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Perception as Unconscious Inference

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Consider for a moment the spatial and chromatic dimensions of your visual experience. Suppose that as you gaze about the room you see a table, some books, and papers. Ignore for now the fact that you immediately recognize these objects to be a table with books and papers on it. Concentrate on how the table looks to you: its top spreads out in front of you, stopping at edges beyond which lies unfilled space, leading to more or less distant chairs, shelves, or expanses of floor. The books and paper on the table top create shaped visual boundaries between areas of different color, within which there may be further variation of color or visual texture. Propelled by a slight breeze, a sheet of paper slides across the table, and you experience its smooth motion before it floats out of sight.

The aspects of visual perception to which I've drawn your attention are objects of study in contemporary perceptual psychology, which considers the perception of size, shape, distance, motion, and color. These phenomenal aspects of vision are sometimes contrasted with other, more typically cognitive aspects of perception, including our recognition that the objects in front of us include the table, books, and paper, our seeing that the table is old and well crafted, and our identifying the sheets of paper as the draft of an article in progress. All of these elements of our visual experience, whether characterized here as phenomenal or cognitive,[1] seem to arise effortlessly as we direct our gaze here and there. Yet we know that the cognitive aspects must depend on previously attained knowledge. We are not born recognizing books and tables, but we learn to categorize these artifacts and to determine at a glance that a table is an old one of good quality. What about the phenomenal aspects?

A persistent theme in the history of visual theory has been that the phenomenal aspects of visual perception are produced by inferences or judgments, which are

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unnoticed or unconscious. The persistence of this theme is interesting because, unlike our capacity to recognize a book or to identify something as the draft we have been working on, simply having a phenomenal experience of surfaces arranged in space and varying in color does not obviously require prior knowledge (even though describing such experience does). Nor does such experience seem on the face of it to be the product of reasoning or inference, such as we might employ in reasoning from the fact that our friend's books are lying open on the table to the conclusion that she is about. Nonetheless, from ancient times theorists have accounted for visual perception of the size, shape, distance, motion, and (sometimes) color of objects in terms of judgment and inference.

Hermann Helmholtz (1867/1910) provided the paradigm modern statement of the theory that visual perception is mediated by unconscious inferences. His name is frequently invoked by recent advocates of the theory (Barlow, 1990; Gregory, 1997, p. 5; Hochberg, 1981; Rock, 1983, p. 16; Wandell, 1995, pp. 7, 336). Helmholtz maintained that perception draws on the same cognitive mechanisms as do ordinary reasoning and scientific inference (1867/1910, 3: 28–29), and some theorists make similar comparisons (Barlow, 1974; Gregory, 1997, pp. 9–13). Others in the twentieth century have argued that perception is not literally inferential but is "like inference" or "ratiomorphic" (Brunswik, 1956, pp. 141–146), while still others postulate special-purpose inferential mechanisms in perception, isolated from ordinary reasoning and knowledge (Gregory, 1974, pp. 205, 210; Nakamura et al., 1995, p. 2; Rock, 1983, ch. 11).

In this chapter I examine past and recent theories of unconscious inference. Most theorists have ascribed inferences to perception literally, not analogically, and I focus on the literal approach. I examine three problems faced by such theories if their commitment to unconscious inferences is taken seriously. Two problems concern the cognitive resources that must be available to the visual system (or a more central system) to support the inferences in question. The third problem focuses on how the conclusions of inferences are supposed to explain the phenomenal aspects of visual experience, the looks of things. Finally, in comparing past and recent responses to these problems, I provide an assessment of the current prospects for inferential theories.

UNCONSCIOUS INFERENCES IN THEORIES OF PERCEPTION

The idea that unnoticed judgments underlie perception has been in the literature of visual science at least since the *Optics* of Ptolemy (ca. 160; see Ptolemy, 1989, 1996). In the past millennium, Alhazen (ca. 1030; 1989), Helmholtz (1867/1910), and Rock (1983) have offered explicit versions of the theory that perception results from unconscious inferences, in the form of (respectively) syllogisms, inductive inferences, and deductions in predicate logic. I will sometimes apply the term "unconscious inference" to all such theories, despite the fact that this technical term was introduced by Helmholtz (in a German equivalent), and despite variations in theorists' characterizations of such inferences, which are noted as needed. To give some sense of the range of theories, I begin by briefly examining two areas: size and distance perception, and color constancy.

PERCEPTION OF SIZE AT A DISTANCE

Prior to the development of new conceptions of optical information by Gibson (1966) and their extension by Marr (1982), theories of the perception of size relied on a common analysis of the stimulus for vision. One element of this analysis was contributed by Euclid (fourth century B.C.; 1945), who equated apparent size with the visual angle subtended at the eye. Five centuries later, Ptolemy argued that the perception of an object's size depends on both visual angle and perception or knowledge of the object's distance (1989, 1996, II.56). Surviving versions of his work illustrate the problem, as in Figure 5.1. The eye at E sees objects AB and GD under the same visual angle. If size were determined by visual angle alone, the two objects would appear to have the same size. But, Ptolemy says, when the difference in distance is detectable, such objects do not appear to be of the same size, but are seen with their real sizes (if our apprehension of the distance is accurate). Ptolemy was an extramission theorist who held that the crystalline humor (now known as the lens) is the sensitive element in the eye; he argued that the eye sends something out into the air, which allows the eye to feel the length of visual rays such as EA or EG (Ptolemy, 1989, 1996, II.26). Leaving aside the direct apprehension of distance, his position on the relation between visual angle and distance in size perception was accepted by subsequent authors, whether extramissionists or intromissionists, and whether they believed the crystalline or the retina is the sensitive element. Indeed, the geometrical analysis of the perception of size-at-a-distance was unaffected by Kepler's discovery that the lens causes inverted images to be formed on the retinas (see Hatfield & Epstein, 1979).

Ptolemy made only brief allusion to the judgments he posited for combining visual angle and distance in size perception. Nearly a millennium later, Alhazen (Ibn al-Haytham) developed an extended analysis of such judgments (Alhazen, 1989). According to Alhazen, the sense of sight perceives only light and color through "pure sensation" (1989, II.3.25). Alhazen was an intromission theorist, who held that the

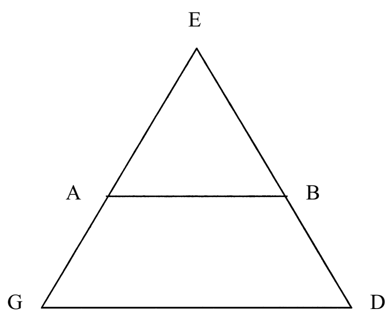

Figure 5.1

eye receives and transmits into the brain a cross-section of the visual pyramid, which constitutes a two-dimensional, point-for-point ordered record of the field of view (1989, I.6.22–32). In receiving this cross-section, the sense of sight also registers the direction from which the light and color comes (1989, II.3.97), and so has available the visual angle subtended by an object. The faculty of judgment then combines visual angle and distance information, through an "inference and judgment" that has become habitual, rapid, and unnoticed, to yield a perception of the size of an object that takes distance into account (1989, II.3.145–148).

Although the Euclidean equation of apparent size with visual angle was sometimes rehearsed in subsequent literature (e.g., Chambers, 1738, vol. 1, "Apparent magnitude"; Smith, 1738, 1: 31–32), Alhazen's view that size perception depends on rapid, unnoticed judgments that combine perceived distance with visual angle became standard doctrine. The judgmental account of size perception was repeated in diverse works, including those of Descartes (1637/1984–85, pt. 6), Rohault (1735, 1: 254), Porterfield (1759, 2: 377–380), Le Cat (1767, 2: 441–484, especially 471–484), and Gehler (1787–96, 2: 537–542). Berkeley (1709) rejected the judgmental account, arguing that the perceptual processes leading to size and distance perception are mediated by association, not by judgment or inference. Helmholtz combined aspects of the judgmental and associative accounts by proposing that size perception results from unconscious inference while giving an associative analysis of the process of inference itself (1867/1910, 3: 24, 236–237, 242, 434, 439). More recently, neo-Helmholtzians have used the language of inference without association (Gregory, 1997; Rock, 1983), and so in fact are in the tradition of Ptolemy and Alhazen. Others have developed a subjectivist probabilistic analysis of perceptual inference (Bennett et al., 1989).

