E. H. Gombrich, Western Art and the Perception of Space, Space in European Art, Council of Europe Exhibition, Japan, 1987, pp.5-12 [Trapp no.1987G(ENG).1]

Few terms occur more frequently in the discussions by art historians of Western painting than the term "space ". It needs an effort, therefore, to realize that space as such cannot be represented in painting (1). Just as an English proverb says that " beauty rests in the eye of the beholder ", so space in painting is a matter of the individual imagination. It is easy to demonstrate this simple fact in a number of schematic drawings [1a-c]. Take an ordinary oval and it will be clear that it will depend entirely on the context whether or not you will " see " it as surrounded by space or not. The letter 0 which occurs in this text is experienced as a sign which is associated with a sound but not with space [la]. It sits comfortably on the flat surface of the page and is seen against a neutral background. Imagine a string of such ovals; it might well be part of a decoration, in which case again it will lack all spatial implications [1b]. But as soon as the oval is identified by the mind as an object, such as a plum, we cannot but imagine it as occupying a space like any other solid object [1c]. We also feel that it could be moved in space and that its background therefore must be seen as a three-dimensional void. From this point of view it may safely be said that there can be no artistic style of representation which does not imply the rendering of objects in space. This is as true of the earliest renderings of animals in prehistoric caves as it is true of the ancient Egyptian style of painting, however flat its figures may appear to the eye used to other conventions. How wonderfully the varying styles of Far Eastern art have succeeded in suggesting the space surrounding its images of nature need hardly be stressed. Even so it remains a fact that the rendering of space in Western art was seen as a special problem, a problem which was to be linked with the science of optics and the study of perception. In approaching the rendering of space from this theoretical angle Western artists have posed a number of complex questions which are still being hotly debated. In fact it may be said that certain assumptions which had been taken for granted for centuries have recently been challenged and that the whole subject is now in the melting-pot.

The causes of this crisis can perhaps be best understood if we insist on the clear distinction between the two areas mentioned before, that of the science of *optics* and that of the study of *perception*. Not that the two areas can ever be regarded as wholly independent. The science of optics, after all, is concerned with the behaviour of light, without which there would be no visual perception. On the other hand there are aspects of visual perception which are relatively independent of the behaviour of light (though not of course of the existence of light). I am referring to the many phenomena known as visual illusions (2). Generally speaking, we mean by this term that the impression or effect made by certain configurations of lines or shapes in two or three dimensions will surprise us when we resort to measurement. Certain lines will notoriously look longer or shorter according to the context in which they are placed, they will look more or less sloping or bent than they really are. Among these visual or pictorial effects we may also count the impression of space or solidity made by certain forms or lines on a flat surface.

It is interesting to learn that it is these pictorial effects which were first discussed in Classical antiquity as part of the theory of art. Plato in his *Republic* shows himself fully aware of these so-called illusionistic effects, even though he deplores this possibility because it leads away from truth (3). One of his examples is scene-painting, which, he says, is an exploitation of the weakness of our nature, because — we may supplement his argument — it is capable of conjuring up a three-dimensional building on a flat plane. We know from the Roman author Vitruvius that Democritus and Anaxagoras wrote about the theory of these effects which resulted in scene-painting achieving the illusion of reality (4). There are a number of passages in ancient authors which testify to the surprise and delight

created by these effects, not only on the stage but also in easel paintings. Thus Pliny singles out for special mention a painting by the famous Apelles representing Alexander the Great wielding a thunderbolt, in which — as he says — the fingers appear to protrude out of the picture and the thunderbolt to hover in the air in front of the painting (5).

More generally Quintilian, the Roman teacher of oratory, discusses the creation of such illusions as a deliberate act: " When a painter, by his artistic skill, makes us believe that certain objects project from the picture, white others are withdrawn into the background, he knows perfectly well that they are all in the same plane " (6).

