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Perceptions as Hypotheses

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Perceptions as hypotheses

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Perceptions may be compared with hypotheses in science. The methods of acquiring scientific knowledge provide a working paradigm for investigating processes of perception.

Much as the information channels of instruments, such as radio telescopes, transmit signals which are processed according to various assumptions to give useful data, so neural signals are processed to give data for perception. To understand perception, the signal codes and the stored knowledge or assumptions used for deriving perceptual hypotheses must be discovered. Systematic perceptual errors are important clues for appreciating signal channel limitations, and for discovering hypothesis-generating procedures. Although this distinction between 'physiological' and 'cognitive' aspects of perception may be logically clear, it is in practice surprisingly difficult to establish which are responsible even for clearly established phenomena such as the classical distortion illusions.

Experimental results are presented, aimed at distinguishing between and discovering what happens when there is mismatch with the neural signal channel, and when neural signals are processed inappropriately for the current situation. This leads us to make some distinctions between perceptual and scientific hypotheses, which raise in a new form the problem: What are 'objects'?

1. Introduction

Are perceptions like hypotheses of science? This is the question that I propose to examine; but there is an immediate difficulty, for there is no general agreement on the nature of scientific hypotheses. It may be said that hypotheses *structure* our accepted reality. More specifically, it may be said that hypotheses allow limited data to be used with remarkable effect, by allowing interpolations through data-gaps, and extrapolations to be made to new situations for which data are not available. These include the future. (They also include inventions and indeed the whole of applied science, which apart from cases of pure trial and error, are surely created by the predictive power of hypotheses.)

I shall hold that all of these statements are true, and that they apply to perception. In addition, both the hypotheses of science and the perceptual processes of the nervous system allow recognition of familiar situations or objects from strictly inadequate clues, as signalled by the transducer-instruments of science and the transducer-senses of organisms. This is at least true for typical situations: in atypical situations the hypotheses of both science and perception may be dangerously and systematically misleading. Errors and illusions can be highly revealing for appreciating the similarities – and the differences – between perceptions and the conceptual hypotheses of science.

It is not always allowed that hypotheses are predictive, or have all or even any of the powers that I have credited them with. I take Sir Karl Popper to hold that hypotheses do not have predictive power, and that they do not have *a priori* probabilities. This is part of his rejection of induction as a way of gaining knowledge. Here I shall not follow Popper's notion of 'objective knowledge' (Popper 1972), for my theme is what happens to observers when they observe and when they learn. On this account much of learning is induction and behaviour is set very largely by probabilities based on past experience and so is predictive. Probable objects are more readily seen than improbable objects, so 'subjective' probability seems to apply, both for selecting perceptions and for perceptions to have the predictive power evident in much behaviour and all skills.

To suggest that perceptions are like hypotheses is to suppose that the instruments and the procedures of science parallel essential characteristics of the sense organs and their neural channels, regarded as transducers transmitting coded data; and the data-handling procedures of science may be essentially the same as cognitive procedures carried out by perceptual neural processes of the brain. There will clearly be surface differences between science and perception, and we may expect some deeper differences, but for the suggestion to be interesting there should be more than overall *similarities*: there should be significant conceptual *identities*.

I shall start by setting out three claims, which I hope to justify, and no doubt qualify.

Claims:

(1) that perceptions are essentially like predictive hypotheses in science;

(2) that the procedures of science are a guide for discovering processes of perception;

(3) that many perceptual illusions correspond to and may receive explanations from understanding systematic errors occurring in science.

It is hoped that by exploring this analogy (or perhaps deep identity) between science and perception, we may develop an effective epistemology related to how the brain works. I shall attempt to indicate concepts and processes that seem important for the opening moves towards the end play of this understanding.

The approach is based on regarding perception and science as *constructing hypotheses* by 'fiction-generators' which may hit upon truth by producing symbolic structures matching physical reality.

2. STEPS TO PERCEPTION

In the first place we regard the sense organs (eyes, ears, touch receptors, and so on) as transducers essentially like photocells, microphones and strain guages. The important similarity, indeed identity, is that the sense organs and detecting instruments convert patterns of received energy into signals, which may be read according to a code. As a signal, the neural activity is fully described in physical terms and measurable in physical units; but the code must be known in order to use or appreciate it as data. We suppose that the coded data are – in perception and science – used for generating hypotheses. For perception we may call them 'perceptual hypotheses'. These are what are usually called 'perceptions'. Here are the three stages of perception, in these terms.

(a) *Signals*

Patterns of neural events, related to input stimulus patterns according to the transducer characteristics of sense organs.

For the eye, for example, there is a roughly logarithmic relation between intensity of light and the firing rate of the action potentials at the initial stage of the visual channel. Colour is coded by the proportion of rates of firing from the three spectrally distinct kinds of cone receptor cell, and so on. These transducer characteristics must be understood before the physiologist can appreciate what is going on. He can then (with other knowledge or assumptions) describe the neural signals as data representing states of affairs.

(*b*) *Data*

Neural events are accepted as *representing* variables or states, according to a code which must be known for signals to be read or appreciated as data.

This necessity of knowing the code is surely clear from examples such as signals conveying data in Morse code. The dots and dashes have no significance, and may not even be recognized as signals conveying data when the code is not known. The same holds for the words on this page: we must know the rules of the English language, and a great deal more, to see them as more than patterns of ink on paper.

It is generally true that a lot more than the code must be known before signals can be read as data. For a detecting instrument (such as a radio-telescope, magnetometer, or voltmeter) it is essential to know something of the source, whether it is a star, a given region of the Earth, or just which part of the circuit a voltmeter is connected to. The outputs of some instruments (such as optical telescopes, microscopes, and X-ray machines as used in medicine) may give sufficient structure for the source to be identified without extra information. This is especially so when the structure of the output matches our normal perceptual inputs. This is, however, somewhat rare for instruments. A voltmeter provides no such structured output by which we can recognize its source of signals without collateral knowlege. Some sense organs (especially the eye) provide highly structured signals allowing identification of the source; but visual and any other sensory data can be ambiguous (including touch, hence the game of trying to identify by touch objects in a bag), and indeed all sensory and instrumental data are, strictly speaking, ambiguous. The fact that vision is usually sufficient for immediate object identification distracts us from realizing the immense importance of contextual knowledge for reading data from signals. Scientific data from instruments are almost always presented with explicit collateral information, on how the instrument was used, what source it was directed to, its calibration corrections and scale settings. The gain setting of oscilloscopes and the magnification scale of photographs and optical instruments of all kinds are essential for scientific use. If the scale is given incorrectly, serious misinterpretation can result, even to confusing the surface of a planet with biological structures. So, not only the signal code must be known, but also a great deal of context knowledge is required for signals to be read as data. This holds for perception as it does for the use of scientific instruments, though for perception the context knowledge is generally implicit and so its contribution may not be recognized.