COLOR CONSTANCY

The tendency of observers to perceive objects as having a constant size at various distances despite variations in the visual angle they subtend at the eye was dubbed "size constancy" in the twentieth century. A similar constancy occurs in the case of color. We typically see objects as having the same color (e.g., as being the same shade of blue) under varying conditions of illumination (e.g., in sunlight and under artificial lighting). There is, within limits, constancy of perceived color under variations in the intensity and color of the ambient light.

Alhazen produced an early description of color constancy. He observed that light reflected by an object is modified by the color of the object. As he put it, the quality of the light and of the object are "mingled" in the light that reaches the eye. Through a cognitive act, the perceiver is able to separate light and color:

> from perceiving the variations of lights falling upon visible objects, and from perceiving that objects are sometimes luminous and sometimes not, the faculty of judgement perceives that the colours in these objects are not the same as the lights that supervene upon them. Then, as this notion is repeated, it is established in the soul, as a universal, that colours in coloured objects are not the same as their lights. (Alhazen, 1989, II.3.48)

Alhazen indicated that through experience the faculty of judgment learns the characteristics of various forms of illumination (1989, II.3.50). He presumably held that it then is able to separate the color of the object from the quality of the illumination.

Unlike size and shape constancy, color constancy did not become standard fare in the early modern literature and was prominently discussed starting only in the nineteenth century.[2] Twentieth-century theorists have been fascinated by color constancy and achromatic brightness constancy, and some hold that the fundamental task of color perception is to extract information about the reflectance properties of objects from the light reaching the eyes. Specifically, many investigators formulate the task of the visual system in color constancy as that of recovering the spectral reflectance distribution of surfaces. A spectral reflectance distribution describes the percentage of ambient light of differing wavelengths reflected by a surface. It thus gives a precise physical description of the property of objects that gives them color: the disposition to absorb and reflect differing amounts of light as a function of wavelength. If we represent this distribution by R, let I stand for the spectral composition of the illuminant and L for that of the light reaching the eyes, then $L = I*R$. The problem for the visual system is to disambiguate I and R, which requires additional information or background assumptions.

Maloney and Wandell formulate the problem of color constancy as that of "estimating the surface reflectance functions of objects in a scene with incomplete knowledge of the spectral power distribution of the ambient light" (1986, p. 29). They show that approximate color constancy is possible if the visual system uses the fact that many natural surfaces can be modeled as linear combinations of a small number of "basis functions" (spectral reflectance functions), and if the range of ambient light is also describable as a linear combination of a small number of basis functions. That is, they suggest that the visual system makes limiting assumptions about the composition of natural illuminants and the shapes of surface reflection functions, which allow it to make nearly accurate estimates of distal surface reflectance distributions on the basis of the incoming light. On this view, the goal of color constancy is to generate a physical description of the spectrophotometric properties of distal surfaces. In a recent theoretical survey of linear models and other computational approaches to color constancy, Hurlbert (1998) endorsed this conception of the aim of color constancy, arguing that since "spectral reflectance is an invariant property of surfaces," it is therefore "plausible, if not perfectly logical, to assume that color constancy results from the attempt to recover spectral reflectance in the more general pursuit of object recognition" (1998, p. 283).

PROBLEMS FOR UNCONSCIOUS INFERENCE THEORIES

In order to count as a psychological or perceptual *theory*, a description of visual perception as involving unconscious inferences must do more than simply compare perceptual processes to the making of inferences. It must do such things as the following: describe the premises of such inferences, say how the premises come to be instantiated, account for the process of inference from premises to conclusions, describe the conclusions, and say how arrival at the conclusion constitutes or explains perception.

My own reflections on theories of unconscious perceptual inference indicate that they face (at least) three challenging problems. First, since they attribute unconscious inferences to the perceptual system, they must account for the cognitive resources needed to carry them out. Are the unconscious inferences posited to explain size perception and color constancy carried out by the same cognitive mechanisms that account for conscious and deliberate inferences, or does the visual system have its own inferential machinery? In either case, what is the structure of the posited mechanisms? This is the *cognitive machinery problem*. Second, how shall we describe the content of the premises and conclusions? For instance, in size perception it might be that the premises include values for visual angle and perceived distance, along with a representation of the algorithm relating the two. Or in color constancy, the conclusion might describe a spectral reflectance distribution. But shall we literally attribute concepts of visual angle and wavelength to the visual system? This is the *sophisticated content problem*. Third, to be fully explanatory, unconscious inference theories of perception must explain how the conclusion of an inference about size and distance leads to the experience of an object as having a certain size and being at a certain distance, or how a conclusion about a spectral reflectance distribution yields the experience of a specific hue. In other words, the theories need to explain how the conclusion to an inference, perhaps conceived linguistically, can be or can cause visual experience, with its imagistic quality.[3] This is the *phenomenal experience problem*.

COGNITIVE MACHINERY

Inferential theories typically posit an early sensory representation that differs from ordinary perception in its portrayal of various properties of objects. This original sensory representation, or sensation, might represent the shape of an object as a two-dimensional projection, so that a circle tilted away from the observer would be represented as an ellipse. Judgment or inference would then be called upon to mediate the change in representation from sensation to perception—in this case, to the perception of the true (circular) shape. The means for carrying out such inferences need to be specified, and the long history of inferential theories has seen various conceptions of the psychological processes thought to be involved.[4]

Although Ptolemy assigned a role to judgment in the apprehension of size, he provided little analysis of such judgments, simply referring them to a "governing faculty" or "discerning power" (1989, 1996, II.22–23, 76). Alhazen, by contrast, carefully analyzed the role of judgment in perception (1989, II.3.1–42). He contended that any perceptual act beyond the passive apprehension of light and color requires judgment or inference. Such acts include recognition of color categories (as opposed to mere sensations of color), perception of similarity or dissimilarity between objects, and perception of distance. Further, the judgments or inferences in question typically require comparison with previous instances (in the case of acts of recognition), or depend on previous learning (as when the known size of an object is used together with visual angle to judge distance). But since on his view the senses themselves do not judge, compare, or learn from previous instances (1989, II.3.17–25), the faculty of judgment must enter into perception.

Judgmental theories are faced with the fact that if perception relies on judgments, the judgments go unnoticed. In providing an explanation of this fact, Alhazen gave his fullest description of the judgments themselves. He began by contrasting the unnoticed judgments of perception with the visual theorist's careful and deliberate judgment that perception is judgmental (1989, II.3.26, 30, 36). The former judgments are rapid and habitual, the latter slow and reflective. In ordinary acts of perceiving we do not usually undertake the slow and reflective act of determining that, say, the perception of size requires a judgment. We therefore remain unaware that a rapid and habitual judgment has occurred. Alhazen nonetheless argued that unnoticed perceptual judgments are carried out by the same "faculty of judgment" involved in all judgments, including conscious ones. He further contended that perceptual judgments are equivalent to syllogistic inferences (1989, II.3.27–42). This identification of the process of perception with logical inference required further explanation, since perception is on the face of it not linguistic, whereas syllogisms apparently are.

Alhazen explained away this apparent dissimilarity between perception and inference by arguing that ordinary syllogistic inferences need not be properly linguistic, either. He contended that syllogistic inferences of the sort that can be expressed by a verbal syllogism need not be and typically are not actually produced in explicit linguistic form. He compared the rapid inferences of perception to cases in which we reach a conclusion rapidly, without consciously entertaining any logical steps. In one of his examples, upon hearing someone exclaim "How effective this sword is!" the listener immediately understands that the sword is sharp. She does so on the basis of the universal premise "Every effective sword is sharp". But the conclusion is achieved "without the need for words or for repeating and ordering the premisses, or the need for repeating and ordering the words" (1989, II.3.28). As Alhazen explained, in neither perception nor in the sword example (where one premise is given verbally) does the faculty of judgment need to formulate an explicit syllogism using words in order for it to carry out an inference. Rather, from the moment it understands the content of the particular premise, given that it remembers the content of the universal, it immediately understands the conclusion (1989, II.3.29). Alhazen would seem to suggest that in both sorts of case the faculty of judgment operates from a non-linguistic grasp of the content of premises and conclusions. Accordingly, he could claim that the same judgmental capacity which underlies our rapid understanding of everyday events serves as the cognitive machinery for perception. It carries out its operations by grasping content directly, and does not require linguistic form.

