is a step function that uniformly collapses a range of intensity values to a single value.

In addition to basic intensity manipulations, digital filtering can remove or enhance information in an image. Shown in Figure 2(f) is an image that has been blurred to remove image details. Shown in Figure 2(g) is an image that has been sharpened to enhance image details. And shown in Figure 2(h) is the result of filtering that isolates edges. Each of these filtering operations involves adjusting pixel values based on the values of neighboring pixels. An image is blurred by replacing each pixel value by the average of its neighboring pixel values—the larger the neighborhood, the greater the blurring. An image is sharpened by replacing each pixel with the difference between itself and its neighboring pixels. And, an image’s edges are enhanced by replacing each pixel with a combination of horizontal and vertical differences in pixel values.

Many photo-editing software packages perform these LUT and filter operations, along with many more sophisticated manipulations: red-eye can be removed from flash photographs, objects or people can be added or removed from an image, several images can be stitched together to create a wide-angle mosaic, and much more.

Implications

Advances in digital and computer technology have revolutionized photography in ways that could not have been imagined when the CCD was first invented. These advances have had an exciting impact on science, medicine, and art. These advances have also had the problematic consequence that they make it easy to doctor images in ways that are difficult to detect. Doctored images are appearing with a growing frequency and sophistication in tabloid magazines, fashion magazines, mainstream media outlets, scientific journals, political campaigns, courts of law, and our e-mail in-boxes. As a result, our trust in photography has been diminished. This in turn has given rise to the field of digital forensics and the development of techniques to authenticate digital images. In the coming years, digital and computer technology will continue to develop, and the field of digital forensics will try to help us regain our trust in photography. Although it is impossible to imagine precisely how these fields will develop, digital imaging has forever changed our relationship with visual imagery.

Hany Farid

See also Computer Vision; Eye: Structure and Optics

Further Readings

Matrix, with an illusory tomato induced by electrical stimulation of our brains.

The indirect realist goes a step further, arguing that the perceiver can at least make inferences about environmental objects based on sensory states. When we look at a tomato, we construct a mental representation of it; we are directly aware of this internal representation, and indirectly perceive the tomato.

The direct realist is willing to go all the way, holding that the perceiver is directly aware of environmental objects, not just their mental proxies. When we look at the apocryphal tomato, we are in perceptual contact with and have access to the tomato itself, without mediating inferences or representations. The challenge for the direct view is to articulate a theory of perception that can sustain this claim.

The position one takes on this philosophical question has practical consequences for psychology and cognitive science. Most researchers have adhered to an indirect view, ranging from the constructivist theories of the 1950s through 1960s, in which perception is an internal construction based on impoverished cues and rules of inference; to the computational approach of the 1970s through 1980s, in which perception is the computation of an internal representation based on insufficient input and prior assumptions; and the Bayesian framework of the 1990s through the early 2000s, in which perception is statistical inference based on ambiguous image data and prior knowledge of probabilities.

Yet, during the last century, prevailing opinion among philosophers of mind has shifted from indirect theories to some version of direct perception. This entry briefly presents several of the arguments for and against direct perception and introduces the main scientific theory that aims to sustain a direct view, the ecological approach developed by James J. Gibson and his followers.

Problems for the Indirect View
Arguments for direct perception often begin with a concern that the indirect view is insupportable, easily sliding into phenomenalism and even skepticism. On the indirect view, perception consists of getting a representation of the world into the observer's head; the direct realist's concern is that this doesn't really solve the problem of perception.

Representationalism
Traditionally, the indirect view has claimed that the perceiver is aware of an external object in virtue of being aware of something else, such as an internal mental or brain state. These intervening states may be representations, mental images, sensory impressions, sense-data, neural signals, or retinal images. However, this view commits what is called the representationalist fallacy. The claim that the perceiver is aware of an internal state confuses the object of awareness (the actual tomato) with the vehicle of awareness (the intervening state). In particular, to say that the perceiver is aware of an internal representation sets up a logical regress, implying an inner perceiver (homunculus) who must create an inner representation of the representation. The traditional version of the indirect view is thus confused.

The regress can be avoided by claiming that awareness of an external object is constituted by having an internal representation of it; the perceiver is not aware of the representation itself, but of what it represents (its content). Thus, one perceives the tomato (the object of awareness) in virtue of possessing an internal representation of it (the vehicle of awareness). This move satisfies some philosophers that perception is direct in the traditional sense, yet on this view, the perceiver experiences the content of a representation rather than the living tomato. The representation must somehow be derived from the visual input by a process that establishes its content. This leads to a skeptical argument known as Hume's problem.