It is important to note that signals can be fully described and measured with physical concepts and physical units, but this is not so for data. Data are highly peculiar, being (it is not too fanciful to say) in this way outside the physical world, though essential for describing the physical world.

The codes necessary for reading signals as data are not laws of physics. They are, rather, essentially arbitrary and held conventionally. Some may be more convenient or efficient than others, but in no case are they part of the physical world as laws of physics are, or reflect, ‘deep structures’ of reality. Further, data are used to select between *hypothetical* possibilities, only one of which (if indeed any) exists. The greater the number of alternatives available for the selection (or rather the greater their combined probability) the greater the quantity of information in the data (Shannon & Weaver 1949). The information content thus depends not only on what *is* but on the hypothetical stored alternatives of what *may be*. But these are not in the (physical) reality of the situation, so data cannot be equated with what (physically) *is*; neither can they be equated with signals, for data are *read from* signals by following the conventional rules (which are not physical laws) of a code.

(*c*) *Hypotheses*

There is, unfortunately, no general agreement as to just what hypotheses are or what characterizes them. This, it must be confessed, is a weakness in our position. If there is no agreement on what are hypotheses, how can it be argued cogently that perceptions are hypotheses? Just what is being claimed? With the present lack of agreement, one must either be vague or stick out for a particular account, which may be arbitrary, of the nature of hypotheses. Current accounts range from Popper's view that they have no prior probabilities and no predictive power (and that they cannot be confirmed but only disconfirmed) to very different accounts, such as that they can be in part predicted; that they can be used for prediction; and that they can be confirmed (though not with certainty) as well as disconfirmed by observations. I shall not entirely follow Popper's account of hypotheses (Popper 1972), but hold, rather, an alternative account: that they have *predictive power*, and that they can be suggested by observation and induction, and can be confirmed or disconfirmed though not with logical certainty.

It may be objected here that if perceptions are themselves hypotheses, they cannot be evoked to confirm or disconfirm the explicit hypotheses of science. This is, however, no objection, for it is common experience that a perception can confirm or disconfirm other perceptions. And one scientific hypothesis may (it is usually held) confirm or disconfirm other hypotheses in science. So there is no clear distinction between hypotheses and perception here to make my argument invalid.

There is, however, this problem of the lack of agreement of what constitutes hypothesis. The notion of hypothesis has grown in importance with the rejection of hopes of certainty in science like the supposed certainty of geometrical knowledge before non-Euclidian geometries, and with Kuhn's (1962) paradigms. Perhaps all scientific knowledge is now regarded as hypothesis. But if Popper is right, would we have any wish to associate perception with hypotheses? For in his view they have none of the power we attribute to perception. What, then, are hypothesis?

I suggest that *hypotheses are selections of signalled and postulated data organized to be effective in typical (and some novel) situations*. Hypotheses are effective in having powers to predict future events, unsensed characteristics, and further hypotheses. They may also predict what is *not* true. I shall assume that we accept that these are important characteristics of scientific hypotheses and perception.

To amplify this, we may now consider in some detail similarities – and also differences, for there clearly *are* differences – between hypotheses and perceptions. We shall look first at similarities when perceptions and scientific hypotheses are appropriate. We shall then go on to compare them when they are inappropriate, or 'false', and finally we shall consider ways in which perceptions clearly differ from hypotheses of science.

3. Perception and scientific hypotheses compared

(a) *Results of appropriate uses of perception and science*

(1) *Interpolation across gaps in signals or data*

This allows continuous behaviour and control with only intermittent signals, which is typical of organisms and important in science, though rare in machines.

Interpolations may be little more than inertial or may be highly sophisticated and daring constructs. Let us first consider interpolation in a graph, such as figure 1. The curve is derived according to two very different kinds of processes. It is generated from the readings by following procedures, which are easy to state and to carry out automatically without particular external considerations. The most common procedure here is fitting by least squares. The curve may not touch any of the points representing the readings and yet it is accepted as the 'best' curve. It is an idealization – a hypothesis of what should occur in the absence of irrelevant disturbances and an infinite set of readings with no gaps.

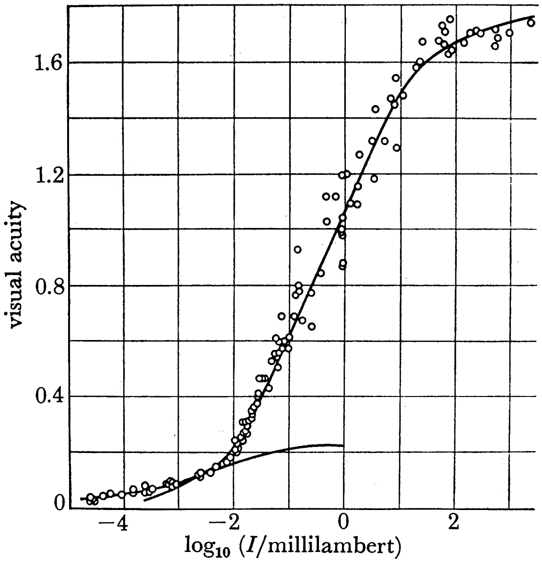

Figure 1. A typical graph of experimental readings with a fitted curve. The fitting may be done both 'upwards', by a routine procedure such as by 'least-mean' squares; and 'downwards', from which (generally theoretical) function is most likely. The fitted curve may be regarded as a predictive hypothesis. Contour perception seems similar.

Any graph of experimental or observational data has some *scatter* in the readings through which the curve is drawn. The scatter may de due to random disturbances of the measuring device, or to variation in what is being measured, such as quantal fluctuations. These kinds of scatter have very different statuses, though for some purposes they may be treated alike and there may be a mixture of the two. In any case the curve may not touch any of the points indicating the readings. So it is a kind of fiction, accepted as the fact of the situation.

The second kind of procedure for obtaining the curve and for gap-filling is selecting a *preferred* curve, on theoretical or other general grounds, which may be aesthetic. The first kind of procedure is 'bottom-upwards' from the readings, by following procedures without reference to contextual considerations; the second is 'top-downwards', from stored knowledge or assumptions suggesting what is a likely curve. This may be set by a general preference (or prejudice) for example for a linear, or a logarithmic, or some other favoured type of function; or it may be set by particular considerations. Both have their dangers: the first biases towards the accepted, and the second tends to perpetuate false theories by bending the data in their direction.

The example of a graph illustrates that hypotheses – for the accepted curve or function may *be* a predictive hypothesis – can be *non-propositional*. Perhaps hypotheses are generally thought of as sets of propositions, but there seems no reason to restrict hypotheses to propositions as expressed in language. An equation such as $E = \frac{1}{2}mv^2$ is a hypothesis, in this case concerning quite abstract concepts (energy, mass and velocity), believed to represent something of the deep structure of physics, but it is not propositional in form. It could be written in language as a set of sentences expressing propositions but this would be relatively clumsy. It could also be expressed as a graph, and this could be adequate for some purposes. Analogue computers, indeed, work from this kind of non-propositional representation.