Five centuries later the philosopher and mathematician René Descartes, who wrote in an optical tradition continuous with Alhazen, appealed to unnoticed processes of reasoning in explaining size, shape, and distance perception.[5] In his *Optics* Descartes explained that the size of objects is judged "by the knowledge or opinion we have of their distance, compared with the size of the images they imprint on the back of the eye—and not simply by the size of these images" (1637/1984–85, 1: 172).

In the sixth set of Replies to Objections to the *Meditations*, he explained that these judgments, though rapid and habitual, are made "in exactly the same way as those we make now" (1641/1984–85, 2: 295). Descartes held that sensation yields an image whose elements vary (at least) in size, shape, and color. As infants, we gain habits for judging the size, shape, distance, and color of distant objects on the basis of such images. Apprehension of shapes, size, and color in the images, as well as other relevant information (such as eye position), provide the content of the minor premises of our perceptual inferences. The major premises are rules such as the one relating size, visual angle, and distance. Through repetition the transition from visual angle and distance information to the experience of an object's size becomes habitual and so is no longer recognized as being judgmentally based. Nonetheless, Descartes affirmed that both the unnoticed judgments of perception and the reflective judgments of the mature thinker are carried out by the same cognitive mechanism, which he described as the faculty of intellect.

The fact that Descartes and Alhazen (and many others) proffered a faculty analysis of mind has been seen as an embarrassment. Such analyses were later ridiculed in the manner of Molière's famous jest in which a doctor says that opium makes people sleepy because it has a dormitive virtue (Molière, 16xx/1965, p. 143). Such jokes, and the easy dismissal of faculty psychology, fail to distinguish two potential aims of faculty theories, only one of which is sometimes laughable. Molière's joke plays on the idea that a physician has sought to *explain* how opium puts people to sleep by appealing to its dormitive virtue, rather than simply to *describe* its power to do so. Now it may well be that some of those ascribing "faculties" or "powers" to things understood this to be an inherently explanatory act, as it may be in some circumstances (see Hutchison, 1991). But in other cases talk of powers is descriptive and taxonomic, and amounts to a nontrivial parsing of the real capacities of things. In the case of Alhazen's and Descartes' appeal to the intellectual faculty, Molière's joke would apply to them only if they tried to explain how the mind reasons by saying it has a faculty of reason. Instead I see their efforts as part of an attempt to analyze the mind into a set of primitive capacities that are then used to explain particular abilities. So, in the case of size perception, a seemingly pure sensory ability is explained by appealing to an interaction between the capacity for rational inference and the passive reception of sensory information. The mind's capacity for rational inference is invoked to explain how sensations are transformed or supplanted to yield perceptions of shape. The judgmental capacity itself is not explained.

One might expect that since Descartes argued that the same intellectual faculty is involved in perception and other reasoning he would hold that perceptual judgments are subject to modification and correction in relation to consciously entertained knowledge. But he (in effect) admitted the opposite. In the familiar illusion of the straight stick that appears bent when half submerged in water, Descartes held that the appearance results from unnoticed judgments (habits of judging visual position) learned in childhood (1641/1984–85, 2: 295–296). When an adult suffers the illusion, the intellect operates by habit, without forming a new judgment for the occasion. At the same time, the intellect is able, by reflecting on its tactual experience, to know that the stick is really straight. Descartes wrote with full appreciation of the fact that this judgment does not affect the appearance of the stick. In general, the unnoticed judgments he posited to explain perception were not open to conscious revision. Later, Immanuel Kant drew explicit attention to the fact that the moon illusion is impervious to knowledge, presumably because the judgments that underlie it are habitual and unnoticed and so not open to scrutiny or correction (Kant, 1787/19xx, pp. 384, 386; see Hatfield, 1990, pp. 105–106).

Berkeley introduced a new position into the psychology of visual perception when he sought to replace the accepted judgmental account of the processes underlying perception with an associational account. Motivated in part by a desire to support his immaterialist metaphysics (Atherton, 1990, ch. 12), Berkeley rethought visual theory from the ground up, focusing on the psychology of vision. He began from a point that was shared by intromission theorists, that distance is not "immediately sensed" (as Ptolemy, an extramissionist, had held), but must be perceived via other cues or sources of information, whether contained in the optical pattern or received collaterally (as in feelings from the ocular musculature). In Berkeley's terms, since distance is not directly perceived, it must be perceived "by means of some other idea" (1709, sec. 11). From there, he mounted a frontal assault on the widely shared theory that distance is perceived via "lines and angles", as when distance is allegedly perceived by reasoning using the angle–side–angle relation of a triangle and the perceived convergence of the eyes, or using the known size of the object together with perceived visual angle. Berkeley's argument unfolded in two steps. First, he maintained that "no idea which is not itself perceived can be the means for perceiving any other idea" (1709, sec. 10). Second, he denied that we are ever aware of "lines and angles" in visual perception: "In vain shall all the mathematicians in the world tell me that I perceive certain lines and angles which introduce into my mind the various ideas of distance so long as I myself am conscious of no such thing" (1709, sec. 12). He explained the perception of distance by means of several cues, including: (1) the interposition of numerous objects between the viewer and the target object (1709, sec. 3; 1733, sec. 62); (2) faintness of the target (1709, sec. 3; 1733, sec. 62); (3) visible magnitude in relation to known size (1733, sec. 62); (4) height in visual field (objects further off are typically higher in the field of vision but below the horizon; 1733, sec. 62); and (5) the muscular sensation accompanying the rotation of the eyes during convergence (1709, sec. 16; 1733, sec. 66).

Counterparts to each of these five cues were in the optical literature. Berkeley departed from previous accounts in contending that in none of the cases is there a "rational" or "necessary" connection between cue and perceived distance. The various factors listed in (1) to (5) serve, in his view, as so many arbitrary visual signs, whose meanings with respect to tactually perceived distance must be learned. For example, for angle–side–angle reasoning in distance perception he substituted an acquired association between ocular muscle feelings and tactually perceived distance (1709, secs. 12–20). Such associations, or connections of "suggestion", are formed between two ideas that regularly co-occur. They are not the result of a cognitive connection judged to exist between the perceived contents of the ideas, but arise solely from repeated co-occurrence. But, Berkeley argued, connections made through blind habit are distinct from (content-sensitive) inferences (1733, sec. 42). His process of habitual connection or suggestion is equivalent to what became more widely known as the association of ideas.

Berkeley is the originator of the associationist account of distance perception. He also made famous the position that we "learn to see" objects in depth at a distance. In the 150 years after he wrote, various judgmental or associationist accounts of perception were proposed. Some authors took the analysis of perceptual experience into sensational ingredients even further than Berkeley, and attempted to show how spatial representations could be derived form aspatial or punctiform elementary sensations via association (Steinbuch, 1811) or via a combination of reasoning and association (Brown, 1824, lecs. 22–24, 28–29). Others adopted the radical analysis of spatial perception into aspatial elements, but posited innate laws of sensibility (distinct from judgment and inference) to govern the construction of spatial representations (Tourtual, 1827). In each case, the authors supposed that each nerve fiber in the optic nerve produces a single sensation, varying only in quality and intensity. Meanwhile, the textbooks repeated the older account that size perception starts from an innately given two-dimensional representation and proceeds via unnoticed judgments (see Hatfield, 1990, ch. 4).

