Do we see with microscopes?

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I

Trying to understand better the role played by epistemic artifacts in our quest for reliable knowledge, it is interesting to compare their contribution with the one made by the epistemic organs or systems with which we are naturally endowed. This comparative approach may yield the further benefit of an improved understanding of the nature and epistemic functions of our natural epistemic equipment. In this paper, I shall concern myself with comparing the role of a family of instruments, microscopes, with that of visual systems and with assessing the similarities and dissimilarities in accounts of their epistemic contributions.[2]

Prima facie, the eponymous question may sound silly, the answer being an obvious yes. Surely, the use of a microscope involves sight, not hearing or smell or touch. One could be deaf, smell nothing, have one's tactile sensations anesthetized and still be perfectly capable of using a microscope. By contrast, a blind person would have no use for a microscope. Yet, an advocate of a negative answer to our question may well concede this point and nevertheless maintain that the question is far from silly. He could argue that, although for something to qualify as visual perception, the existence and operation of an intact visual apparatus is indeed a necessary condition, it is not a sufficient condition, and that other conditions have to be satisfied as well. Our opponent to microscope 'vision' might then go on to claim that what is lacking in the case of microscopy is precisely one of those further conditions that he also deems to be definitory of seeing.

My concern will be with reviewing and assessing a number of possible lines of arguments of that kind. Thus, I shall consider several normative accounts that differ in what they take to be definitory of seeing. I shall also consider differing accounts of the actual workings of the visual system and assess the consequences that the adoption of one account in preference to an other would have for our question. Normative accounts of seeing can be divided into two categories depending on whether they focus on external conditions of vision — the relations that hold between the distal stimulus and the proximal stimulus — or on internal conditions of vision — the relations that hold between the proximal stimulus and the end-product of visual perception. First, I shall discuss accounts in the 'external' category and give some illustrations of the wide variety of physical principles exploited in microscopes of different types. I shall then turn to accounts in the second category. This is where matters become both philosophically interesting and much more complicated. Although there might still be disagreement about some aspects of the description of the physico-physiological side of vision, the amount of controversy is minimal compared to what one finds when one turns to the physio-psychological side of vision. There, disagreement is the rule rather than the exception. There is no consensus, be it among philosophers or cognitive scientists at large, as to what visual perception is about, what should count as an instance of visual perception, or what the mechanisms and processes that underlie perception are or need be.

Instead of giving a general survey of the battle field, I shall restrict my inquiry to the discussion of the set of options that remain open, once it is granted, first, that the main purpose of (advanced) visual perception is to inform us on distal spatial layouts, and, second, that this goal is common to both unaided visual perception and microscope observation. A discussion of Dretske's distinction between sense perception and cognitive perception will serve to introduce this conception of the purpose of visual perception. I hope that the discussion of examples will convince the reader that this conception is plausible, but I shall not give a full-blown argument in favor of it. Furthermore, I shall simply assume the commonality of purpose between normal visual perception and microscope observation. My discussion will concentrate rather on whether, by contrast, one can claim that there are substantial differences as to the means employed for reaching this goal.

II

The first category of accounts I shall be concerned with includes readings of the question that focus on the relation that hold between distal stimulus and proximal stimulus in the case of normal vision and that consider some aspects of this relation as necessary conditions of seeing. Whether microscope observation (henceforth 'M-observation') qualifies as seeing is therefore deemed to depend on the holding of those aspects of the relation taken as constitutive of seeing. In normal vision, the proximal stimulus is commonly but not always[3] identified as the pattern of excitation on the retina produced by light intensities. In unaided vision, the retinal image results from the projection of light from the surfaces of distal layouts onto the eyes according mainly to the laws of reflection of light. The relation between distal and proximal stimulus is then determined by the geometric laws of projection, the physical laws of reflection and refraction of light and the physiological properties of the eye.

One might suggest that the answer to our question depends on whether the relation between distal stimulus and microscope image (i. e. the image produced by a microscope, henceforth 'M-image') is sufficiently similar to the relation between distal and proximal stimulus in the case of unaided vision. Hacking (1983) insists on the great diversity of physical principles exploited by different kinds of microscopes. I borrow from him a sample of the numerous examples he gives. The most ancient and familiar type of microscopes are optical microscopes. Yet, it is only in 1873, more than two centuries after their invention, that a correct account of the functioning of optical microscopes was given by Ernst Abbe who explained the role of diffraction in microscope vision. We know since Abbe, that the image of the object produced by an optical microscope is in fact a Fourier synthesis of the sets of both transmitted and diffracted light rays. But the optical microscope is only the first of a long series. As Hacking points out, what Abbe's account of the functioning of optical microscopes shows is that, in order to perceive the structure of a specimen, it is not necessary to exploit the normal physics of vision. Properties of light other than those exploited in normal vision or, indeed, properties of other kinds of waves can be made use of.