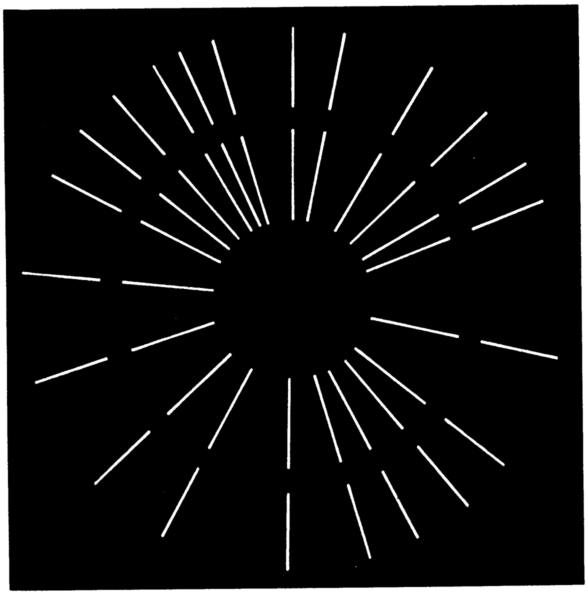

FIGURE 2. Illusory contours and regions of modified brightness seem to be postulates of nearer eclipsing objects, to 'explain' unlikely gaps. It seems that an essentially Bayesian strategy is responsible.

There seems no reason to hold that 'perceptual hypotheses' require a propositional brain language, underlying spoken and written language, though this might be so. The merits of this notion need not be considered here, as we are free to regard hypotheses as not *necessarily* being in propositional form.

Perhaps interpolations are generally regarded as gap-filling in situations for which we do not have complete or strictly adequate readings, but interpolation can be far more elaborate than this, for example postulating unknown species to fill gaps in evolutionary sequences. For a visual example, consider figure 2. Perhaps 'illusory contours' are edges of objects postulated to account for gaps in available sensory signals or data. They take more or less ideal forms, and they are (generally useful) fictions joining data. This indeed defines interpolation in perception and science.

2. *Extrapolation from signals and data, to future states and unsensed features*

Extrapolation allows hypotheses to take off from what is given or accepted, into the unknown. Going beyond accepted data is not very different from filling gaps, except that interpolations are limited to the next accepted data point; extrapolations, however, have no endpoint in what is known or assumed, so extrapolations may be infinitely daring, and so may be dramatically wrong.

Extrapolation beyond the end of graphs of functions supported by data is sometimes essential (as for determining 'absolute zero' temperature by extrapolating beyond the range through which measures can, even in principle, be made). Extrapolations can leap from spectral lines to stars, and from past to future. With interpolation and extrapolation, data become stepping stones and springboards for science and perception. This is to say that perceptions are not confined to stimuli, just as science is not limited to signals or available data; neither, of course, is confined to fact.

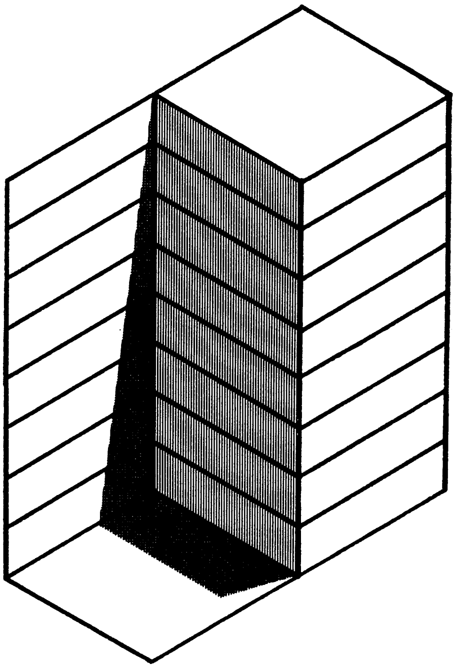

FIGURE 3. In this depth-ambiguous figure the grey rectangular region changes in brightness for most observers according to whether this area is a probable shadow. The systematic brightness change with depth-reversal is, clearly, centrally initiated and is a 'downwards' effect.

(3) *Discovery and creation of objects, in perceptual and conceptual space*

The perceptual selection of sensed characteristics may create *objects*. There is also strong evidence for creating visual *characteristics* from what is accepted as objects (cf. figure 3).

We know too little about the criteria for *assigning* data to objects, and *creating* object-hypotheses from data. What science describes as an object may or may not correspond to what appears to the senses as an object; different instruments reveal the world as differently structured. Further, general theories change what are regarded as objects. There is evidently a complex multi-way traffic here by which the world is parcelled out into objects; it seems that here again we have 'upwards' and 'downwards' procedures operating. The various rules of 'closure', 'common fate' and so on, emphasized by the Gestalt psychologists such as Wertheimer (1923), reflect features typical of the vast majority of objects as we see them. Most objects are closed in form, and their parts move together. These common object characteristics become identifying principles – and may structure random patterns to *create* object forms, even from noise. More recently, the work in artificial intelligence on object recognition makes use of typical features – especially the intersections of lines at corners of various kinds – to describe objects and their forms in depth (Guzman 1968). The effectiveness of these classifications and rules depends on what objects are generally like (cf. Guzman 1971). For exceptional objects, the rules mislead, as we see in the Ames demonstrations (Ittelson 1952) and in distortion figures (Gregory 1968). The object-recognizing and object-creating rules are applied *upwards* to filter and structure the input. (It is, however, interesting to note that they may have been *developed* downwards, by generalized experience of what are, through the development of perception, taken as objects. For the Gestalt writers this is largely innate; but our similar experience and needs might well generate common object-criteria through experience.)

Knowledge can work downwards to parcel signals and data into objects; as knowledge changes, the parcelling into objects may change, both for science and perception, We see this most clearly when examining machines: the criteria for recognizing and naming the various features as separate depend very much on our knowledge of functions. Thus the pallets on the anchor of a clock escapement are seen and described as objects in their own right once the mechanism is understood, though they are but shapes in one piece of metal, which happens also to look like an anchor. So we see here again the importance of *upward* and *downward* processing in perception and science – the complex interplay of signals, data and hypotheses. Unravelling this is surely essential for understanding the strategies and procedures of perception and science. It is also important for appreciating the status of objects. How far are objects *recognized* and how much are they *created* by perception and science? This is a deep question at the heart of empiricism.

What may be a profound difference between perceptual and conceptual objects is that perceptual objects are always, as Frege put it (Dummett 1978) *concrete objects*, while the conceptual objects of science may be *abstract objects*. The point is that objects as perceived have spatial extension, and may change in time, while conceptual objects (such as numbers, the centre of gravity of concrete objects, and the deep structure of the world as described by laws of physics) cannot be sensed, may be unchanging and spaceless, and yet have the status of objects in that they are *public* though not sensed. We all agree that the number 13 is a prime number, that it is greater than 12 and less than 14, that it is odd and not even, and that *all* prime numbers except 2 are odd numbers. This kind of agreement is characteristic of the agreement and public ownership of objects as known by the senses (tables, stones, and so on), yet numbers cannot be sensed, though they are as 'public' as tables and stones.