It is not too difficult to imagine the kind of *trompe-l'oeil* the Roman writer had in mind: there are many decorative wall paintings in Pompeii and elsewhere which simulate an architectural articulation, showing columns, pilasters and set-in panels. The three-dimensional effect tends to be entirely achieved by the clever manipulation of light and shade, that is to say of brighter and darker tones. The effect of a protruding rectangular panel will be achieved by framing the area on top and the left-hand side with a white streak and the opposite two sides with a dark pigment [2]. Since, in our world, light generally comes from above, this will produce the appearance of relief. Turn the arrangement round so that the shaded part is on top and on one side and then the panel will appear to be in a recess. It is difficult to tell how much this effect is due to habituation (particularly the expectation of light falling from the left) and how much of it may be due to an inborn disposition. In any case we here encounter the mutual share of the science of optics and of the psychology of perception which must be the theme of this chapter.

Another trick frequently employed by painters and decorators avoids this psychological ambiguity of convexity and concavity by adding the effects not only of light and shade but also of the reflection of light on a shiny surface . Any convex surface of this kind will show such a reflection of the light source which painters call the highlight; the steeper the curvature, the more will the reflection intensify as it marks the highest ridge [3]. This is the explanation, in terms of the science of optics, of a pictorial effect which was singled out for discussion by the Greek philosopher Philoponos of the fifth century AD in his commentary on Aristotle's *Meteorologica*.

"If you put white and black upon the same surface and then look at it from a distance, the white will always seem much nearer and the black further off. Hence when painters want something to look hollow, such as a well, a cistern, a ditch or a cave, they colour it black or brown. But when they want something to look prominent, such as the breasts of a girl, an outstretched hand, or the legs of a horse, they lay black on the adjoining areas in order that these will seem to recede and the parts between them will seem to come forward "(8).

Whether or not the explanation was known to the craftsmen who practised these visual effects it is hard to tell, but as I have shown, the effects themselves form part of a repertory of decorative painting in antiquity and were obviously carried by wandering painters as far as India and beyond; they also appealed to the artists of the Middle Ages who conjured up sophisticated spatial effects of this kind in decorative borders of paintings [4].

I have here concentrated first on these pictorial effects in order to make it clear that they were not necessarily connected with the portrayal of individual motifs in painting. The creation of illusion and the skill of mimesis, the imitation of reality, went to some extent their own separate ways.

It was a momentous event in the history of art when the two came together in the early 15th century in the City of Florence. I am alluding to the famous experiment made by the great architect Filippo Brunellesco (9). Brunellesco put the methods of Italian painters in rendering objects in space to the test by creating a device that permitted the comparison between the appearance of a building — the Florentine Baptistery — from a given viewpoint and its depiction on a flat panel. Since the device is lost and we only have a description in the earliest biography of the architect, there are almost as many interpretations of what Brunellesco did as there are modern writers on the subject. What matters in the present context, however, is only that the device must have been constructed on the basis of geometrical optics. It has never seemed surprising to me that a great architect such as Brunellesco should have been familiar with these elementary theoretical facts. We need only imagine him being asked during the erection of the famous cupola of the Florentine cathedral whether the lantern of the cupola would be visible from the piazza below. It would have been clear to him that all that was needed to answer this question was to draw an imaginary line from the lantern to the point in question. If it was blocked by a building the lantern would be occluded, if the path was free it would be visible [5]. Something very much like this reasoning may have prompted the architect to take up his Position a few steps inside the cathedral to look out at the Baptistery which lies opposite. He could then plot the Position of the imaginary line against the door-frame, or conceivably against a net or veil hung across the opening, and this would give him the reference points for his panel [6]. The comparison between the panel and the real building would also have convinced painters how far their traditional methods of representing architectural features needed adjustment to conform with the facts of vision.

