but rather is built into the brain; (2) the philosophical position suggesting that the psychological notion of absolute space must be derived from notions of relative space, or from experience with a world of relative space, is wrong. The adoption of this position within mainstream psychology seriously hindered the advance of understanding concerning space perception. It focused the attention of most investigators upon objects and subject-object relations (cf. Ittelson 1973). This, in turn, totally emphasized egocentric space at the expense of objective, non-egocentric space, a position which is only recently being reversed in the surge of interest in environmental perception. It is clear that whatever the status of relative space in physics and mathematics, it cannot be given ontological priority within psychology.

We shall conclude this chapter with a return to the epistemological issues with which we began. We ask the reader's forbearance in this, but we simply cannot leave the questions raised earlier unanswered. There are two related issues worth discussing here: the status of extension, and the means by which things are identified and re-identified. In the course of this discussion we think that the inevitable failure of relative theories in psychology will be understood not as a function of any lack of ingenuity on the part of their adherents, but more as a function of the basic flaws in the notion of relative space.

1.4.5(a) The concept of extension. One of the implications of any model denying an *a priori* concept of unitary space is that the notion of extension must precede that of space, which can only be constructed out of the relations between extended objects. For nativists extension derived inherently from sensations, and it was assumed that the extended fields so perceived could be integrated into a three-dimensional world. For empiricists the concept of extension itself had to be constructed from experience, to be followed by that of space.

The assumption that extension precedes space raises several serious problems. Russell (1901) noted that the relativist falls into a vicious circle because he can define space only in terms of objects assumed to exist in space. In a related manner, Hooker (1971) points out that, according to the relative theory,

> 'Material objects are spatially extended. Space cannot therefore consist solely in external spatial relations among material objects, for then material objects could not be regarded as spatially extended-their spatial exteriors could not be constructed' (p. 99).

Hooker concludes that this problem can be circumvented only by positing the existence of basic material objects which have no parts, that is, things which are not extended. Leibniz clearly foresaw this problem when he postulated the existence of monads.

In order to construct a space from a plenitude of partless 'things' it is essential that each of these 'things' be qualitatively unique. Identical objects can only be distinguished by their spatio-temporal position; it is not possible to construct space from them. Thus, one is caught in the dilemma of requiring certain relata to constitute space, but then finding that these relata can only be distinguished in certain cases if space already exists. Leibniz tried to avoid this trap by specifying that every monad was qualitatively unique; thus, space in the monadic realm could be easily constructed. This uniqueness required the assumption that intermonadic 'perceptions' be asymmetrical; the distance between two monads, or points, differed depending on where one stood. This non-commutativity of distance means that the space of one monad could not be transposed onto the space of another.*

This curious notion of asymmetrical space was essential to Leibniz's

* This model serves as a useful approach to the personal spaces described by Lewin and others, where distances are often non-commutative, as we shall see. However, this property appears to be a function of experience and the learned meanings of places, rather than of the organising system itself (see pp. 37-40).

theory, for without it certain identification of monads would be impossible, an issue discussed at some length by Strawson (1959). The extent to which Leibniz went to solve the problem of identification attests to the fundamental nature of the issue. We have seen, for instance, that the ability to identify objects was taken as an *a priori* by Poincaré, in one of the major failings of his model.* This failure, we would submit, is not accidental, for the issue of identification lies at the root of all theories working with relative space.

1.4.5(b). The problem of identification. The theory proposed by Poincaré attempted to specify the means by which localization and a reference framework can be established solely through experience, and can be used as a starting point in our discussion. Poincaré provides some details of the required mechanisms when he discusses the way in which an organism localizes an object in space. Let us follow the gist of his argument.

The problem is simply stated: one is at A and the object to be localized is at B. According to Poincaré, one localizes the object by representing to oneself the movements required to reach it. It is clear, as Poincaré recognized, that a variety of movements will take one from A to B and, conversely, that the same set of movements, under different environmental conditions, might lead to different places. It is thus necessary to build up, by successive sets of movements, an 'association of ideas'. This was the basis for the group of displacements. However, one should only associate those movements which one took from A to B; it is crucial to start each set of movements from exactly the same place. But, how is this place to be identified? This difficulty can be overcome by postulating two objects, one at A and the other at B, and allowing the organism to shuttle back and forth between the two. However, this only works when one is certain that neither object has moved in the interim. Poincaré's solution to the problem of determining the immobility of the reference objects has been noted already; it involves identifying objects. But, what if there are identical objects in the world, differing only in terms of spatial location? This brings us right back to the necessity for a world of qualitatively distinguishable objects, so we can return to Leibniz for a further look at how his model fares.