Hume's Problem
Hume's problem, posed by David Hume, also called the semantic problem or grounding problem, is the problem of how internal representations get connected to the world. If perceptual awareness consists of having representations, how does the perceptual system determine the environmental entities to which they correspond? Without some independent, extrasensory access to the world, there appears to be no way to establish which internal states indicate which environmental properties, or which representations stand for tomatoes and which for elephants. The perceiver is trapped in a closed universe of sensory phenomena or uninterpretable representations.
The indirect solution is inference to the best explanation: The perceptual system infers a representation of the world that best accounts for the order in sensory input. For example, a particular sequence of gray blobs with an extended protuberance may be best explained by the presence of an elephant, rather than a tomato. However, as Hermann von Helmholtz understood by the mid-19th century, this inference process presumes that the perceptual system already possesses knowledge about (1) the structure of the world, including the sorts of entities that exist and predicates to describe them, and (2) how the world structures sensory input, such as a theory of image formation and transduction.

The trouble is that such prior knowledge must somehow be acquired, again in an extrasensory manner. As Gibson observed, knowledge of the world cannot be explained by supposing that knowledge of the world already exists. A common response is that prior knowledge has evolved via natural selection or learning, but as pointed out by Michael Turvey and Robert Shaw, this seems to require an organism that already has a working perceptual system—including the requisite prior knowledge—as a precondition. The indirect position thus appears to be circular.

Inference

There is a further problem with treating perception as a process of inference. Inference is a logical relation that holds between conscious mental states (beliefs, thoughts, statements) corresponding to premises and conclusions. But as we have just seen, if we are to avoid the representationalist fallacy, perception cannot be based on conscious awareness of internal states.

If the perceptual process is unconscious, then whatever else it may be it cannot be inferential; the same goes for related terms such as hypothesis, clue, evidence, and assumption. The notion of perception as unconscious inference, originally suggested by Helmholtz, is thus inconsistent. Computational theories seek to avoid this objection by treating perception as a process of computation over representations, but this leaves Hume’s problem unresolved.

Obstacles for the Direct View

These objections to indirect perception tend to drive theorists either to outright phenomenalism or some form of direct perception. But the direct view is not without its own obstacles.

The Argument From Illusion or Hallucination

Direct perception seems to imply that perception is veridical, that is, that the world is as it appears to be. Yet in cases of visual illusions and hallucinations, the world is not actually as it appears to be. According to the argument from illusion or hallucination, such cases undermine the claim that perception is direct:

1. Assume it is possible to experience illusions or hallucinations that are subjectively indistinguishable from cases of veridical perception. For example, we may have an alcohol-fueled experience of a dancing pink elephant that seems compellingly real.

2. In such cases, we are aware of something, but it is not a normal physical object. Hence, we are aware of a nonnormal object, such as a dancing pink sense-datum or an elephantine representation.

3. If we are aware of sense-data in cases of hallucination, and we cannot distinguish them from veridical cases, this implies we are aware of sense-data in veridical perception as well. Therefore, perception is not direct. As Hippolyte Taine famously remarked, veridical perception is merely hallucination that happens to be true.

The argument gets its force from the parsimony of admitting only one kind of object of awareness, nonnormal sense-data. The disjunctivist response (named after the logical or relation) denies that there is only one kind of object of awareness, rejecting step 3: It is logically possible that we are aware of nonnormal objects in cases of hallucination, while being aware of normal objects in cases of perception. Hence, we are aware of a normal or nonnormal object, although this is less parsimonious.

One might go further and deny step 2, arguing that when we hallucinate a dancing pink elephant, we are not aware of any object at all, normal or nonnormal. We are merely having a subjective experience that arises from some neural activity in our visual systems. If we can account for hallucinatory
experiences in this manner and avoid introducing a spooky class of nonnormal objects, this approach appears more parsimonious. Although an observer may not be able to tell “from inside” whether a subjective experience of an elephant is veridical or hallucinatory, “from outside” the former involves awareness of a normal environmental object whereas the latter does not.

The Argument From Underspecification

Another argument against direct perception holds that perception is underdetermined by the available information. The stimulation at the receptors is said to be inherently impoverished or ambiguous, insufficient to uniquely specify environmental objects and events. A tomato is a three-dimensional spherical object, but its retinal image is just a two-dimensional circular form; working backward, this image could correspond to a flat disk or various ellipsoidal objects stretched along the line of sight (as illustrated by Adelbert Ames’ famous distorted room).