In fluorescence microscopy incident light is suppressed and what is observed is only the light re-emitted on different wavelengths by natural or induced phenomena of fluorescence or phosphorescence. Phase contrast microscopes exploit differences in the refraction indexes of different parts of a specimen and convert these differences into differences of intensities visible on the image of the specimen. Contrast interference microscopes work according to the following principle: the light source is divided by a semi-reflective mirror, half of it goes through the specimen, the other half is retained as a reference wave. The two waves are then recombined to produce the final image where the changes in the optic path caused by differences in the refraction indexes of the specimen produce interference effects with the reference ray.

Finally, we can consider acoustic microscopes. In their case, it is not light rays but sound waves that interact with the specimen. The basic principles are quite simple:

electric signals are converted into acoustic signals (ultrasonic waves) which, after interacting with the specimen, are converted back into electric signals. These electric signals are converted into images on, for instance, a TV screen. Acoustic micrography has a number of interesting features. There are many more variations in the refraction indexes of sound than of light, which allows for a finer-grained image of the structure of specimens. Moreover, sound waves can go through objects that are entirely opaque to light. Still another advantage, important in biology, is that short sonic emissions do not immediately damage the cells of living organisms and, thus, allow the biologists to quite literally study *living* cells.

These examples provide a concrete basis for discussing whether we see with microscopes. There are several potential types of difference between the way in which an image is produced in normal vision and the way a M-image is produced. The difference might concern the properties of light that are involved in the production of the image, or it might concern the nature of the physical interaction between light rays and specimen, or it might concern the type of information about the specimen that the image carries.

The first two possibilities can be illustrated by passages drawn from different handbooks on microscopy and quoted by Hacking (1983). According to the view expressed by a president of the Royal Microscopic Society soon after Ernst Abbe had explained the workings of optical microscopes and reproduced for years in S. H. Gage's book, *The Microscope*, we don't see with a microscope because the M-image depends entirely on the laws of diffraction. Thus, according to this view, images can be seen only if they were produced according to the laws of reflection and diffraction that underlie normal vision.

A more recent and more interesting definition is given in E. M. Slayter's book, *Optical Methods in Biology*. Slayter defines an image as a map of the interactions between the specimen and the radiation producing the image. She considers that it is acceptable to say that we see with a microscope only if the physical interactions between the light pencils and the specimen are identical to the interactions one encounters in normal vision. Contrary to the first definition, this definition allows us to say that we see with optical microscopes. On the other hand, if the type of radiation used is not visible light (e.g. UV beams or X-rays) or if the microscope comprises some device for converting phase differences into intensity variations, then it would be improper to say that we see the M-images obtained using such techniques.

This definition of seeing — as well as the definition reproduced in Gage's book — can be taken as purely stipulative or it can be taken as involving more substantial claims. One might ask why differences in the conditions of physical interaction between radiation and specimen should be considered important. The definition of an image as a map of interactions suggests two possibilities. Maps resulting from different kinds of interaction can be different in two ways: the difference can lie in the type of information conveyed by the interactions or it can lie in the type of mapping rule involved and hence in the key needed to read the map. To put it briefly, the difference can lie in what information is coded or in how it is coded. Slayter's statement that we don't see with microscopes that use UV beams or X-rays suggests either that she intends the second reading or that she assumes that, in microscopy at least, differences in how things are mapped always yield differences in which things are mapped.

However, if one does not accept this assumption, a third definition of seeing is possible, a definition that insists not on how images map but on what they map. According to this view, which seems closest to Hacking's position, we see with a microscope if the M-image is the direct[4] result of an interaction between a wave source and a specimen and if this image carries information about the structure and spatial configuration, bidimensional or tridimensional, of the specimen. On this view, insofar as the images they produce possess these characteristics, it is permissible to say that we see with acoustic microscopes.

The three definitions of seeing just reviewed focus on some aspect or other of the relation between the object (distal stimulus), the image (proximal stimulus), and the physical properties of the radiation that mediates between them. Although each of them seems acceptable as a stipulative definition of seeing, stressing the differences in physical conditions *per se* might not be philosophically as interesting as assessing the consequences of these differences for the processing of the images.