Leibniz specified that his monads were unique, and within this notion it would seem as though space could be articulated. However, the spaces of

* The reader should not assume that the problem of identification is limited solely to those versions of relative theory we have chosen to discuss. On the contrary, it is central to any relative theory. For example, Bohm (1965), in a book on relativity theory, falls into the same dilemma when he attempts to show how organisms can learn about relative space. Even before the young child has secure concepts of space Bohm assures us that it 'can go from one place A to another B by many different paths, and that all these paths lead him to the same place (or alternatively that if he goes from A to B by any one path, he can "undo" this and return to A by a large number of alternative paths)'. Thus, the child can apparently re-identify places before it has a fixed notion of space. Bohm does not specify how this is managed.

each monad could not be superimposed. Without the panoramic 'vision' of the monad how could a continuous stable world be articulated? The asymmetry built into the monadic realm means that distance relations cannot be constructed. Cox (1975) has suggested that an ordered space within the monadic realm could be achieved if one drops asymmetric perceptions, but here she falls prey to Strawson's argument that this would make re-identification theoretically impossible. Her added assumption that two monads with the same set of perceptions could never exist co-temporally in the infinite complexity of our universe is special pleading.

Leibniz's difficulties increase when he moves to the phenomenal world of objects and extension. In order to construct objects Leibniz clumps similar monads together as aggregates on the assumption they can be viewed as identical by distant observers. These objects in turn form the relata for psychological space. But, the monads forming them no longer incorporate the essential property of uniqueness. In negotiating the gap between monad and object Leibniz has been forced to abandon the very feature of monads which enabled them to be perceived as occupying different parts of space. *Leibniz' objects can not be extended in space,* and therefore at the phenomenal level his system falls victim to the Russell-Hooker criticisms set out above.

We must return from Leibniz to the problem of identifying objects, then, without a solution. There would seem to be a limited number of alternatives available. One might suggest that it is not necessary that all objects be distinguishable, merely that there be some set of objects which contains only unique members, assumed not to move relative to one another. This 'reference set' could be specified by innately available information or it could be learned through experience. The former possibility leads ultimately to the doctrine of innate ideas. The latter demands some mechanism for determining when objects move. But here the argument doubles back on itself, for only by identifying objects in the first place can one distinguish between objective and subjective movements. It is hard to avoid the conclusion that experience alone cannot specify the objects to be chosen as a reference framework. Either one accepts the notion that there are innate ideas, or innate dispositions to choose certain objects, or one is left without a means of object identification.

Gibson's model comes closest to satisfying the second of these procedures. The invariance inherent in textures during movements could, as he suggests, form the basis for the disambiguation of objective and subjective movement. As we have argued, additional information about the organism's movement seems crucial to the objectification of perception; absolute distances cannot be obtained without it. Once we accept the idea that there is a fixed input from movement processes which objectifies the three-dimensional space articulated by sense data, we have adopted Kant's solution. Strawson (1959), in his discussion of the problem of identification,

concludes that it rests 'ultimately on location in a unitary spatio-temporal framework' (p. 39). We agree with his conclusion: there must be a pre-existent spatial framework in order for organisms to experience the world coherently. Objects could not be identified, nor localized, nor even seen as extended in the absence of this framework.

1.4.5(c). Final Views. We have organized this chapter around the dichotomy between absolute and relative space in the hope of showing how the choice of either of these as prior crucially influences the ability of any theory to cope with space perception. Most contemporary models start with relative space and attempt to build first a framework and then metrical space. These models rarely get off the ground, stumbling over the problems of re-identification and movement.