In the latter half of the nineteenth century, Helmholtz formulated the classical statement of the theory that spatial perception results from unconscious inferences. The primary statement of the theory occurred in section 26 of his *Handbuch der physiologischen Optik* (1867/1910). Helmholtz combined the associative and inferential accounts by giving an associational account of inference. He compared the inferences of perception to syllogisms in which the major premise has been established inductively. He adopted the radical punctiform analysis of visual sensation. In his account, stimulation of any given retinal nerve fiber initially yields a sensation that varies in only three ways: hue, intensity, and "local sign". A local sign is a qualitative marker peculiar to each nerve fiber (Helmholtz 1867/1910, 3: 130, 435–436). These signs originally carry no spatial meaning, but through coordination with bodily motion and sensations of touch (which are assumed to have spatial meaning) the observer acquires the ability (unconsciously) to localize sensations on the basis of local signs. For example, the observer might acquire a universal premise that light hitting the right side of the retina comes from the left (1867/1910, 3: 24). Helmholtz described the process of learning the spatial meaning of local signs in terms of active testing, and compared it to hypothesis testing in science. But in both cases he conceived the psychological processes that yield inductive conclusions from testing as associative. In the case of learning the meaning of local signs via touch, Helmholtz maintained that "while in these cases no actual conscious inference is present, yet the essential and original office of an inference has been performed" (1867/1910, 3: 24).[6] The inference is achieved "simply, of course, by the unconscious processes of the association of ideas going on in the dark background of our memory" (1867/1910, 3: 24). In this way, Helmholtz assimilated inference to association.[7]

The most explicit recent analysis of unconscious inferences in perception is due to Irvin Rock (1983). Rock identified four sorts of cognitive operations at work in perception: (1) unconscious description, in the case of form perception (1983, ch. 3); (2) problem solving and inference to the best explanation, in the case of stimulus ambiguity or stimulus features that would yield unexplained coincidences if interpreted literally (1983, chs. 4–7); (3) relational determination of percepts, such as those involved in perceiving lightness and relational motion through the interpretation of relational stimulus information in accordance with certain assumptions (1983, ch. 8); and (4) deductive inference from a universal major premise and an unconsciously given minor premise, used to explain the constancies (1983, ch. 9). All four operations posit unnoticed acts of cognition. The first operation is not inferential, since it merely involves description; but it illustrates Rock's view that the cognitive operations of perception are based upon internal descriptions in an (unknown) language of thought (1983, p. 99). Rock's formulations are cautious: he says perception is "like" problem-solving and deductive inference (1983, pp. 1, 100, 239, 272, 341). But his account is not merely ratiomorphic. In the end, he held that perception does involve unconscious reasoning, including both inductive formation of rules (1983, pp. 310–311) and deductive inference from rules. The cognitive machinery for such inferences operates in a linguistic medium and follows the rules of predicate logic (1983, pp. 99, 272–273). The rules governing perceptual inference may be either learned or innate—Rock rejected Helmholtz's emphasis on learning (1983, pp. 312–316).

Rock's cautious formulations reflect the fact that he recognized a sharp divide between the processes of perception and the processes that underlie conscious describing, problem solving, rule-based calculations, and deductive inference. Some separation of this kind is demanded by the fact known to Descartes, Kant, and others: that the perceptual process often is impervious to knowledge, as when visual illusions persist despite being detected. It is a seeming paradox for cognitive accounts of perceptual processing that perception is isolated from and inflexible in the face of other cognitive factors, such as the conscious knowledge that the lines are the same length in the Mueller–Lyer illusion (Rock, 1983, pp. 336–337). Rock responded by proposing a strict separation between ordinary cognition and the cognitive processes underlying perception. He separated the knowledge relevant to perception into two divisions: immediate stimulus-based information, and unconscious descriptions, concepts, and rules (1983, p. 302). The unconscious processes typically take into account only such information about a particular stimulus as is available in current stimulation; he called this the condition of "stimulus support" (1983, p. 303). Achromatic color illusions, such as the Gelb effect—in which a black circle appears white if it alone is illuminated by a spotlight in an otherwise dark room—disappear when a white contrast paper is moved into the light, but reappear as soon as the stimulus support provided by the white paper is removed. Apparently the perceptual system is caught up in the moment! Rock further postulated that the concepts and rules used in the unconscious cognitive operations of perception are isolated from central cognitive processes of description, categorization, and hypothesis formation (1983, pp. 306, 310, 313, 315). He in effect posited a special-purpose domain of concepts, rules, and reasoning to support the processes of perception.

Rock supported his comparisons of perception to problem solving and inference with an extensive program of empirical research. Others, pursuing general theories of mind in the fields of artificial intelligence and cognitive science, have used perception as an example of a mental process that fits their general model. Such theoreticians have of necessity been explicit about the cognitive machinery. They have sought to provide an explanation of the cognitive capacities that were used as explanatory primitives by earlier theorists.

Fodor (1975) was an early and articulate advocate of the theory that the mind is importantly similar to a general-purpose digital computer and that its cognitive operations are carried out in an internal language of thought. He compared the language of thought to the machine language in a computer (1975, pp. 65–68). Just as a computer is "built to use" its machine language, and so need not acquire it, the brain comes with its own built-in language. This language then serves as the medium in which perceptual hypotheses are framed and tested. Although I agree with Crane (1992, p. 148) that it remains an open question whether one absolutely must posit an internal language in order to account for the inferential abilities of humans and other cognitive agents, Fodor's posit of a language of thought does provide a powerful model for unconscious inferences. The inferential machinery of perception is a full-scale language, with syntactically based inference rules for drawing conclusions from premises.

Fodor (1983) took into account the same fact that we have found in Rock (1983), that perceptual inferences are relatively insulated from the consciously available knowledge of the perceiver. Largely in response to this fact, Fodor adopted the position that perceptual processes take place in cognitively insulated modules. Although Fodor (1983) did not describe precise structures for his innate machine language, he gave no reason to suppose that the language-of-thought of the various perceptual modules is the same as that of other cognitive modules. Theory would dictate that the output of such modules must be usable by subsequent processes. But there is no necessity for the postulated linguistic medium that underlies the processes of shape perception to have precise analogues of the shape vocabulary of the central cognitive processes of shape identification. The modularity thesis and its counterpart in Rock (1983) undermine the assumption that perceptual inferences are one with ordinary thought.

Acceptance of the modularity thesis forsakes the (perhaps implausible) parsimony of traditional inferential accounts. From Alhazen (ca. 1030/1989) to Helmholtz (1867/1910), theorists had posited a unity between the mechanisms underlying perception and those underlying thought more generally. The notion of cognitively isolated (Rock, 1983) or insulated (Fodor, 1983) modules replaces this simple unity with distinct cognitive mechanisms and processes for the postulated inferences of perception and the inferences of conscious thought. This separation of processes places a new burden on contemporary inferential theories, for now they must account for the cognitive resources employed in perception independently of the general cognitive resources of perceivers.

SOPHISTICATED CONTENT

Theorists who posit that perception occurs via inferences from sensory premises to perceptual conclusion take on a commitment to the psychological reality of the premises and conclusions. This in turn requires a commitment that the visual system, governing agency, faculty of judgment, or the intellect has the resources to think the premises and conclusions. If perceptual processes are indeed unnoticed judgments, then the cognitive faculty that carries them out must be able to comprehend the content of such judgments. In more modern terms, if unconscious processes are posited that involve descriptions, then the perceptual system or its auxiliary must have the conceptual resources to express the content found in the descriptions.[8]

Early theorists recognized the need for supplying conceptual resources to the visual system by bringing the faculty of judgment or the intellect into perception. Thus, when Alhazen argued that one and the same intellectual faculty operates in everyday cognition and in the unnoticed judgments of perception, he presumably assumed that the faculty has the same conceptual resources available in both cases. Alhazen held that over the course of a lifetime, we learn to recognize instantaneously all of the visible properties of things, without being aware of the acts of recognition or judgment involved (1989, II.3.42). He thus believed that the perceiver's full range of concepts is available for perception.

Descartes also maintained that sensory perception relies on habitual judgments of the intellect. Because he attributed innate ideas to the perceiver, one would expect him also to believe that the intellect has all its concepts available for perceptual inference. Nonetheless, he recognized a *de facto* limitation on the conceptual vocabulary expressed in unnoticed perceptual judgments. He suggested that we are unable to revise our habitual judgment, formed in childhood, that objects contain something "wholly resembling" the color we experience (1644/1984–85, I.70–72). Because the childhood judgments have become frozen as unnoticed habits, we are unable to use the concepts of the true physics, discovered through mature intellectual reflection, to revise our early judgments about resemblance. As befits the infantile formation of unnoticed perceptual judgments, their conceptual content is restricted by comparison with the sophisticated concepts of the metaphysician and natural philosopher.