These facts of vision are usually treated under the heading of perspective, the pictorial method which has come to play such a crucial part in the rendering of space in art ". Whether or not this method was wholly known to the ancient world is still a matter of some controversy ". What is certain is only that the first text we have in which the procedure is expounded dates from the early Renaissance. It is Leon Battista Alberti's *De Pictura*, which was written in 1435, the Italian translation being dedicated to Brunellesco (13). Alberti takes his starting point from a discussion of the visual rays which enter the eye from the outside world. Since these rays come from various sides and meet in the eye, he speaks of a "visual pyramid ", which we can imagine composed of fine threads gathered in a bunch at one end which is located in the interior of the eye [7]. Geometry tells us that any parallel transversal section through this pyramid will be proportional to any other, and it is on this basic geometrical fact that Alberti grounds his theory of perspective: " A painting will be the intersection of a visual pyramid at a given distance, with a fixed centre and certain position of lights, represented artistically with lines and colours on a given surface " (op. cit., p. 49). "Let me tell you what I do when I am painting. First of all, on the surface on which I am going to paint, I draw a rectangle of whatever size I want, which I regard as an open window through which the subject to be painted is seen" (op. cit., p. 55).

Given this basic assumption, Alberti proceeds to explain how to represent the gradual diminution of objects as they recede from the window, by explaining the accurate construction of the appearance of a floor consisting of square tiles. The prolongations of the sides of the square will naturally meet at one point on the horizon, each one appearing as a trapezoid. The rule for finding the diminution of the transversals is less easily explained, but Alberti shows that it will depend on the distance of the eye from the plane. The resulting geometrical scaffolding for representing that level ground on which the scene to be viewed through the window can be enacted is known as the *costruzione legittima* [8].

This conception of the picture as a window within which at least some of the distances can be measured or calculated has proved so powerful an intellectual tool that it was destined to conquer the

world. It spread from Florence to the other parts of Italy and was soon adopted by painters north of the Alps. In the 18th century it even reached the Far East.

Part of its strength is due to the fact that it is capable of empirical verification. We need only replace Alberti's imaginary window by a real window with a pane of glass, and we can see that the painter can trace the view through the window on the glass provided he closes one eye and keeps the other absolutely still. Leonardo, the great scientist, certainly made this experiment, and so did Albrecht Dürer, who illustrated various versions in his theoretical writings [9a and 9b]. I have always advised my students to do the same, simply tracing the view through their window on the glass with a felt pen (14).

Strangely enough, however, the very power of the method has tended to hide from its practitioners its intrinsic ambiguity. For though it is true that the level squared floor will project on the window in the way the method predicts, it is also true that the two-dimensional projection can never suffice to tell us that that floor out there was in fact level and composed of squares (15). It might have been inclined at any angle, in which case it would not have been composed of squares but of trapezoids of various shapes [10]. If this fact is initially a little hard to grasp, this is simply due to our conditioning. We expect floors to be level, and we are quite ready to enter into the compact with the painter which is needed for the procedure to work. Even so it cannot be sufficiently stressed that Alberti's procedure rests on an assumption, the assumption that we have a prior knowledge of the shapes to be represented. Brunellesco and his public, of course, had this knowledge of the Baptistery even before he painted his perspective panel, which corresponded so strikingly to what they could see themselves from a given point. But Alberti wanted the same system also to be applied to imaginary scenes, episodes from ancient history or from the Bible. As soon as this anchorage in reality is lost, the resulting painting could stand for an infinite number of arrangements out there, arrangements with sloping floors and ceilings between which dwarfs or giants rather than normal human beings are Seen moving and acting. This is a fact rarely discussed in books on perspective but brilliantly demonstrated in a number of psychological experiments, of which the most famous are those by Adelbert Ames (16). In these experiments we are asked to put our eye to a peephole through which we seem to see a chair or even a normally proportioned room. It turns out, however, that what we took to be a chair was a complex configuration and what looked like a normal room was quite askew. Once we have thus been made aware of the infinite multiplicity of interpretations which Alberti's view through the window permits, we are again confronted with a question that belongs to psychology rather than the science of optics. Why do we pick out one of these readings with such apparent assurance that we are disinclined to believe in the existence of other possibilities?