It seems reasonable to conclude, first, that there is a clear need for the concept of unitary space. Further, it appears that this framework cannot be acquired through experience; it must be available soon after birth, for the processes of localization, identification and the coherent organization of experience depend on it. Finally, the weakness of Gibson's model indicates that not only must the framework be built in, but that its metric must be specified as well. To reinforce this conclusion we can consider briefly the implications of assuming that the metric of objective space is acquired through experience, a position adopted even by those who would accept the idea that the framework is itself innate (e.g. Haber and Hershenson 1973). This particular argument has been voiced most emphatically in the course of cross-cultural investigations concerned with the theory of cultural relativity. Whorf (1956) stated this position clearly:

'Newtonian space, time and matter are no intuitions. They are recepts from culture and language' (p. 153).

More recently, Bertalanffy (1971) has expanded upon this position. Briefly, he argues as follows: (1) because of the existence of non-Euclidean geometries and relativity physics it is impossible to accept Kant's *a priori* intuitions; (2) the space of our perceptions, particularly visual space, is also non-Euclidean (see, for instance, Blank 1959); (3) different cultures have different basic ideas about space; thus (4) culture must be responsible for the fact that we use Euclidean and Newtonian concepts.

Bertalanffy also discusses the concept of the *ambient,* that slice of reality to which each species is attuned by virtue of its sensory apparatus. He admits that primates live in an ambient which is accurately mapped by Euclidean and Newtonian concepts. That is, we neither perceive, nor act relative to, the spaces of astrophysics or quantum mechanics. But, Bertalanffy does not concede that, if our concepts are to be Euclidean and Newtonian, a problem arises in acquiring them from experience with non-Euclidean visual space. If we dismiss the notion that different cultures conceptualize space in different ways,* we are left with explaining how Euclidean space is abstracted from a non-Euclidean world in a uniform fashion by all members of the species, and we have already seen the difficulties inherent in this.

The ubiquity and adaptiveness of Euclidean and Newtonian concepts in the ambient in which we live indicates that there must be mechanisms guaranteeing that these concepts are used by everyone, even without their being aware of it. Given that practical experience might not, by itself, lead us to them, we must assume that they are inherent in our structure. We *must* perceive the world in these terms, though we *can* conceptualize it in others. Paradoxically, the demonstration that physical space is non-Euclidean, rather than invalidating Kant's theory, seems to necessitate it. Grunbaum (1964), approaching this problem from a rather different angle, arrives at the same conclusion, stated in the form of a series of questions, worth paraphrasing here:

(1) How do we arrive at an appropriate Euclidean metric through the use of a visual system working with non-Euclidean data?
(2) If we have been seeing non-Euclidean space all along, why has it taken 2000 years to conceive of these geometries?
(3) Why was it necessary for Helmholtz and Poincaré totally to retrain their intuition in order to pictorialize non-Euclidean space? **
(4) Why is Euclidean geometry easier to learn than non-Euclidean geometry (if it is)?

Our attempt to answer the problems posed by Grunbaum's questions provides the basis for this book. While we readily accept the existence of the types of relative space described by Poincaré and others, we think there is substantial evidence for the independent existence of another spatial system, one which generates a Kantian unitary space.

We shall postulate that, in most of the brain, space is represented in the relative manner; that is, referenced to the organism and built up through experience. We shall refer to these egocentric spatial systems as *taxon* systems, and this type of space will be called *taxon space.* Included within this category are all the sensory and motor systems. In Kantian, or *locale,* space, representations are located within a Euclidean system, yielding a space which does not depend for its existence on particular objects but which serves as a framework for relating these objects to each other independent of the observer. The location of an object in this space is, as Poincaré suggested, a function (although only indirectly) of the organism's

* The evidence is very spotty on this question, and is completely confounded with language usage. There are differences in certain perceptual functions across cultures, but no good evidence that the basic intuitions of space differ. As we shall see, there is strong evidence that members of so-called primitive cultures are particularly good at mapping and navigational abilities, both of which would seem to presuppose a Euclidean framework. Again, the difference between perception and (linguistic) representation must be stressed.

** If in fact they actually did so, which we doubt.

movements in space relative to that object. The details of the mechanism accomplishing this will be discussed later (see Chapter 4). Locale space is non-egocentric. We agree with Kant that the relations embodied in this space are the content of what is usually called knowledge, the knowing *that* as opposed to the knowing *how*, to use Ryle's (1949) terms.