This situation is rendered even more difficult by the consideration that, clearly, *concrete* objects have some features that are abstract, as we believe especially from scientific knowledge. Take, as an example, centre of gravity: stones have centres of gravity, which is useful as a scientific concept, and are indeed what Newton took to be the 'objects' of the solar system for his astronomy. Centres of gravity may indeed lie not *in* but *between* concrete objects, such as between Earth and Sun, or between binary stars. Does the centre of gravity exist, as stones and stars exist? Or is it a useful fiction created as a tool for scientific description?

Even within what is clearly perception, we can be uncertain of what is 'concrete' and what is 'abstract'. We see that a triangle has three sides, and yet number is regarded, at least by Frege, as 'abstract'. Are shadows 'concrete objects'? The trouble here is that they are known by only one sense (if we except differences of sensed temperature) and they have few causal properties. Also, they are always attached to what is clearly a concrete object (which may be the ground) and by contrast they seem far less concrete, almost abstract though we see them.

These are exceedingly difficult issues, which can hardly be resolved without deeper understanding of hypothesis-generation, and further analysis of the similarities and differences between perceptual and conceptual hypotheses.

If we consider such 'objects' as electrons, which are clearly inferred indirectly from observational evidence, how do they compare with concrete objects of perception? If we believe that normal perception of concrete objects such as tables and stones requires a great deal of inference ('unconscious inference', to use Helmholtz's term), then the difference may not be great. The more perception depends on inference the more similar we may suppose is the status of perceptual and conceptual objects.

We shall now consider inappropriate or 'false' hypotheses and perceptions. Here I describe certain phenomena of perception, such as various kinds of illusions, as our actually *seeing* what are *described* when occurring in science as errors; various kinds of ambiguities, distortions, paradoxes and fictitious features. The claim is that these categories, which are normally applied to arguments and descriptions, appear in perceptions as experiences of recognizable kinds, which can be investigated much as the phenomena of physics can be investigated; though for some of these perceptual phenomena rather different kinds of explanations from those of physics may be required.

(*b*) *Results of inappropriate uses of perception and science*

(1) *Ambiguity, sometimes with spontaneous alternations and disagreements*

The point here is that alternative hypotheses can be elicited by the same signals. There are many examples of visual ambiguity in which a figure (or sometimes an object) is seen to switch from one orientation to another, or transform into another design or object. This has been attributed to bi-stable (or multi-stable) brain circuits (Attneave 1971) and, very differently, to putative hypotheses in rivalry for acceptance when their probabilities on the available evidence are nearly equal. The first would be an account in terms of *signals*, the second in terms of *data*. Inspection suggests strongly that the second is what is going on in most cases, for the stimulus pattern can be immensely varied, but what it *represents* matters a great deal. There are, however, many examples of the first kind: retinal rivalry, from different colours presented to the eyes producing spontaneous alternations, and lines of different orientation presented binocularly, producing rivalry. Here it is purely the stimulus characteristics that matter. On the other hand, figures such as the Necker cube, the Schroeder staircase or the Boring wife–mistress figure, present equal evidence for example for two very different faces, which gives the ambiguity. For the Necker cube there is no evidence favouring either of two or more orientations. For both figures the ambiguity no doubt depends on our knowledge of faces and cubes. (We studied the case of a man blind from infancy and allowed to see by corneal graft when in his fifties: when we showed him ambiguous figures such as Necker cubes he saw no depth and no reversals. He made nothing of pictures of faces (Gregory & Wallace 1963).) It is likely that different experience might change the bias of ambiguous alternations in cases such as the Boring figure.

That science can be ambiguous is shown by the frequent changes of opinion and the occasional disputes which give it light and heat. For a current example of scientific ambiguity: are quasars astronomically near objects with abnormal red shifts, perhaps due to their powerful gravitational fields (and thus not obeying the Hubble law of increasing red shift with distance), or are they very distant, but of enormous intrinsic brightness? Here is a clear case of an important ambiguity which is not yet quite resolved. It might de resolved by further data derived by instrumental signals, or by a change in the general theoretical position, for which this is a central question. In short, the change that resolves the paradox might be 'upwards' or 'downwards' – both in science and in perception.

(2) *Distortion, especially spatial distortions*

Distortions can occur at the *signal* level by loss of calibration (as by sensory adaptation), by inappropriate calibration corrections, by mismatch of the instrument or sense organ 'transducer' to the input (or affecting the input, as by loading with a voltmeter of low internal resistance, or detecting temperature by touch of thin metal, which rapidly adopts the skin temperature).

Distortions may also occur in the *data* and stored knowledge level, as when knowledge is transferred inappropriately to the current situation, so that signals are misread.

Signal errors are to be understood through physics and physiology; data errors (which are cognitive errors) are understood by appreciating what knowledge or strategies are being brought to bear, and in what ways they are inappropriate to the current problem or situation.

Visual distortions can occur with: (i) mirrors, mirages, sticks bent in water, or astigmatic lenses giving optical distortion of the input; (ii) astigmatic lenses of the eyes (physiological optical distortion); (iii) inappropriate neural correction of optical astigmatism (a calibration correction error); (iv) neural signal distortion (which may be pathological or may be due to other signals interfering by cross-talk, or neural lateral inhibition, or some such); (v) signals being misread as data (especially by 'negative transfer' of knowledge: generally from typical to similar but atypical situations).

I shall not expand on these, except the last, and that only briefly. Here again we find the distinction between processing *upwards* and *downwards* important. To take an example of misreading data that has received a great deal of attention, though explanations are still controversial, we may consider visual distortion illusions.

Since the perceived size of things is ambiguously represented by retinal image size, size must be *scaled*. Visual scale is set by what I have called (Gregory 1970) 'constancy scaling'. It seems that scaling can set *upwards*, from stimulus patterns normally accepted as data for distances (especially converging lines and corners normally indicating depth by perspective). When these stimulus shapes occur without their normal depth – as when perspective is presented on a picture plane – they may be accepted as though they correctly represented depth, there to set the scaling inappropriately. Features represented as distant on a picture plane are perceptually expanded, for normally expansion with increased object distance is required to compensate for the shrinking of retinal images with object distance; but this is not appropriate for the flat-perspective drawings. Scale-setting is essential for maintaining perceived size independently of object distance (giving 'size constancy'), but when scale-setting by perspective features occurs other than by the retinal projection of parallel lines, etc., lying in the three dimensions of normal space, then the scale is set inappropriately, to generate distortion 'upwards' from the misleading perspective features.

'Downwards' distortions occur when an incorrect depth hypothesis is adopted. This is clear from depth-ambiguous objects, such as wire cubes, which change shape with each depth reversal, though the retinal input and neural signals from the eye remain unchanged. Ambiguous objects and figures are extremely useful in this way for separating upward from downward perceptual processes (Gregory 1968, 1970).