To solve this “inverse optics” problem, the perceiver must somehow “go beyond the information given,” inferring or computing a representation of a spherical tomato based on prior knowledge or assumptions. Perception is consequently indirect. However, if we accept that all stimulation is ambiguous, it is not clear how a working perceptual system (with the requisite prior knowledge) could evolve in the first place, returning us to Hume’s problem.

Gibson’s Ecological Realism

Gibson sought to dissolve these paradoxes by reformulating the problem of perception to sustain an ecological version of direct realism. Instead of treating perception as a process of getting a representation of the world into the perceiver’s head, he considered it to be a relation between the perceiver and its environment that puts the perceiver in epistemic (knowing) contact with aspects of the environment that are relevant to its way of life.

The starting point for the ecological approach is Gibson’s principle of animal-environment mutualty. Because a species and its ecological niche co-evolve, the perceiver is adapted to regularities of its niche that support successful perceiving and acting. In particular, perceptual systems have evolved to detect patterns of stimulation (optical, acoustical, mechanical, chemical) that uniquely specify behaviorally relevant aspects of the environment (affordances). The frog’s visual system, for example, is tuned to the motions of small black specks that specify edible prey and large expanding patches that specify looming threats. Because such information is specific, not equivocal, perceptual systems can evolve by adapting to the available stimulation without prior knowledge, putting organisms in direct contact with the affordances of their niche and guiding effective action. This offers a means to resolve Hume’s problem.

Gibson thus rejected the argument from underspecification. Information, in Gibson’s sense, is a complex spatiotemporal pattern of stimulation that is lawfully structured by the environment and is specific to environmental features, under ecological constraints. The perceptual system need not “know” or “assume” these constraints explicitly, merely adapt to the informational regularities they guarantee. Within the frog’s niche, for example, moving black specks overwhelmingly correspond to edible insects (although there may be an occasional blowing bit of bark), so adapting to this motion pattern promotes successful action and survival. Research has shown that there is sufficient information available to a moving observer to specify many (but not all!) aspects of environmental layout, objects, events, their relation to the perceiver, and what they afford for action.

Direct perception does not mean there is no perceptual process or mechanism, only that the process is based on specific information and hence non-inferential. In Gibson’s view, perceptual systems are active attentional systems with ascending and descending neural pathways that seek and “resonate” to information. These systems become tuned to available information through evolution and learning and come to embody an implicit mapping from patterns of stimulation to behaviorally relevant environmental features. When information is detected, the perceiver is put in direct contact with its environment: The object of awareness is the environmental situation and the vehicle of awareness is the resonating perceptual system.

Optic Flow and the Control of Locomotion

A primary example of such information is the optic flow field. When an observer moves through
the environment, a radial pattern of motion is produced at the eye, much like the outward expanding motion on the screen of a driving video game. The focus of expansion specifies the observer’s direction of travel, the rate of expansion specifies the time-to-contact with objects, and velocity gradients specify the layout of surfaces.

Species ranging from insects to primates possess neural pathways that are selective for such complex flow patterns. Research by David Lee, William H. Warren, and others has shown that optic flow (along with other information) is used to control locomotion, including balance, braking, steering, and landing and escape responses. Many behaving animals thus appear to be connected to their environments by the optic flow field.

**Invariants and 3-D Shape**

How we perceive three-dimensional (3-D) shape with a two-dimensional (2-D) retina is often considered a classic example of underdetermined perception. But Gibson argued that such constant properties as surface shape are specified by constant spatiotemporal patterns of stimulation, which he called higher-order invariants. Recent work by Jan Koenderink, James Todd, and others has begun to bear out this claim: Higher-order patterns of texture, shading, optic flow, and binocular disparity indeed specify the 3-D shape of a smooth surface. However, this information is not sufficient to determine Euclidean shape (absolute depth, slant, curvature) as researchers have typically assumed, but rather qualitative surface shape (hills, dales, ridges, valleys, and plains). These qualitative features are perceived more accurately and reliably, and are theoretically sufficient to identify objects and guide actions like grasping.

An important implication of this research is that whether we consider perception to be veridical depends on the properties we assume are perceived. Perception can be accurate and direct only insofar as the property is specified by information.

The definition with which we began can now be refined. In Gibson’s view, direct perception means that the perceiver is in epistemic contact with behaviorally meaningful aspects of its environment by virtue of detecting specific information, without mediating representations, inference processes, or prior knowledge.

William H. Warren

**See also** Action and Vision; Constancy; Ecological Approach; Indirect Nature of Perception; Spatial Layout Perception, Psychophysical

**Further Readings**


**DIRECT REALISM**

**See** Naïve Realism

**DYSLEXIA**

*Dyslexia* is marked by unusually slow reading development in children who are otherwise normally