I shall presently turn to this second category of answers to the eponymous question that focuses on the processes involved in deriving knowledge about the world from either M-images or proximal stimuli. Readings in this category define seeing in terms of the types of processes involved in this task and thus engage a certain conception of unaided perception. For instance, one might claim that we don't see with microscopes not because the physical conditions for the production of the M-image differ in some important respects from the conditions that obtain in normal vision, but because the processing of M-images involves an inferential component normally not found in unaided vision. Nevertheless, there may be an important link between the physical conditions for the production of the image and the way it is later processed. Differences in the processes involved may be consequences of differences in the conditions of production.

However, saying that the processing of M-images involves a special inferential component is scarcely less ambiguous than saying that we see (or don't see) with microscopes. This phrase can be used to express a number of different claims. Different understandings of what is meant by inference as well as different theories of visual perception — theories of what normal visual perception yields and how it yields what it does — give rise to different claims. Some preliminary ground-clearing is in order. Therefore, before launching in a discussion of our second category of readings of the eponymous question, I will examine some important distinctions that have been proposed and spell out the main points of disagreement between the principal trends in theories of perception.

III

Although his terminology varies, Dretske has emphasized in several places (1969, 1978, 1979, 1990) an important distinction between two ways of seeing or perceiving. Non-epistemic versus epistemic seeing, simple seeing versus cognitive seeing, seeing objects versus seeing facts, sense perception versus cognitive perception are all meant to capture the same distinction. In order to illustrate it, Dretske (1990) proposes the following example. Suppose a small child glances at a sofa and mistakes a sleeping cat for an old sweater. As Dretske puts it, "although the child does not recognize the cat, she must, in some sense, see the cat in order to mistake it for a sweater. [...] She sees an object (the black cat on the sofa) but not the fact (that there is a black cat on the sofa) corresponding to it. " (1990: 131). Dretske proposes that we use the phrase 'sense perception' to refer to the perception of objects and the phrase 'cognitive perception' to refer to the perception of facts. What distinguishes cognitive perception from sense perception is that it requires the subject to know what it is he is seeing, to have the capacity to recognize it and to distinguish it from other kinds of things. Sense perception involves no such requirements. For a child to have a sensory perception of a cat it suffices that the child not be blind and that "light rays, reflected from the cat, [be] entering the child's eyes and, in some perfectly normal way, causing within her a visual experience that would be quite different if the cat were not there" (1990: 132).

Although, as I shall argue below, Dretske's distinction may be in need of some refinement, it allows us to highlight some commonalities between unaided perception and M-observation and, thus, helps to narrow down the purview of our investigations in search of putative differences between them. In order to make things as clear as possible, I introduce now two distinctions pertaining to the notion of inference. Very broadly, an inferential process is a rule-governed process leading from given premisses to certain conclusions. The first distinction of import to us is the classical distinction in logic between inductive and deductive rules of inference. The key difference here is that deductive rules of inference correctly applied are always truth preserving — if the reasoning is valid and the premisses are true, the conclusion is true — whereas reasoning based on inductive rules yields only more or less probable conclusions. The second distinction concerns the origins of the premisses used in the inferential process. I shall speak of an inferential process as *endogenous* to a domain when all the premisses it makes use of are either based on information from stimuli in the domain or correspond to assumptions that are built in the system dedicated to the processing of information in this domain; I shall speak of an *exogenous* inferential process in case at least some of the premisses used are derived from other sources of information. Moreover, these sources can be at the same level or can be higher-order sources of knowledge.

The distinction of immediate interest in our discussion of Dretske's notion of cognitive perception is the distinction between endogenous and exogenous inferential processes. It is clear that cognitive perception as conceived by Dretske is based on exogenous inferential processes and draws from higher-order sources of knowledge. Dretske himself hammers down this point:

> It should be obvious that cognitive perception — our perception of facts, our seeing *that* (and hence coming to know that) there is a cat on the sofa — is the result of a process that is strongly influenced by higher-level cognitive factors. [...] The upshot of cognitive perception is some *known fact* (say, that there is a cat on the sofa) and such facts are not learned without the cooperation of the entire cognitive system. By changing a subject's cognitive set — changing what the subject knows or believes about the way things look, for instance — one easily changes what the subject learns, comes to know, hence perceives in a cognitive way, about the objects he sees (in a sensory way). (1990: 142).