By contrast, Berkeley's associationist account avoided any need for the unnoticed processes of perception to use sophisticated conceptual content, because the processes he described make no use of conceptualized content of any sort. In his account of size perception, visual ideas corresponding to visual angle give rise to perceptions of size as a result of acquired associations among visible magnitudes (visual angle), visual cues for distance, and tactual perceptions of distance. The elements to be associated are related to one another as arbitrary signs. In his view, there is no intelligible connection between cues such as ocular muscle feelings and tactual distance. The mind does not perceive distance because it understands that certain muscle feelings result from accommodations of the lens that vary with distance; rather, the perceiver is simply trained by experience to associate specific muscle feelings with specific tactual distances.

Berkeley contrasted his account with that of Descartes, in which a perceiver might make use of intelligible relations among ideas, as in angle–side–angle reasoning about distance.[9] He challenged the proposal that perceivers make use of geometrical lines and angles in everyday perception by asserting that most people do not possess the requisite notions. He denied that lines and angles are "ever thought of by those unskillful in optics" (Berkeley, 1709, sec. 12). Ordinary perceivers therefore cannot bring the technical concepts of optics to bear in unconscious or unnoticed descriptions of the objects vision. He further argued that since perceivers (whether geometrically sophisticated or not) are not conscious of reasoning from lines and angles, they do not reason from them. On the face of it this argument seems weak, for Berkeley himself posited unnoticed processes of suggestion (or association). But he might argue that it is plausible for at least some noncognitive habits to remain unnoticed throughout both their formation and operation, while sophisticated geometrical inferences could not. Some noncognitive motor habits are surely formed without our even knowing we have them (e.g., habits of gait). By contrast, we are all familiar with the ways in which we at first have to pay attention to new cognitive tasks, before they become habitual. But the adherents of unconscious inference posit inferential acts of which we seem never to have been aware. Hence Berkeley might be proposing that the sort of sophisticated mathematical reasoning ascribed by the "natural geometry" argument is not the sort of thing that could become habitual if it had not first been part of a conscious reasoning process. By contrast, his unnoticed processes are habits formed through blind acts of association, which serve to connect ideas to one another simply as a result of their temporal co-occurrence.

Early nineteenth-century theorists, such as Steinbuch (1811) and Tourtual (1827), developed an extensive analysis of visual perception which described its initial content as phenomenal and unconceptualized. They described the sensational elements of visual perception as unspatialized punctiform sensations varying in hue and intensity, and then gave a detailed account of how psychological operations create spatial representations from this nonspatial sensory core (see Hatfield, 1990, ch. 4). Both theorists posited noncognitive operations, distinct from the judgment and intellect, that order sensations by quality and intensity. Steinbuch posited learned associations among muscle sensations, built up slowly, starting *in utero*, to create a mapping from retinal fibers to two-dimensional representation (allegedly) on the basis solely of phenomenal similarity and temporal contiguity.[10] Tourtual posited innate laws of sensibility, also operating on the qualitative character of elemental sensations. In each case, there was no question of sophisticated conceptual content doing the ordering, since the operations were conceived as preconceptual.

We have seen that Helmholtz also posited aspatial elemental sensations, but that he characterized the transformative processes as at once associational and inferential. His contention that unconscious inferences could be explained psychologically as resulting from associational processes meant that his analysis of the psychology of perception could focus on the phenomenal character of sensations, since association operates on phenomenally characterized sensations. His description of the resultant perceptual images as the conclusions of inferences introduced a certain tension into his account, because of the apparent difference between perceptual images and the linguistic conclusions of logical inferences. But Helmholtz held that there is "only a superficial difference between the inferences of logicians and those inductive inferences whose results we recognize in the intuitions of the outer world we attain through our sensations". (By "intuition" he means a perceptual image.) He continued: "The chief difference is that the former are capable of expression in words, while the latter are not, because instead of words they deal only with sensations and memory images of sensations" (1896, 1:358; 1995, p. 198). So the content of perceptual premises and conclusions are sensations and images.[11] What about the major premises, the universal rules for localizing sensations in space? These are associations among sensations, forged through relations of contiguity and resemblance. They operate over the phenomenal properties of sensations, including, for vision, punctiform sensations varying in hue, intensity, and local sign, and feelings of innervation of the ocular (and bodily) musculature. Helmholtz's associationist account of unconscious inference allowed him to restrict the content and operation of perceptual inferences to the phenomenal properties of sensations and phenomenal relations among sensations, operated upon by conceptually blind laws of association. There is no need to attribute sophisticated content to Helmholtzian perceptual inferences.

In the twentieth century, appeal to laws of association operating over aspatial sensations characterized by phenomenal qualities has fallen out of favor.[12] The most developed of today's inferential accounts posit underlying language-like representations to mediate the inferential connections. As we have seen, theorists such as Rock (1983) and Fodor (1983) posit special cognitive subsystems for perception. This allows them to restrict the range of concepts attributed to the subsystem. Rock's isolated cognitive domain requires only a comparatively modest conceptual vocabulary for describing sensory aspects of objects, such as form and other spatial characteristics. His problem-solving and inference-formation operations work on these perceptual features. A typical Rockian inference might combine information about the egocentric tilt of line with information about head-tilt to yield a perception of real-world orientation, or combine visual angle and distance information to yield a perception of size (Rock, 1983, 273–274). The descriptive vocabulary here is impoverished relative to general cognition, focusing as it does on spatial properties in egocentric and environmental frames of reference (1983, 331–332). Fodor's (1983, pp. 86–97) point about the conceptually "shallow" outputs of perceptual modules provides a more general framework for attributing special-purpose, modest conceptual vocabularies to the visual system.

Other computational accounts of vision strain the bounds of plausibility in ascribing perceptual inferences with sophisticated content. Difficulties arise especially for certain computational models of color constancy. We have seen that Maloney and Wandell describe the task of the visual system in color constancy as that of "estimating the surface reflectance functions of objects in a scene with incomplete knowledge of the spectral power distribution of the ambient light" (1986, p. 29). If one takes these authors at their word, they attribute a rich conceptual vocabulary to the visual system, including sophisticated physical concepts such as surface reflective function (spectral reflectance distribution). It seems implausible to attribute such content to encapsulated processes of early vision. The human species came upon these physical concepts only late in its development, after the time of Newton. Yet the species developed trichromatic color vision hundreds of thousands of years earlier (Goldsmith, 1991). So the mechanisms and processes that yield our trichromatic color vision, whether viewed as occurring in a language of thought or via nonlinguistic processing mechanisms, could not have had access to sophisticated physical concepts. And if they are encapsulated, as seems certain, then these processes still would not have access to such concepts (even if the perceiver has "central system" knowledge of physics). Consequently, the output of the color system does not conceptually encode such notions.

There is an alternative way of construing the statements of Maloney and Wandell (1986), which would make sense of their saying that the visual system contains information about spectral reflectance distributions, but which would cut against inclusion of their color constancy model in the family of "unconscious inference" theories. The mathematical notion of information—developed by Shannon (1948) and others and brought into perceptual theory in the 1950s by Attneave (1954)—provides a way of describing the information contained in a signal (or a perceptual state) without needing to attribute knowledge of or access to that information to the containing system. Dretske (1981) has provided a thorough analysis of the use of this notion of information to describe perceptual content. On this way of viewing things, if perception of a particular hue is strictly correlated (under appropriate environmental background or "channel" conditions) with a particular reflectance distribution in the stimulus, then perception of that hue carries the information that the reflectance distribution is present (but see Hatfield, 1992a). It can do so without the perceiver even knowing what a reflectance distribution is—for, as Dretske explains (1981, ch. 9), this notion of information is distinct from conceptual meaning. But, if so, then any supposition that the visual system "estimates" the physical properties of the distal stimulus from its "knowledge" of retinal values is thereby undercut. Inference and estimation are cognitive acts. Our best philosophical and psychological accounts of such acts suggest that they occur through operations over premises that encode knowledge conceptually (Crane, 1992, pp. 142–149; Smith, 1995). But the color constancy models mentioned above make no provision for that sort of cognitive act. Hence, they would appear to be better classed as cases of the metaphorical application of an inferential model to perception. The computational aspects of color vision would then be understood as cases of informational combination and transformation via noncognitive mechanisms.