Astronomy is rich in examples of scales set *upwards* from instrumental readings (with fewest assumptions by heliocentric parallax) and also *downwards* from considerations such as the mass–luminosity relation applied to a certain class of variable star, so that their observed periodicity can be used, together with their apparent luminosity, to infer distance. This involves a great deal of stored knowledge and associated assumptions. When these change, the Universe may be rescaled.

There seems to be a remarkable similarity in the setting of scale for perceptual and for scientific hypotheses. Perceptual space is not, however, Euclidian, except for near objects. Consider the perception of an engine driver: the rails appear parallel only for a few hundred metres, then they converge alarmingly. The driver can use his *perceptual* Euclidian near-space, in which parallel lines never meet, with confidence; but for greater distances he must reject his non-Euclidian perceptual space in favour of his Euclidian *conceptual* space, to drive his train further without a certainty of disaster. If, now, the driver reads Einstein in his spare time, he will adopt still another space: then what he relies upon professionally will become for him a parochialism, adequate for the job but not for fuller understanding. Each view – perceptual or conceptual – which seems undistorted will appear distorted from the spaces of his other views.

(3) *Paradoxes, especially spatial paradoxes*

Paradoxes can be generated by conflicting inputs, or by generating hypotheses from false or inappropriate assumptions. A well known conflicting-input perceptual paradox is given by adapting one hand to hot water and the other to cold, and then placing both hands in a dish of warm water. To one hand this will be cold and to the other hot. The adaptation has produced (or rather *is*) mis-calibration, which gives incompatible signals to produce a paradox, since we do not allow that an object can be both hot and cold at the same time.

In recent science there has been a relaxing of the strictures of paradox, such that what now seems paradoxical to common sense may, sometimes, be accepted as scientifically true. An example is light accepted as both waves and particles. Also, what *appears* paradoxical may be *understood* as non-paradoxical – as indeed for the 'impossible triangle' object or drawing (figures 4 and 5). Here we discover that conceptual understanding is sometimes powerless to correct or modify even clearly bizarre perceptions. We can, at the same time, hold incompatible perceptual and conceptual hypotheses: so we can *see* a paradox.

The 'impossible triangle' is clearly a cognitive illusion, for there is nothing special about this as a *stimulus* to disturb the physiology or signals of the visual channel. By making a model (figure 5), it may be seen and understood that this occurs with a special view of a normal object. When viewed from the critical position, the perceptual system assumes that two ends of what appear to be sides of a triangle are joined and lie at the same distance, though they are separated in distance. Even when we know this we still experience the visual paradox. It is very interesting that this false visual assumption – that the ends are at the same distance though they are separated – can generate a perception which is clearly extremely unlikely, and recognized as unlikely or even impossible. This shows convincingly that perceptions are built up by following rules from assumptions. Since perceptions can be extremely improbable and even impossible, it follows that perceiving is not *merely* a matter of accepting the most likely hypotheses. Figures and objects of this kind present useful opportunities for discovering perceptual assumptions and rules by which perceptual hypotheses that may conflict with high level knowledge are generated 'upwards' from assumptions by rule-following.

Our ability to generate and accept extremely unlikely perceptions must be imporant for survival, for occasionally highly unlikely events and situations do occur and need to be appreci-

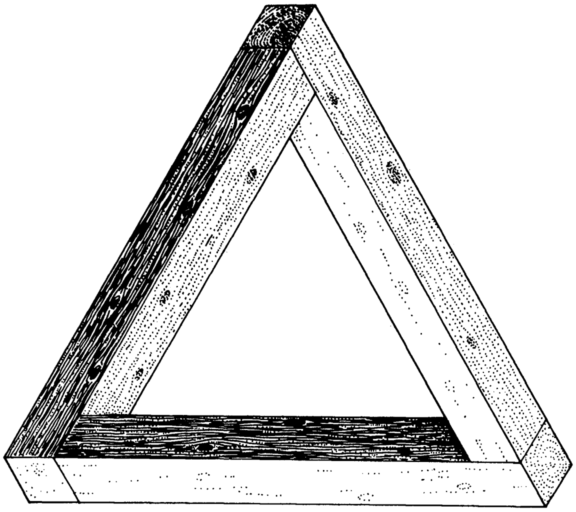

FIGURE 4. The Penrose 'impossible triangle' drawing. This appears paradoxical; but it can be an object lying in normal three-dimensional space as viewed from a critical position, as shown in figure 5.

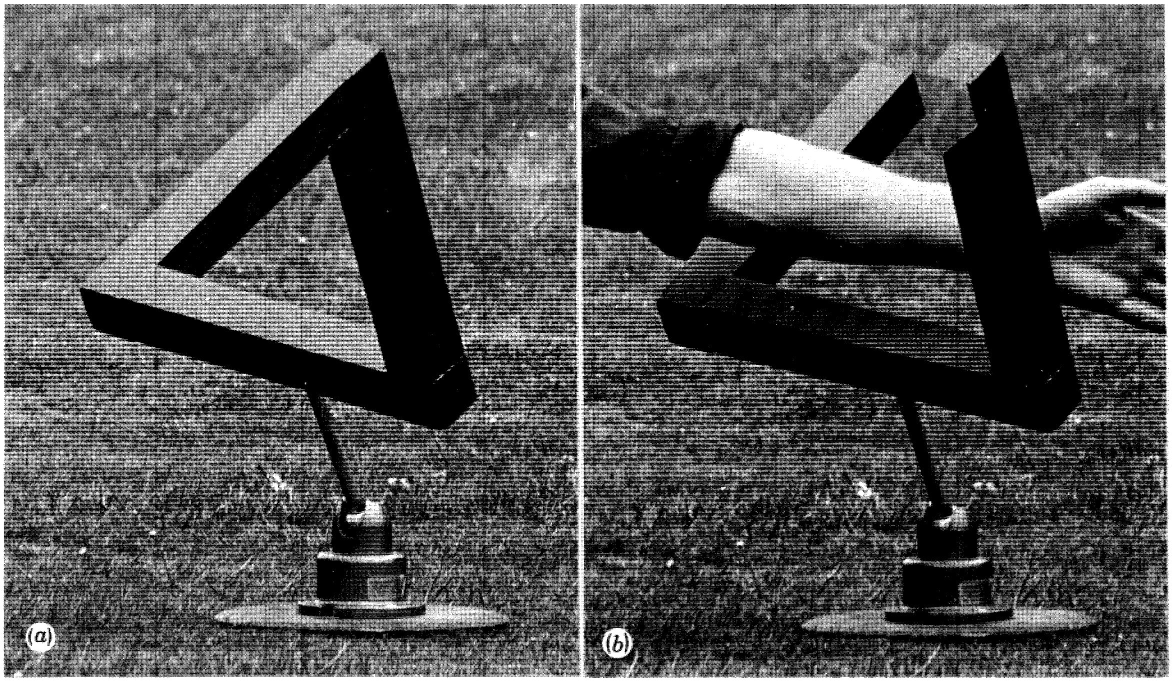

FIGURE 5. This wooden object appears paradoxical when viewed from a critical position. This is as true of the object itself as of the photograph.

ated. Indeed, perceptual learning would be impossible if only the probable were accepted. At the same time, though, there is marked probability biasing in favour of the likely against the unlikely; as in the difficulty, indeed the impossibility, of seeing a hollow mask as hollow, without full stereoscopic vision (figure 6). So there are, again, the two opposed principles – processing upwards and downwards – the first generating hypotheses which may be highly unlikely and even clearly impossible, the second offering checks 'downwards' from stored knowledge, and filling gaps which may be fictional and false.