One of the reasons which hides these multiple readings from us in normal life and in our commerce with paintings is, of course, that we do not rely on outlines alone in our estimations of spatial arrangements. The psychology of perception speaks of any number of ancillary clues which we use quite unconsciously in these matters. The most important of them is, of course, overlap. We see which object in space is closer to us when it partly occludes or hides an object further off [11] (17). This clue serves us so well in life and in art because we are generally familiar with the shape of objects. We know, or we believe we know, that if we see a book lying on a table the table top will continue under or behind the book — though who knows if there is not a hole which the book covers? It is easy to show, however, that it is always our assumptions rather than our knowledge that result in the impression of space. Take the simple pattern of rectangles 112] which may be used to decorate a wall or a floor. For most of us it looks like the product of basketry or interweaving — we assume instinctively that the bands or ribbons continue behind each other and thus we perceive the whole configuration as being three-dimensional. In fact, of course, this impression is due to our assumption.

We can also see the arrangement as being composed of rectangles rather than ribbons, in which case it could be entirely flat.

We have seen that our instinctive assumptions play an equally vital part in the reading of the information we receive through the effects of light and shade, but despite this ambiguity these effects greatly restrict the number of interpretations. The bare outline of a shape drawn on a flat surface must inevitably allow of infinitely multiple readings: the ovals of fig. 1 might represent a round shape such as a loop or a hoop seen in foreshortening. But as soon as it exhibits "modelling" in light and shade these alternative readings are excluded [13].

Here another effect comes to our aid in estimating Position in space — the contrast between light and shade looks stronger in objects nearby than further off, and this diminishing contrast has frequently played a part in the history of painting in suggesting recession [14]. It was known to the ancient world no less than to the Far East. One result of this effect has become known as aerial perspective; it was particularly explored by Leonardo who also speaks in this context of the perspective of disappearance (18). He and others generally explained the effect by the density of the air, and certainly this can play a part in somewhat misty conditions. What was less considered was the limit to the powers of the eye, which was only fully known when artificial correctives like lenses, telescopes and field-glasses demonstrated the variability of appearance of distant objects.

Anybody who has ever contemplated one of the masterpieces of 17th-century landscape painting, or indeed a modern colour Photograph of scenery, will have become aware of the multiple interaction of clues which together conjure up a convincing image of the outside world in space and in light.

Even so, it can be argued and has been argued that such a landscape painting on a flat canvas cannot possibly reproduce our perceptual experience, because it is bound to represent the horizon as a straight line, while our horizon curves around us. From this point of view the panorama paintings which became popular in Europe at the end of the 18th century should reproduce our visual experience of the world much more closely than any painting within a frame (19). If that is true, Alberti's one-eyed view through a window stands condemned as an unrealistic convention, and indeed this is what has been claimed by several eminent critics, notably by Erwin Panofsky in a famous article entitled " Perspective as a Symbolic Form "(20). According to his view, the very fact that straight lines are rendered straight in the classical method condemns it as unrealistic, for he argues that we really see them as curves. His arguments, ingenious as they are, have not gained universal acceptance. Basically they ignore the simple fact of the window experiment. Even if he is right that we see the façade of the house opposite as bounded by curves, we would still have to trace it in straight lines to see these lines in turn as curved. In fact if there is one aspect of perception which is pretty well explored, it is our capacity to recognize a straight line.

But Panofsky's criticism is not the only argument that has been and can be used against the validity of the perspectival construction. Another is based on the very experiment of tracing the view through a window on the glass pane which was implied in Alberti's demonstrations. No doubt the demonstration proved, if proof were needed, that light is propagated along straight lines and that we can therefore always work out which object can be seen by a stationary eye situated at a given point. Where the rays impinge on an opaque object we cannot see beyond it, nor can we see round the corner, and these basic facts of optics suffice to explain that the view through the window is in this respect an objective fact which has nothing to do with conventions. But granted that from this point of view the tracing on the window records an objective fact, would this not also imply that the viewer of the perspectival image has to place his eye exactly at the same point for the experience to be repeated?

