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Perception as Unconscious Interference*

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Abstract

Since antiquity, visual theorists have variously proposed that perception (usually vision) results from unconscious inference. This paper reviews historical and recent theories of unconscious inferences, in order to make explicit their commitments to inferential cognitive processes. In particular, it asks whether the comparison of perception with inference has been intended metaphorically or literally. It then focuses on the literal theories, and assesses their resources for responding to three problems that arise when visual perception is explained as resulting from unconscious inference: the cognitive machinery problem, the sophisticated content problem, and the phenomenal problem.

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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

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

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 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

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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, chap. 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. 332-5). 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.

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 (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. 141-6), while still others postulate special-purpose inferential mechanisms in perception, isolated from ordinary reasoning and knowledge (Gregory 1974, pp. 205, 210; Nakamura, He & Shimojo 1995, p. 2; Rock 1983, chap. 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 <u>Optics</u> 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 (4th 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 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 (ca. 1030; 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 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.3.145-8).

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, 1:31-2), 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, 2:377-80), Le Cat (1767, 2:441-84, especially 471-84), and Gehler (1787-96, 2:537-42). 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, 236-7, 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, Hoffman & Prakash 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" (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

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, 243-4) and Ewald Hering (1875, pp. 335-8; 1920, pp. 13-17), who discussed the constancy of object colors in addition to white.

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]

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3. Dennett (1991, chap. 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.
398-39) 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 are 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

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

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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.

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" (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

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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).

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 1682/1965, 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 <u>explain</u> how opium puts people to sleep by appealing to its dormitive virtue, rather than simply to <u>describe</u> 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's 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, 2:295-6). 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 1787/1998, pp. 384, 386; see Hatfield 1990, pp. 105-6).

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, chap. 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, chap. 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

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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.

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, chap. 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, chaps. 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, chap. 8);

and (4) deductive inference from a universal major premise and an

unconsciously given minor premise, used to explain the constancies (1983,

chap. 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.

310-11) and deductive inference from rules. The cognitive machinery for such

inferences operates in a linguistic medium and follows the rules of predicate

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7. Helmholtz (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.

logic (1983, pp. 99, 272-3). 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. 336-7). 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

(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

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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, chap. 2).

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 Descartes's, 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" (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.

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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).

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, chap. 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

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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).

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

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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 examples, 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.

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 ego-centric 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, 273-4). The descriptive vocabulary here is impoverished relative to general cognition, focusing as it does on spatial properties in ego-centric and environmental frames of reference (1983, 331-2). 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.

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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).

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, chap. 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, chap. 4; Tye 1991,
chap. 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,
however, not 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, chap. 1; Koffka 1935, chap. 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, chap. 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, chap. 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, chap. 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, chap. 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, chap. 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 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, chap. 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, chap. 2; Pylyshyn 1984, chap. 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

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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.

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. 290-2). 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 thousand years (since Alhazen ca. 1030), and have been widespread for nearly four hundred 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 latter 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

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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

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

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attitude that mechanisms of information transformation, from the bacterium
to the human, are best treated as a 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.

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, chap. 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

towards thinking it does not.

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