It seems to me equally obvious that a distinction very similar to Dretske's can be made in the case of microscopes. One can "see" something with a microscope without recognizing it as what it is — as a paramecium, for instance — and it seems difficult to deny that in order to see a paramecium as a paramecium some knowledge drawn from higher-order sources is needed. Thus, it seems that whatever reason one might have to contend that we don't see with microscopes, the reason cannot be that the distinction drawn by Dretske between sense perception and cognitive perception has no counterpart in the case of microscopes nor that the processes involved in "naked-eye" cognitive perception are different in kind from the processes involved in microscope cognition. In both cases, exogenous inferential processes are involved and in both cases higher-order sources of information are exploited. One cannot even contend that the types of knowledge exploited are different and claim that for cognitive M-observation scientific knowledge is required, whereas it is only common-sense knowledge that is needed in the case of normal vision. For even assuming that this claim has some plausibility in the case of the perception of cats and paramecia, it is less than clear why seeing a piece of metal and recognizing it as, say, niobium should count as less demanding in terms of scientific knowledge than the identification of a paramecium.

Thus, it seems that, if it is to have some appearance of plausibility, a claim to the effect that we do not see with microscopes because of differences in the processes involved in M-observation and in normal vision would have to invoke not differences in the kinds of processes underlying cognitive perception but rather differences in the kinds of perceptual processes involved prior to or independently of cognitive identification. This is why it is important that we have a more precise idea of what these processes are.

The notion of sense perception is but minimally characterized by Dretske who fixes only the lower and upper bounds of it, so to speak. For a sighted subject to have a sense perception of an X, it is required that an X be a cause of the subject's visual experience[5], and it is not required that the subject have any beliefs about X. There is room within those bounds for rather different notions of perception depending on what further conditions one takes to be necessary for the sense perception of an X to occur. In some of his writings (1990), Dretske leaves the question pending and seems to imply that it is a matter for empirical investigations. In other places, however, Dretske commits himself to the view that for sense perception of an X to occur, no further requirement is needed than that information about an X be made available to the organism by the sensory system. Dretske (1978) speaks for instance of "the difference between *perception*, the kind of sensory information available to the organism and *cognition*, the kind of information actually extracted from that which is made available" (1978: 124).

Thus, sensory perception seems to amount to little more than a transduction and transmission of information from the eyes to the cognitive centers; the exploitation of this information thus remains outside the realm of sense perception and within the province of cognition or cognitive perception.

One reason for Dretske's minimalism might be that he does not want to limit himself to human perception but wants his account to hold for all species endowed with a visual system, however primitive. I think, however, that the more advanced a visual system is, the more important is the need for a notion of perception intermediate between sensory perception, as defined by Dretske, and cognitive perception. Since in the question 'Do we see with microscopes?' I take the 'we' to refer to human beings, I shall now concentrate on features of advanced vision — found normally in humans, but presumably in other species as well — that might play a decisive role in settling our issue.

There are two aspects of advanced visual perception that I take to be essential to it and that, to put it mildly, don't seem to play a crucial role in Dretske's account of perception. These are the exteriority and the spatiality of visual perceptual experience. By exteriority I don't mean to refer to the general property of intentionality or aboutness but to a distinctive feature of perceptual intentionality. This feature of perceptual intentionality consists in the fact that a visual perception is always as of something actually present out there now, quite independently of the fact that this something can be identified, recognized or categorized in any way. This feature distinguishes perceptions from, for instance, memories or imaginings[6]. By spatiality, I mean the fact that visual experience is an experience of the spatial properties of things. As Marr puts it "the quintessential fact of human vision is that it tells us about shape and space and spatial arrangement" (Marr, 1982: 36). I will use the label 'intermediate perception' to refer to the level of perception where these two features of exteriority and spatiality are present.[7]