(21) It seems a perfectly logical conclusion, but strangely enough it is belied by experience. If the argument were correct we could not walk through a picture gallery and look at the paintings on the wall without taking the elaborate precaution of viewing each from a pre-established point. We do not have to do that; in fact, if we pay attention we shall notice that the paintings oblige, as it were, by orientating themselves in our direction so that they look right from almost any angle(22). The extreme example of this shift is the Illusion — already known to the ancient world — that a person looking out of the portrait will apparently look at us wherever we stand, just as a pointing finger will appear to point at us as we change our position. This puzzling phenomenon, to which tourist guides like to draw attention, is by no means as trivial as it may look. It clearly indicates that in looking at a perspectival picture we not only see the surface, but have the impression of looking through the projection plane into an imaginary space in which the position of objects shifts as we move.

Nor is this unexpected effect the only surprise we may experience when making the window experiment. For as we are tracing the objects seen out there on the window pane we will be likely to be puzzled by their scale or size [15]. The high tower seen from a distance will come out surprisingly small on the window pane, and so do the windows or doors of the building we look at. Does it make sense to say that from where we stand, these features " look " no larger than they appear on our tracing? After all the tower looks like a real tower and the windows like real windows, not like miniature postage stamps. The surprise we experience would appear to indicate that, while it is true to say that we can plot on the pane what we see through the window, we must be careful before we assert that it also shows us how we see the view.

Psychologists have long realized that the geometrical laws of projection on a plane are no guide to the perceptual experience. According to the geometrical law a man seen from twice the distance should only appear half the size of the man dose by. But nobody sees a friend who comes to greet him in the street as growing in stature while he approaches. He remains the same friend, and we are aware of his size from whatever place we look at him. In the psychology of perception this fact used to be described under the heading of perceptual constancies. We experience the shape and size of the objects in our environment almost independently of their distance or illumination. This fact has been traditionally explained in terms of the contrast between "knowing " and " seeing ". Our knowledge of what things are like was said to modify the way we see them. This contrast is familiar to any art teacher who wishes to train his students in recording what they really see rather than merely know. It gave rise to the Slogan of the "innocent eye" which the painter has to strive for if he wants to produce a faithful rendering of the visual experience. But does not this demand involve us in a contradiction? If we do not see distant objects as the laws of projection demand, why should we paint them according to that demand? It is at this point the debate has become dangerously confused. Briefly, we must never forget that there are two questions involved, the question of how we see the world, but also the question of how we see the painting. It was the failure to take account of the second question which led to the confusion about curvature and about the need to maintain the identical station point. It must also be considered when we speak of the apparent size of objects represented in a perspectival picture. For while the painter is compelled by his task to ignore or break down the constancies, the viewer is free to restore them again (23). Even in the photograph through the window the tower does not look as small as measurements would suggest. We need only cut out the silhouette and move it within the frame to demonstrate that its appearance changes according to context [16]. Anybody who is interested in these matters is advised simply to take a pair of dividers and measure the objective size of features represented in a perspectival landscape. He will soon realize that the area taken up on the surface of the picture by any individual object is only one of the factors which determine our visual experience. The spatial context is another.

If that is true of the painting or photograph, the effect of the constancies becomes even more compelling in the moving picture of the film or the television screen. It needs an effort there to look at a man moving towards the camera and to concentrate not on him but on the increasing area he takes up on the screen. Viewing the screen is even more like looking at the world than viewing a picture.