PHENOMENAL EXPERIENCE

The aim of much visual theory has been to explain the contents of phenomenal experience, the "way things look". This has been the case in central areas of perceptual theory, such as the perception of spatial and chromatic aspects of things. To meet this explanatory aim an unconscious inference theory of perception must provide some explanation of how inferences yield phenomenal experience. A complete explanation of the production of phenomenal experience would presuppose a solution to the mind–body problem. It would require explaining how perceptual processes in the brain produce phenomenal experience, which is a difficult problem. But less ambitious explanatory agendas are available. One might, for instance, posit psychophysical linking propositions (Teller & Pugh, 1983), or psychoneural linking hypotheses (Hatfield & Pugh, unpublished), to bridge the gap between the brain states and experience, without thereby seeking to explain the ontology of such links. Similarly, one might treat the conclusions of inferences as a certain kind of data array (Marr, 1982, ch. 4; Tye, 1991, ch. 5), and use the representational content of the data array to explain imagistic experience.

Alhazen sought to explain the looks of things, as is apparent in his distinction between size as a function of visual angle and (phenomenally) perceived size. I think he would have had little problem explaining the looks of things via judgment, since on his view the judgments of perception are not linguistic and they operate directly on phenomenally given materials. He was not, however, explicit on how inferences operate on sensations to produce the ultimate looks of things. Two possibilities suggest themselves: inferences operate either to transform the representation of spatial properties in sensation into a representation of perceived spatial properties, or inferences operate to create a new representation exhibiting the perceived properties. Leaving aside metaphysical difficulties about the status of phenomenal experience itself—which are common to all theories and remain unresolved—no special problem of phenomenal experience arises for Alhazen.

As we have seen in the previous section, perceptual theory from Descartes to Helmholtz retained phenomenally-defined theoretical primitives. Descartes followed Alhazen and the optical tradition in conceiving the premises of perceptual inferences as graspings of phenomenally given sensations, and the conclusions of such inferences as phenomenal experiences. The associationist tradition developed a finer analysis of the processes by which the spatial representations of perceptual experience are constructed from sensory elements. Aspatial sensory elements are conjoined associatively to yield phenomenal representations of a three-dimensional visual world. Although Helmholtz adopted an inferential account of perception, he offered a phenomenalist account of the conclusions of perceptual inferences. Since he considered the conclusions of such inferences to be images, he left no gap between conclusion and experience.

The notion that perceptual psychology attempts to explain the "looks of things" was fundamental to the work of the Gestalt psychologists (Köhler, 1929, ch. 1; Koffka, 1935, ch. 1 and pp. 73–76), who used a principle of spatial isomorphism to explain how brain states are related to experience. They argued that experience of voluminous shaped regions is produced by (or identical with) three-dimensional isomorphically shaped areas in the brain, so that the experience of a sphere is caused by a spherical region of brain activity. Although the Gestaltists' brain theory has been rejected, many investigators hold that phenomenal experience is a primary explanatory object for perceptual theory (Cutting, 1986, p. 4, ch. 15; Gibson, 1971, p. 4; Goldstein, 1996, pp. 15, 29; Natsoulas, 1991), though some disagree (for instance Kauffman, 1974,

p. 16). Despite this explanatory goal, no detailed explanations of how the processes posited in perceptual theory yield the phenomenal aspects of sense perception are yet extant. The strategy of Helmholtz and his predecessors, of maintaining that perceptual experience is constructed from phenomenally characterized sensations, is no longer accepted. But no generally accepted model of how brain events are related to phenomenal experience has arisen to replace the one-fiber, one-sensation doctrine. Explaining phenomenal experience itself remains an unrealized goal of modern perceptual (and cognitive) theory.

Some proposals have been made. Wandell has offered the intriguing suggestion that phenomenal color, or color appearance, "is a mental explanation of why an object causes relatively more absorptions in one cone type than another object" (1995, p. 289). Although providing a detailed theory of how information about surface reflectance might be recovered (1995, ch. 9), he does not offer anything further on the problem of how an estimation of a surface reflectance's relative effect on a cone type yields the experience of color.

Others have suggested that percepts are generated from early representations in the processing stream via cognitive, language-mediated processes. In his 1975 book, Fodor conjectured that perceptual processes are initially carried out as operations on sentence-like objects, with images subsequently being constructed from symbolic descriptions. He speculated that this construction might be likened to a "digital to analog" conversion (1975, p. 193, n. 26), but said nothing further about how this might occur.

Rock (1975, ch. 11) was acutely aware of the need for and difficulty of explaining perceptual experience. He considered percepts themselves to be "analogic, picturelike, and concrete" (1983, p. 52), by contrast with descriptions of percepts framed in the language of thought. He clearly stated (1983, p. 272) that the outcome of perceptual inference "is a percept rather than a conclusion" (by which he meant a linguistically-expressed conclusion). But he did not say how such percepts are generated from the unconscious descriptions found in perceptual inferences.

Michael Tye (1995, ch. 5) has most fully elaborated a conception of how a language-like symbolist view of perceptual and imagistic representations might explain phenomenal experience. Drawing on Marr (1982, ch. 4), he proposed that imagistic representations be conceived as symbol-filled arrays. Such arrays are formed from a matrix of cells that represent distal surface locations in two dimensions. The individual cells (matrix units) are addressed by the relative positions they represent, corresponding to columns and rows. The physical locations of the cells in the brain is irrelevant on Tye's view; rather, the arrays are treated as having imagistic content in part because the processes operating over them treat the cells with numerically adjacent column and row addresses as if they were adjacent (1995, p. 94). Further imagistic content is provided by symbols within the cells, which represent the depth, color, intensity, and surface texture of a distal point (small area). Full image content arises only when the arrays are associated with a sentential interpretation, such as "this represents a pig". Our imagistic experience arises from the fact that we have symbolic representations of spatial, chromatic, and categorial aspects of things, which we access by symbol-reading processes that treat the areas represented in cells which have contiguous addresses as being distally contiguous. An image is constituted by thousands of words, containing labels for spatial location attached to descriptions of depth and color. The matrix arrays are not analog, but they do represent spatial relations of small areas that may be treated as forming a continuous surface.

Tye's view has the advantage that it can draw on ongoing work seeking to explain the production of the symbol-filled array, including Marr's (1982) explanations of the production of the "$2\frac{1}{2}$-D sketch" (which was a model for Tye's symbol-filled array). But there remains a question of why Tye believes the postulated symbol-filled array explains phenomenal experience. It is the array's representational or informational content that does the work for Tye (1991, pp. 136, 142), and not any relation to neural states or to nonsymbolic mental states. Specifically, Tye posits that phenomenal experience arises when we have symbolic-matrix representations of distal states that are ready to be taken up cognitively (e.g., brought under description). As a description of the role that phenomenal experience itself might play in perception and cognition, as providing representations for further cognitive response, this strikes me as a good description. But Tye intends it to explain our (apparent) phenomenal experience itself. In the case of color vision, he says that phenomenal blue simply arises when we have symbolic states that represent distal blue things (1991, p. 133; 1995, pp. 145–147). He rejects sensations, qualia, or other mental items that might present phenomenal blue (1991, ch. 7). The phenomenal blue, he explains, is not in the head, but is on the surfaces of things. He is aware that the property possessed by some distal things, which makes them blue, is the physical property of having a spectral reflectance distribution that falls within a certain class of such distributions. It is his view that a nonconceptual representation of this property in the visual system at a stage ready for conceptual description just is the perception of the distal blue surface in a phenomenally blue manner (1995, pp. 137–143). No further explanation of the phenomenal content is given.

Kosslyn (1995) surveyed the literature on visual imagery and proposed that there are two sorts of symbolic systems in the head: propositional and depictive. Propositional representations consist of discrete symbols of various classes (signifying entities, relations, properties, and logical relations), with rules for combining them. The spatial relations among the symbols have only an arbitrary significance. Property symbols may always be written to the right of the entity symbols to which they apply, but this does not mean that they are on the right hand side of the entity! By contrast, spatial relations of symbols in the depictive style of representation have that sort of nonarbitrary spatial meaning. The depictive style of representation involves only two classes of symbols, points (small punctiform areas) and empty spaces. The combination rules are merely that the symbols must be put in spatial relation to one another, and any relation is allowed (Kosslyn 1995, pp. 280–282).