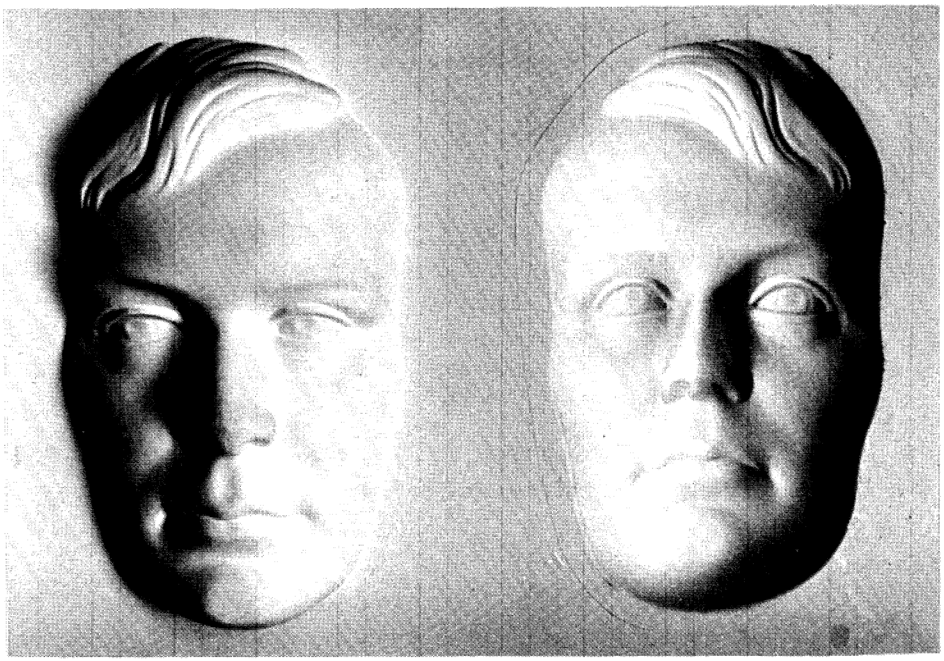

FIGURE 6. The 'face' on the right is in fact the hollow mould of the face on the left. Though hollow, the mould appears as a normal face. Texture and even stereoscopic counter-information are rejected to maintain this highly probable (but incorrect) hypothesis.

(4) *Fictions, sometimes to fit and sometimes to depart from fact*

We can see perceptual fictions in phenomena such as the illusory contours (figure 2). These were described by Schuman (1904) and have recently become well known with the beautiful examples due to Kanizsa (1966). If we are right in thinking (Gregory 1972) that they are postulated masking objects to 'explain' the surprising gaps in these figures, we at once assign to them a cognitive status. Related examples are shadows of writing: letters that would cast such shadows are seen though there is no stimulus pattern of letters. The letters are evidently fictions to 'explain' what are accepted as shadows by postulating letter-shaped objects (Gombrich 1960).

It is resonable to suppose that a very great deal of perception is in this sense fictional: generally useful but occasionally clearly wrong, when it can be an extremely powerful deception. No doubt this holds also for science.

It is particularly interesting that the *absence* of signals can be accepted as data. This is so for the discovery of the van Allen radiation belts, when the space probes' sensors were overloaded so that they failed to provide signals; and the gaps of the illusory contours figures which provide data for an eclipsing (though non-existent) object. These examples indicate ways by which the hypotheses of science and perception become richer than signalled data. They show also that we cannot equate neural signals with experience.

(5) *Causes and inferences link hypotheses and perception to the world*

Hypotheses of science and perceptions are, I believe, linked to reality very indirectly. What kind of relations do they have? There are two important questions here: (*a*) Are they *causally* linked? (*b*) Are they linked by *inference*? We should allow the possibilities that either or both may be true or false. Let us consider these.

(*a*) That hypotheses are *causally* linked to reality would be held, if there are what we have called *signal* links between reality and hypotheses. We accept this for transducers and signal channels, but what of the signals when read as *data*? There can be gaps in signals. These are often filled by interpolating processes (§3.*a*.1), so here science and perception clearly maintain hypotheses (and maintain continuous control from hypotheses) through signal gaps. Nevertheless, we do not want to say that this gap-filling requires processes outside causal explanation. Part of the aim of theories of perception and accounts of science is indeed to explain gap-filling, and these explanations, if they are to be like most explanations, should preferably be causal. We may, however, expect to find some deep conceptual difficulties over *data*, though not signals, as causes.

What of *data* distortions? Are they breaks in causal sequences? One can see cases of data errors (rather than signal errors) in which there clearly are no causal breaks in the signals, and it is possible to understand why the signals are read as misleading data. This occurs when signals are read normally as though occurring in a typical situation, when in fact the situation is atypical. Particular perceptual examples are, on this account, many of the distortion illusions (cf. Gregory 1963). Here the scaling is supposed to be set quite normally by signalled features, but these features do not have their usual significance in these figures. For example, converging lines on a picture plane are read as perspective, as though the convergence were produced as in normal three-dimensional space when parallel lines lying in depth are imaged on the retina. Picture perspective misleads not by distorting neural signals, but by providing signals that are read as depth data although the picture is flat. There is no break in the usual causation of perception, but there is marked distortion, and the distortion is of data, not of signals.

To understand why this happens we always need to know what knowledge (in this case that convergence of lines is associated with depth) has been transferred to the current situation, and why in this situation it is inappropriate.

What of paradoxical hypotheses? Since we do not accept that reality can be paradoxical, we cannot accept that paradoxical hypotheses or perceptions can match or represent reality. There is therefore some kind of gap – but is this a causal gap? We can think of signal distortion paradoxes where there clearly is no causal gap, for example the hands sensing hot and cold for the same bowl of water, when one hand has been adapted to hot and the other to cold. Here we have incompatible signals owing to adaptation of one of more channels, combining to form a paradox – but without any causal break.

Figures such as the Penrose impossible triangle drawing (figure 4) or our impossible model (figure 5) are very different from signal distortions. We attribute these perceptual paradoxes not to signal errors, but to false assumptions. So these are top-down errors.