Experiences of this kind have led to a radical revolution in the psychology of perception, a revolution which has not yet been fully assimilated by the theory of art. It meant the end of a conviction which was held for many centuries, that all we really see are flat patches of colour and that only the experience of touch conveys to us the reality of the third dimension and of the solidity of objects. It was above all the psychologist James J. Gibson who first undermined and ultimately completely overthrew this entrenched opinion ". It may help to explain his novel approach to mention that Gibson was engaged on wartime research for the purpose of aiding fighter pilots to land on the deck of an aircraft carrier. In asking himself how this difficult task is performed he came to see the irrelevance of the traditional account based on the analogy of the photographic camera. What matters to the pilot is not the image formed on the retina of his stationary eye, but the transformation of that image as he swoops down towards the deck. Gibson came to see that our eyes were given us to register not stationary stimuli but the flow of information we receive as we move through the world. By "we" we mean not only human beings but any organism endowed with the gift of sight.

Seen from this biological point of view, the fact of traditional perspective that, for instance, a rectangle will proiect on to the retina or on to the window pane as a trapezoid is not wrong but relatively irrelevant.

A glance back at fig. 8 will make that point clear. We need only imagine ourselves walking past this arrangement rather than keeping our eye at one point to realize that we shall have no difficulty in seeing all the geometrical figures for what they really are. The same is true of a table-top. If we only slightly move our Position it would project a different shape. What Gibson has shown is that these transformations [16] in the shape of things, which can indeed be explained in terms of projective geometry, will inevitably allow the mind to infer their real or, as he calls it, their invariant shape. What matters to us for our survival are not the momentary aspects of things but the perceptions of the things themselves. It is not knowledge which accounts for the deviation we experience from projected size and shape, it is our movement. The importance of what used to be called parallax for the understanding of three-dimensional shapes was not, of course, only discovered by Gibson. After all it has been known for a long time that we are endowed with two eyes which see the objects from slightly different viewing points to grasp their three-dimensional shape. But Gibson has gone much further in his "realism ". He has insisted that we perceive our environment as a three-dimensional invariant array, in other words in real space, and that the "snapshot vision " of the camera or the stationary eye should be regarded as an oddity. Far from telling us how we really see the world, perspective has created a confusion in the mind of psychologists of perception.

One consequence of Gibson's revolution should be clear: we need no longer be surprised at the fact that the large majority of representational styles ignore the facts of projective geometry. They take their starting point from the immense gulf that separates our experience of the real world and the flat surface on which it is to be depicted. Representation takes the form of pictographs of a conventional code by which the objects of this world are described or signified. The attempt to replace this convenient method by paying increasing attention to the passing aspects of things in space will command our admiration as a technical achievement, but we no longer need to regard other systems as primitive or unskilful. The invention of flying is a great feat, but to walk, ride or drive are not therefore primitive modes of locomotion.

There is no reason to believe that Gibson's analysis constitutes the last word, or that perspective presents the end point of man's attempt to come to terms with the representation of spatial experience. The last few decades have witnessed the development of a new, immensely powerful tool — the computer. It has enabled psychologists and technicians alike to analyse the immensely complex events in the brain which contribute to our awareness of moving through the world. A recent book by David Marr (25) has carried the whole debate far beyond Gibson's approach into an area hardly accessible to the layman. Meanwhile, technology has not been idle either. The needs of high-speed flying and of space travel have led to the development of "simulators " in which the visual experience of passing through space is engendered by computer displays for the training of pilots.

A fascinating article in *Scientific American* (26) demonstrates that "Computers can generate motions and visual scenes that accurately mimic the experience of flying ". Some of these devices still in course of construction are mounted in an enclosed dome and project the visual array all around an its wall or even within a helmet worn by the trainee. Describing these technical miracles, the author Ralph Norman Haber concludes with the telling remark that they can " significantly advance understanding of how even earthbound human beings perceive their environment ". Maybe one day these technical developments will lead to the rise of a new art form, as did scene-painting in ancient Greece and Brunellesco's experiment in the early 15th century.