It is misleading for Kosslyn to label the points that compose his depictive representations "symbols", since no operations are defined which respond to the points based on variation in their form, as happens in classical symbol-processing models (Fodor, 1975, ch. 2; Pylyshyn, 1984, ch. 3). Indeed, Kosslyn seems to assume that noncognitive processes yield the depictive structure of the basic parts of images. At least, in Kosslyn's mature theory there is no discernible commitment to positing cognitive or inferential processes to generate the spatial relations internal to image parts.[13] Interpretive processes then operate over spatial relations found in the image, which is composed of points in spatial arrangement (Kosslyn, 1995, pp. 273–275). The images are spatially concrete. The potentially continuously varying spatial relations among points give them their content. Because continuous variation in spatial relations is permitted, the medium is analog.

Originally, Kosslyn (1983, p. 23) understood the spatial relations found in images to be a functional space consisting of paths of access among address labels for represented points as read by processing mechanisms (a conception similar to Tye's symbol-filled array). Neuroscientific findings led him to suggest that these functional relations may indeed be realized by real spatial relations in the cerebral cortex (Kosslyn, 1995, pp. 290–292). Although Kosslyn does not explicitly say so, he appears to suggest that the spatial relations experienced in images result from isomorphic spatial relations in the brain, presumably in accordance with a linking proposition (Teller & Pugh, 1983). This proposal is similar to the Gestalt psychologists' earlier postulation of a spatial isomorphism between brain events and the structure of perceptual experience (Köhler, 1929, pp. 61–66, 142–147; Koffka, 1935, pp. 56–67; see also Scheerer, 1994). An extension of Kosslyn's theory in this direction would yield a noncognitive principle of explanation for the spatial structure in phenomenal experience via spatially isomorphic patterns of activity in the brain. If we treat linking propositions as hypothesized laws of nature, then the existence of spatially organized phenomenal experience is explained as the lawful product of the spatial properties of activity in certain areas of the brain.

Stepping back, it would seem that the most promising route for inferential theories to explain the spatial structure of perception is the postulation of language-like inferential processes that produce analog or depictive representations. If we give due regard to Rock's and Fodor's point about encapsulation, then these inferential processes would take place in a conceptually impoverished vocabulary, perhaps limited to spatial and chromatic properties and focusing on the production of a representation of the spatially articulated surfaces of objects via a symbol-filled array.

At present there is no worked out account of how an encapsulated inferential process would produce either a genuinely analog representation or one of Marr's arrays. Moreover, there are rival accounts of processing mechanisms that could yield analog representations without relying on a language-like or inferential medium. Historically, the Gestalt theory of self-organizing dynamical systems in the brain provided a noncognitive basis for generating perceptual results (Hatfield & Epstein, 1985, pp. 178–179). In more recent times, connectionist models provide a conception of perceptual processing in which perceptual information can be combined in regular ways to yield analog representations, without positing cognitive operations such as inference (Hatfield, 1988, 1991a, b). To the extent that these rival accounts provide a means for modeling the production of analog representations, they go further than inferential accounts in addressing the production of the spatial structure of phenomenal experience.

CONCLUSION

Highly articulated theories of unconscious inference in perception have been extant for a 1000 years (since Alhazen, ca. 1030), and have been widespread for nearly 400 years (following Descartes, 1637). The structure of the theories has varied, as can be seen by reviewing their various theoretical primitives, that is, what is taken as given as opposed to what needs an explanation. Prior to the nineteenth century, the inferential machinery required to make unconscious inferences was taken as a given: it was the intellect, or the faculty of judgment. Subsequently, various proposals were made to explain this machinery: via association in the case of Helmholtz, via an unconscious language of thought in the case of Fodor and Rock. Prior to the late twentieth century, it was assumed that the same concepts are employed in unconscious inferences and conscious thought. In recent decades, the fact that perception is often impervious to consciously entertained knowledge has led investigators to posit a separate, encapsulated domain of perceptual processing, which must then be supplied with its own cognitive resources. Finally, prior to the twentieth century the primitive elements posited in perceptual theories were sensations with phenomenal properties. Processes were then posited to augment or transform those properties, for example, by ordering the sensations spatially. In the twentieth century such sensational primitives have been rejected. For contemporary unconscious inference theories, the problem then arises of explaining how linguistic inferential processes can yield the phenomenal aspects of perceptual experience.

The literature of artificial intelligence and computational accounts of vision is replete with talk of "descriptions" and "inferences". In some cases, such as Marr (1982, pp. 342–344), the approach has been allied with a Fodorean conception of symbolic computation. But in many cases no real support is given for such talk. It is as if causal transitions among information-bearing states of a system that occur according to rules and that lead to appropriate outcomes should be counted as inferences on the face of it, without supplying cognitive machinery or making provision to explain the conceptual content found in the inferences. As we found with the work on color constancy discussed above, such discussions are best classed as metaphorical uses of the concepts of inference and description. They are not inferential theories of perception, but theories of information transformation in perception.[14] The problem with taking these positions as literal inference theories is that they make no provision for the cognitive resources that would be needed to sustain unconscious inferences.

Literal theories of perceptual inference that do posit cognitive resources, in the manner of Fodor (1983) and Rock (1983), have the opposite problem. They need to defend their invocation of cognitive apparatus to carry out rule-based transformations on information-bearing states in perception. Recall that our discussion has been limited to the phenomenal aspects of sense perception, that is, to the generation of imagistic perceptual representations. Rock argues that the outcomes of perception are clever enough to require truly intelligent (or at least genuinely cognitive) mechanisms in their production. The question of whether "smart mechanisms" must simply be engineered smartly (or evolved "smartly"), or must contain genuinely cognitive apparatus, is of great interest (Runeson, 1977). More generally, it would be interesting to contemplate similarities and differences among the various processes by which sensory information is encoded, perceptions are formed and brought under concepts, words are applied to perceptions, and meanings of words are altered on empirical (inductive) grounds (Barlow, 1974, p. 132). But for present purposes it will be enough to consider briefly an alternative means for conceiving perceptual processes noncognitively.

One of the reasons that unconscious inference models are attractive is that perception is mental and involves transformations of information in accordance with rules. It has seemed reasonable or even necessary that the rules would be represented and applied by a cognitive apparatus. But the development of connectionist computational architectures provides a means of conceiving of rules for information transformation that are instantiated in neural nets, without being cognitively represented and accessed. Connectionist models can treat information processing in perception as the outcome of stimulus-driven inputs to nodes in a connectionist net and the subsequent settling down of that net (or one downstream) into a stable state. Spatial information might be carried in such nets by adjacency relations within a retinotopic projection (Bienenstock & Doursat, 1991). By organizing a pyramid of nets that respond to the spatial properties of represented images at many different scales, local computations can respond to global features of images in a reasonable number of steps (Rosenfeld, 1990). Within the connectionist framework it is possible to think of networks of nodes as instantiating processing rules (Hatfield, 1991a) without representing those rules in explicit symbolic form or operating upon them via language-like inferential apparatus. Because such nets process information in accordance with rules without the necessity that the stimulus be described internally in a conceptual vocabulary (however modest), such models are noncognitive (Hatfield, 1988). For basic sensory processes, evolutionary engineering presumably has shaped the instantiated rules. Marr's (1982) theory of early vision, long a bastion of symbolist and inferential conceptions of psychological processes, admits of a nonsymbolic, noncognitive connectionist interpretation (Hatfield, 1991b; Kosslyn & Hatfield, 1984).

Noncognitive models of sense perception face (counterparts to) only two of the three problems discussed herein. As the complement of the cognitive machinery problem, they must provide computational machinery to explain transformations among perceptual representations. As the complement to the phenomenal experience problem, they must explain how the phenomenal aspects of sensory perception arise from noncognitive processes and operations. They are not faced with the sophisticated content problem in relation to sense perception, since they do not posit cognitive operations that represent conceptual content (sophisticated or no) in their explanations. Connectionist versions of noncognitive theories do, of course, face the problem of sophisticated content in framing explanations of cognitive achievements such as object recognition. They will in that case need to provide their own models of conceptual content and object recognition (on which, see Quinlan, 1991, pp. 120–131).