The question is: Do top-down injections of data or assumptions produce causal gaps in signal processing? They certainly introduce considerations that may be very far removed from the current situation, and for quite displaced assumptions it may be very difficult indeed to see how they have come into play. If we give them a 'mental' status, then we may be tempted to say that they are caused mentally; it seems better, however, to say that the situation is something like a filing card index, in that references are sought by criteria of relevance and so on, as formulated within a physical search system. This may go wrong by misreading of signals or by indexing errors, and it may also produce misleading data because what is generally relevant is not appropriate in the particular situation. These mistakes are very different, but they can be explained in terms of the logic of the procedures plus the mechanical steps used to carry out the procedures.

(*b*) If probabilities can affect reasoning and acceptance or rejection of hypotheses, then just how can we hold that signals though not data are causal? To maintain a causal account we must allow that assessed probabilities have causal effects. We may, however, translate this into: *Signals have causal effects according to the significance in the situation of the data that they convey.*

If the distinction between signals and data is seen as a dualism, at least this dualism does not apply uniquely to mind and brain. As argued earlier, it applies with equal force in the case of instruments supplying signals and data for science. So the activity of science becomes a test-tube – indeed a laboratory – for appreciating the mind–brain problem.

We may now consider some *differences* between scientific and perceptual hypotheses.

(*c*) *Differences between scientific and perceptual hypotheses, when they are appropriate or inappropriate*

(1) *Perceptions are from one vantage-point and run in real time; science is not based on an observer's view*

Perceptions differ from conceptions by being related to events in real time from a local region of space, while conceptions have no locale and are essentially timeless. They not only lack any locale in the three-dimensional space of the physical world, but they may express variables and relations in all manner of conceptual spaces, which are not claimed to exist though they are useful fictions for descriptive purposes.

So perception is far more limited in range and application than conception. The basis of empiricism is that all conception depends upon perception. But conception can break away from perception, to create new worlds – though perhaps always using as building blocks the objects of perception.

(2) *Perceptions are of instances; science is of generalizations*

We perceive individual objects, but we can conceive, also, generalizations and abstractions. Thus we can see *a* triangle, but we can conceive general properties of *all* triangles – tri-angularity. Is this difference absolute or, rather, a matter of degree? A chess player may claim that he *sees* the situation rather than the pieces; and when reading, one is more aware of the meaning of the words than their form, and this can hold when the words express generalizations. This is a tricky issue requiring investigation. I incline to think that there is not a sharp distinction here between perceiving and conceiving.

(3) *Perceptions are limited to 'concrete objects'; science has also 'abstract objects'*

This distinction is due to the logician Frege, and is discussed above (§3.*a*.3). Again, this is a tricky issue, closely bound up with the deepest problems of perception and epistemology. The distinction is not clear-cut.

Concrete objects are what are (or are believed to be) sensed. They may be simple or complex. Thus a magnetic field may be simple and a table is complex. It is not, however, at all clear that sensing is *ever* free from inference: for example, perceiving a table is far more than sensing various parts, and sensing a magnetic field requires all manner of inferences about the transducer and how it is placed and used. The contribution of inferences and assumptions to sensing even simple objects makes the distincion between concrete and abstract objects difficult and perhaps impossible to make clearly, for abstract objects – such as numbers and centres of gravity – are or at least may be known via sense experience, and perhaps nothing is sensed 'directly'. If nothing is sensed or perceived directly – if *all* perception and all scientific observation, however instrumented, involve inference – then it seems that there are no purely concrete objects. This is indeed a major conclusion from the thesis that perceptions are hypotheses. This conclusion applies equally to perception and to science.

(4) *Perceptions are not explanations, but conceptions can be explanatory*

Scientific hypotheses are closely linked to explanation: it is an explanation that the tides are caused by the pull of the Moon. Perceptions certainly have far less explanatory power, but perhaps they do have some. One understands social situations, or mechanisms, through looking: is this understanding part of the *perception*? I incline to think that it is. This difference is rather of degree than kind.

(5) *Perception includes awareness; the physical sciences exclude awareness*

This is by far the most striking difference between hypotheses of science and perceptions: sensations are involved in perception (though not all perceptions) but awareness, or consciousness, has no place in the hypotheses of physics.

The scientist may be aware that he is working on a hypothesis; but the hypothesis is not itself aware – or so we assume! On the other hand, we do want to say that awareness is an integral part of many perceptual hypotheses, so here we have a clear distinction between scientific hypotheses and some perceptions.

Returning to our distinctions between signals and data: a traditional view was that perceptions are made up of sensations, but this we have rejected. It must, however, be confessed that the role, if any, of awareness or consciousness in perception is totally mysterious. Much of human behaviour controlled by perception can occur without awareness: consciousness is seldom, if ever, necessary. Perhaps consciousness is particularly associated with mismatch between expectation and signalled events; but if this is so, its purpose remains obscure, because it is not clearly causal.

Popper & Eccles (1977) argue from phenomena of visual ambiguity – especially maintaining or changing visual orientations by will – that mind, as associated with consciousness, has some control over brain. This argument was also suggested by William James (1890), but, as he points out, it could be *other brain processes* affecting reversal rates, or whatever. There seems no good reason to suppose that consciousness, at least in this situation, is causal.

Is consciousness so difficult to understand and describe, just because it is *not* part of scientific hypotheses about the physical world? It is these, only, that provide conceptual understanding? If so, we must be careful with our suggestion that perceptions are hypotheses: for if *all* we can know are hypotheses of physics, then perceptions are *bound* to look like hypotheses of physics. This is an impasse for which I have no ready answer. I can only hope that further consideration will unravel or cut these Gordian knots of knowing.

We may conclude that, all in all, there are marked similarities and important identities between hypotheses of science and perceptions. It is these that justify calling perceptions 'hypotheses'. The differences are, however, extremely interesting, and I fear that I have not done them justice. This is not through any desire to minimize them, but rather that I do not know what to add. Possibly this is because we think in terms of the hypotheses of science so that when something crops up that departs from them drastically, we are lost. We are lost for consciousness. It is very curious that we can think conceptually with such effect 'outwards' but not 'inwards'. It may be that developments in artificial intelligence will provide concepts by which we shall see ourselves.