Notes

1   Kurt Badt, *Raumphantasien und Raumillusionen*, Cologne, 1963.

2   M. Luckiesh, *Visual Illusions, Their Causes, Characteristics and Applications*, London, 1922, Dover Publications, New York, 1965; Ronald G. Carraher and Jacqueline B. Thurston, *Optical Illusions and the Visual Arts*, New York and London, 1966; Nicholas Wade, *The Art and Science of Visual Illusions*, London and Boston, 1982.

3   Plato, *Republic*, X, 602 (Loeb Classical Library, Vol. II, p. 449). I have discussed this passage in R.L. Gregory and E.H. Gombrich, *Illusion in Nature and Art*, London, 1973, p. 193.

4   Vitruvius, *On Architecture*, VII, 10 (Loeb Classical Library, p. 71).

5   Pliny, *Natural History*, XXXV, 92.

6   Quintilian, *Institutio Oratoria*, II, XVII, 21 (Loeb Classical Library, Vol. I, p. 335).

7   See my *The Heritage of Apelles*, Oxford, 1976, especially figs. 11 and 12.

8   Commentary on Aristotle's *Meteorologica* by Philoponos (Johannes Grammaticus), *Commentaria in Aristotelem Graece*, Berlin, 1900, XIV, i, 73.

9   The most accessible publication of this text by Antonio Manetti is in Elizabeth Holt, *A Documentary History of Art*, New York, 1957, Vol. I, pp. 171, 172.

10   Martin Kemp, "Science, Non-Science and Nonsense. The Interpretation of Brunelleschi's Perspective", *Art History*, Vol. I, No. 2, June 1978.

11   M.H. Pirenne, *Optics, Painting and Photography*, Cambridge, 1970. See also the masterly entry *Perspective* by B.A.R. Carter in *The Oxford Companion to Art*, Oxford, 1970, ed. Harold Osborne.

12   Decio Gioseffi, *Perspectiva artificialis*, Istituto di storia dell'arte antica e moderna, No. 7, Trieste, 1957.

13   Leon Battista Alberti, *On Painting and on Sculpture*, edited with translation by Cecil Grayson, London, 1972.

14   See my *The Image and the Eye*, Oxford, 1982, p. 194.

15   See Pirenne, *op. cit.*, p. 151.

16   R.L. Gregory, *Eye and Brain*, London, 1966, pp. 179-80, and my *Art and Illusion*, p. 210.

17   See Gregory, *op. cit.*, p. 182.

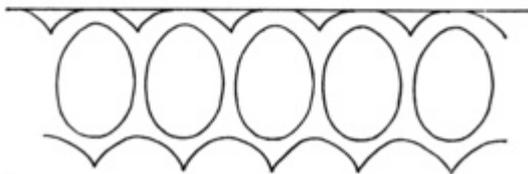18   J.P. Richter, *The Literary Works of Leonardo da Vinci*, Oxford, 1939, pp. 209-219.

19   Stephan Oetermann, *Das Panorama*, Frankfurt on Main, 1980.

20   E. Panofsky, *Die Perspektive als symbolische Form. Vorträge der Bibliothek Warburg 1924-25*, Leipzig and Berlin, 1927.

21   Nelson Goodman, *Languages of Art*, Indianapolis, 1968.

22   See my " The What ' and the How ' ", in *Logic and Art. Essays in honour of Nelson Goodman*, ed. R. Rudner and I. Scheffler, Indianapolis, 1972.

23   See my *The Image and the Eye*, Oxford, 1982, p. 19.

24   J.J. Gibson, *The Perception of the Visual World*, Cambridge, Mass., 1950; *The Senses Considered as Perceptual Systems*, Boston etc., 1966; *The Ecological Approach to Visual Perception*, Boston etc., 1979.

25   David Marr, *Vision. A Computational Investigation into the Human Representation and Processing of Visual Information*, San Francisco, 1982.

26   R.N. Haber, " Flight Simulation ", in *Scientific American*, July 1986, pp. 90-97.

Most of the diagrams and illustrations are drawn by my grand-daughter Leonie Gombrich.

Diagrams and illustrations

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Point of sight.

PICTURE
PLANE

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