The previous hegemony of inferential models of the psychological processes underlying sense perception (by contrast with cognitive or meaningful perception) has fallen subject to challenge (Epstein, 1993; Hatfield, 1988; Kanizsa, 1979, ch. 1, 1985). The fate of inferential models will be decided in the longer course of empirical research and theoretical assessment. It is clear that the mere presence of specified processing rules or of "clever" perceptual outcomes cannot support the theory that sense perception results from inference, to the exclusion of noncognitive theories. Although seeing usually leads to believing, it remains an open question whether simple seeing results from belief-like inferences. The slow movement of theory is toward thinking it does not.

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NOTES

1. In using "phenomenal" and "cognitive" as contrastive qualifiers of "perception" and related terms, I do not mean to imply that our recognition of the table as a table is not a part of our visual experience, or is not as phenomenally immediate as the experience of the shape or color of the table. I need contrastive terms that signal the seemingly noncognitive aspect of shape or color perception (here distinguished from shape or color recognition, classification, and identification), as opposed to decidedly cognitive achievements such as object recognition or identification. For a statement of the distinction between perceptual and cognitive aspects of vision, see Rock (1975, ch. 1, especially p. 24). For a statement of the division from a computational and neurophysiological perspective, see Arbib and Hanson (1987, especially pp. 4–5). For a philosophical statement of the contrast, see Dretske (1995, especially pp. 332–335). The present contrast concerns aspects of perceptual experience itself, and does not describe the processes that produce these aspects, which may themselves be cognitive or noncognitive. In this chapter I focus on cognitive theories of the processes that produce the phenomenal aspects of experience, though I will mention noncognitive theories as well. I am not concerned with epistemological aspects of the theories; on epistemological aspects of inferential theories, see Schwartz (1994, pp. 104–110). Finally, other characterizations of the objects of study in contemporary visual perceptual psychology can be substituted for the traditional list given above (size, shape, etc.), including: the spatial and chromatic layout and changes within it, or the spatial and chromatic structure of surfaces and its changes.
2. Phenomenal color constancy was mentioned by Thomas Young (1807, 1: 456), using the example of white paper under varying intensities and colors of illumination. It was brought into prominence by Helmholtz (1867/1910, 2: 110, 243–244) and Ewald Hering (1875, pp. 335–338; 1920, pp. 13–17), who discussed the constancy of object colors in addition to white.
3. Dennett (1991, ch. 12) would contest this way of posing the third problem, since he denies the reality of imagistic phenomenal experience; but a theorist who subscribed to his views would still be faced with the problem of explaining how an inferential conclusion can *seem* to be the experience of a specific hue, or whatever.
4. My formulation of the cognitive machinery problem is distinct from *a priori* arguments that conclude, on conceptual grounds, that unconscious inference theories must be false, as when Ludwig (1996) argues that the very concept of an unconscious inference is

incoherent. Among Ludwig's other arguments, only one overlaps with my three problems. He requires (1996, pp. 398–399) that the concepts expressed in perceptual inferences be attributed to perceivers (my sophisticated content problem), and argues that the visual system could not have them (on conceptual grounds), and that children and animals do not have them (a common-sense empirical argument). None of my three problems is purely conceptual or *a priori*; the first two concern the empirical plausibility of needed explanatory apparatus, and the third concerns the explanatory adequacy of theories as developed thus far. The question of the attribution of subpersonal cognitive states has generated discussion (see Davies, 1995). On this score I agree with Fodor (1975, pp. 52–53). Although there are various moral, legal, and cultural reasons for wanting, in many contexts, to use the language of "inference" and "belief" to describe only acts of (whole) persons, for the purposes of psychological theory there are not adequate grounds *a priori* to preclude ascriptions of cognitive states to subsystems of persons, including the psychological mechanisms underlying vision. There may of course be theoretical or empirical grounds for such a preclusion.

5. Descartes also gave a purely psychophysical account of distance perception, according to which the brain states that control accommodation and convergence directly cause a corresponding idea of distance (Descartes, 1664/1972, p. 94; 1637/1984–85, 1: 170; see Hatfield, 1992b, p. 357).
6. The translations are mine. The third German edition of 1910 reprinted the text of the first edition of 1867 and added a great deal of useful apparatus and commentary by the editors, and it was translated by J. P. C. Southall as Helmholtz 1924–25. Southall conveniently provided the corresponding page numbers for the third German edition at the top of each page, which makes it easy to coordinate my citations of the German with his translation. Southall's translation, while useful for many purposes, is misleading on numerous occasions, especially concerning Helmholtz's psychological theory.
7. Helmholtz (1867/1910, 3: 23) cited John Stuart Mill in support of his associationist account of inductive inference, and in fact in his *Logic* of 1843 Mill endorsed an associational account; but in the 1851 edition he qualified this endorsement (Mill, 1974, p. 664). For additional problems with Helmholtz's associative account of inference, see Hatfield (1990, pp. 204–208).
8. As is explained at the end of this section, I am assuming that genuine inferences are couched in representations that express their content in such a way that it is available to the subsystem performing the inference. Systems that merely transform and transmit information without sensitivity to its content, such as a computer keyboard system (which transforms physical pressure into internal symbols, and may do so conditionally, as with the "shift" key), do not count as performing inferences. By contrast, in a conceptual encoding, having a concept requires its being connected to other concepts (Crane, 1992, pp. 142–149; Smith, 1995). Philosophers have, of course, been interested in the question of how there could be systems in which conceptual content is expressed (e.g., Dretske 1988). Further, it has been thought that inferential operations might take place solely in virtue of the syntax of internal inscriptions; but even in such cases the syntactic entities will have to be related to other syntactic entities in sufficiently complex ways to treat some of them as predicates corresponding to concepts (Fodor, 1975, ch. 2).
9. Although Descartes provided a purely psychophysical (and so noncognitive) account of distance perception via convergence, in some cases he attributed unnoticed geometrical reasoning to the perceiver, as in the perception of distance from known size and visual angle (see Hatfield, 1992b, p. 357).
10. Although Alhazen (1989, II.13.22) treated similarity as something to be detected intellectually, the associationist tradition in the nineteenth century posited laws as operating blindly over one-dimensional similarities (as among sensations within a single modality, or along a single dimension within a modality, such as hue).

11. Helmholtz believed that an image can contain the content of a judgment: "it is clearly possible, using the sensible images of memory instead of words, to produce the same kind of combination which, when expressed in words, would be called a proposition or judgment" (1896, 1: 358; 1995, p. 199). Indeed, Helmholtz considered concepts of objects to be resolvable into a series of images of the objects, comprising both perspectival and cross-sectional images (1882–95, 3: 545; 1971, p. 507). As Fodor (1975, pp. 174–184) has observed, any theory that attempts to equate propositions with images faces problems of ambiguity. For example, does a picture of a man walking on a slope and facing upwards express the content that he is walking up, or walking down backwards? One cannot avoid introducing an active mental element of grasping or connecting the "relevant" aspects of an image with other images to express a propositional content. The continuation of the passage quoted in this note suggests that Helmholtz was sensitive to this point and believed that associative connections would suffice.
12. Connectionism is often regarded as carrying on the associationist tradition (Quinlan, 1991, pp. 2–3). Further, some connectionist models provide a noncognitive basis for detecting similarities among patterns (Quinlan, 1991, pp. 49–56). The patterns are matched via the activation of patterns of input nodes, not by unreduced phenomenal qualities of hue and intensity. Still, in cases in which the input nodes are feature detectors, these accounts bear an analogy to a dephenomenologized Helmholtzian account, with the important exception that they probably are not aptly characterized as inferential accounts (on which, more below).
13. To put the point in Kosslyn's technical vocabulary, there is no discernible commitment that the operations by which compressed images (1994, pp. 118–119) are used to reconstruct depictive representations are cognitive, though of course the decompression process may be initiated cognitively.
14. It is possible to read this literature as implicitly proposing that all inference should be treated as information transformation, without worrying about the system's sensitivity to the content of the information. More generally, it seems clear that Horace Barlow (1974, 1990) adopts the attitude that mechanisms of information transformation, from the bacterium to the human, are best treated as lying on a continuum, with no in-principle dividing line separating the processes and marking off what I have called concept-mediated inferences from the "inferences" of the bacterium. This line of thought is of great interest. At the same time, without further articulation and defense of its claims about continuity, it would seem to slip into panmentalism; for it equates thought content with information transformations of any kind, and so does not account for the internal structure of conceptual thought (see Dretske, 1981) that distinguishes cognitive beings from computer keyboards.

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