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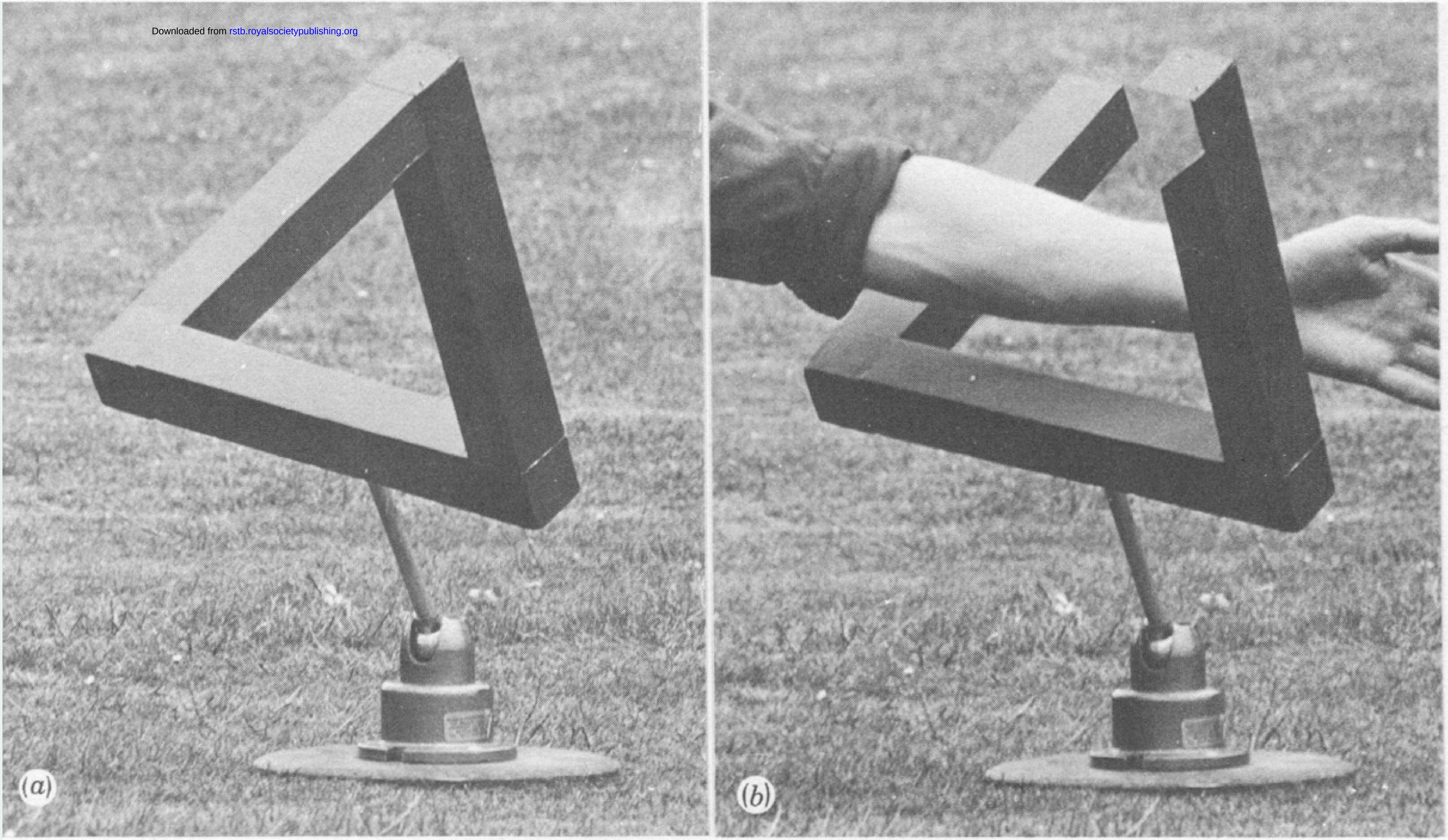
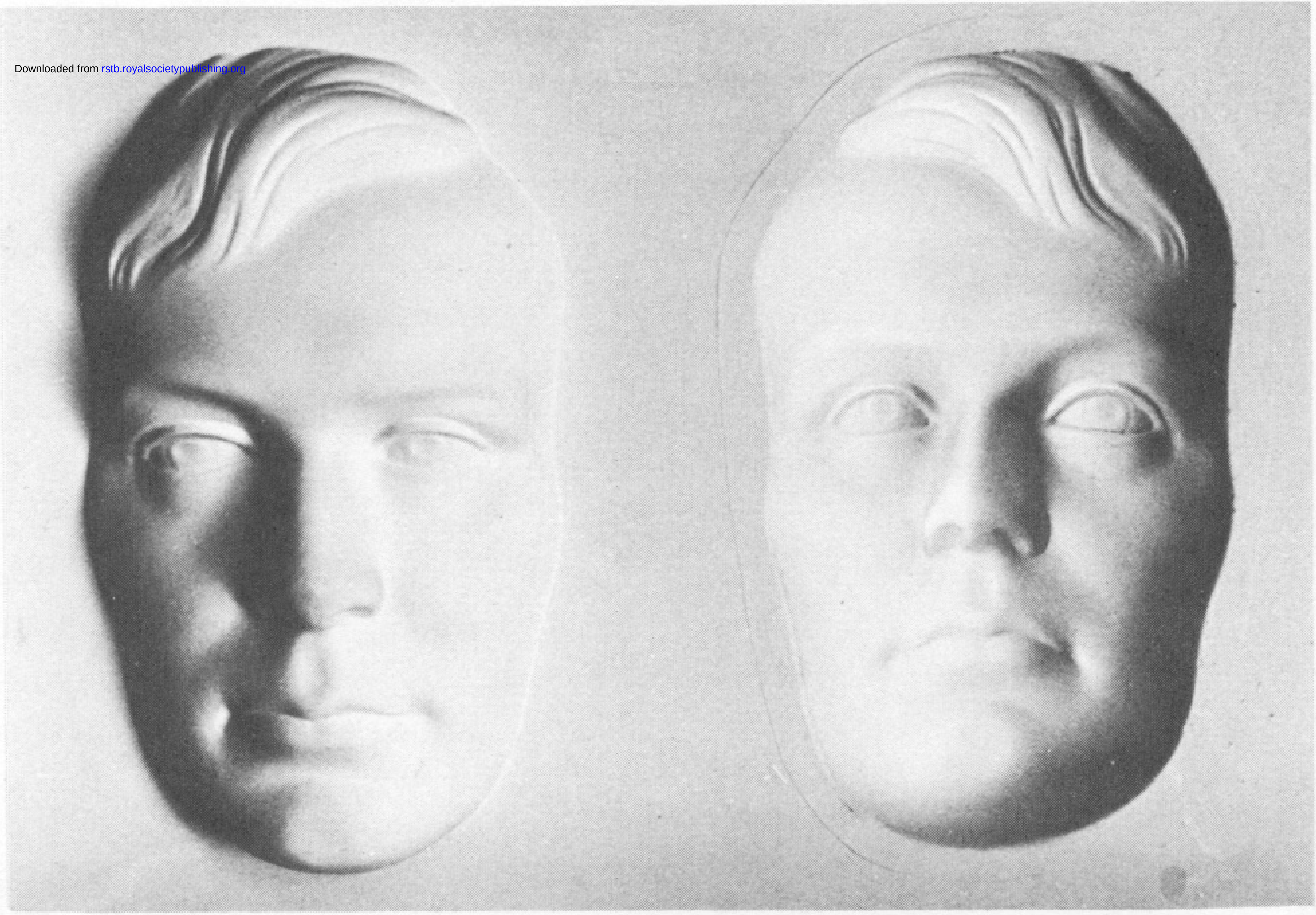


FIGURE 5. This wooden object appears paradoxical when viewed from a critical position. This is as true of the object itself as of the photograph.



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