Let me discuss an example in order to get clearer on where exactly the difference lies between sense perception and intermediate perception on the one hand, and intermediate perception and cognitive perception on the other. Suppose another little child glances at a sofa where a black cat is sleeping. Our child thinks he sees a wimpy. Through the reading of children stories he has come to believe that cat-shaped black things are preternatural creatures called wimpies. Compare this with Dretske's original example. In both cases the child has a sense perception of a cat but no cognitive perception of a cat. However, the reasons why the children don't have a cognitive perception of a cat are rather different in each case. The child who thinks he is seeing a wimpy has inadequate beliefs both about cats and wimpies. He thinks mistakenly that cats come in all colors but black, and he also thinks mistakenly that there exist black, cat-shaped preternatural creatures called wimpies. On the other hand, in order to explain why the child in Dretske's original example does not have a cognitive perception of a cat, we don't have to invoke mistaken beliefs about either cats or sweaters. In her case something went wrong in the process of extracting three-dimensional shape from sensory-information. Here the mistake at the level of cognitive perception is only a consequence of a mistake at an earlier level. Now one might say that the child was influenced by some kind of positive cognitive bias towards sweaters or that her mistake was the result of lack of "intelligence in the applications of [her] concepts to the objects being perceived" (1990: 142). If this should be taken to imply that correct recovery of the spatial properties of an object, in particular its three-dimensional shape, is dependent upon the possession of knowledge as to the conceptual category to which the object belong, I think this is certainly mistaken. It is certainly perfectly possible to see an object and form a correct representation of its three-dimensional shape without having any idea of what this object is, what its name is, what its use and function could be and without having ever seen any object of its kind and shape before.[8]

To sum up, I take it that the proper job of advanced visual perception is to provide us with a certain type of objective information about the world, namely, spatial information. I claim that perception thus conceived goes beyond sense perception as construed by Dretske in that the recovery of spatial information involves processes of extraction that go beyond mere sensory transduction[9]. Finally, I consider that perception in this sense should be distinguished from cognitive perception insofar as cognitive perception implies a conceptual identification of some sort of the things seen. However, I did not intend to commit myself as to the nature of the processes underlying 'intermediate perception'. My claim that intermediate perception has to be distinguished from cognitive perception should not be taken as denying that (some of) the processes underlying intermediate perception could be, are, or must be top-down. For the nonce, I remain agnostic on this issue.

IV

In view of this brief discussion of visual perception, we can now reformulate our eponymous question. Two possibilities emerge. Given that we have claimed that the job of visual perception was to provide us with objective information on spatial properties in the world, we might be wondering whether the information obtained through the use of microscopes is of the same type as the information obtained through unaided vision. Or, on the assumption that they are indeed of the same type, we might be wondering whether the processes used to extract this information in the case of microscopes are of the same type as the processes used for normal visual perception.

In the last part of this paper, I shall concentrate on the second possibility. That is, I shall assume without discussion that both normal visual images and M-images carry information about the spatial properties of distal layouts[10]. I shall focus on the potential similarities and differences in the processing of this information and on whether any of these should prompt us to assert or to deny that we see with microscopes. Such a comparison would be easy enough if there were a general consensus as to what the correct account of visual perception is, but, as we know, this is not the case. There are nevertheless two main opposing trends in accounts of visual perception, often referred to by cognitive scientists as 'theories of direct perception' and 'theories of indirect perception'.[11]

Following Cutting (1986), I define direct versus indirect perception in terms of an information-to-object mapping. Theorists of direct perception assume that in the normal circumstances of visual perception, the information-to-object mapping is a one-to-one mapping. That is to say, the information in the proximal stimulus is supposed to be rich enough to unambiguously determine the distal arrangement that produced it. By contrast, indirect theorists consider the mapping as one-to-many[12]. The information contained in the proximal stimulus underdetermines the distal stimulus: several different distal layouts could have produced that pattern of proximal stimulation. I take it that the other assumptions sometimes associated with either direct or indirect perception are supposed consequences of these primary assumptions.

Let me start with theories of indirect perception. There is a logical possibility that we don't see microscopic objects because, contrary to what happens in the case of normal visual perception, there is a one-to-one mapping between the M-image and the distal layout that produced it and, therefore, because M-images, but not normal images, allow for direct perception. However, I take it that an indirect theorist willing to deny that we see with microscopes is more likely to argue that although both normal visual perception and M-observation are cases of indirect perception, there are crucial differences in the modes of processing involved. What differences could he avail himself of?

Given his assumption that the proximal stimulus does not contain enough information to uniquely determine the distal layout that produced it, it is natural for the indirect theorist to conceive perceptual processing as being primarily a matter of adding information to the information contained in the stimulus in order to reach a conclusion, *i.e.* as an exogenous inferential process. He might therefore claim that the crucial differences in the processing of normal versus M-images are differences in the sources of information tapped or in the origins of this information or indeed in its format.

A discussion of the concept of cues to perception might give an illustration of what I mean. The idea of cues to perception is closely associated with theories of indirect perception. The concept of cues (but not the word[13]) has its origins in Berkeley's book, *A New Theory of Vision* (1710). Berkeley thought that visual images contain no information about depth, and that in order to perceive depth we first have to learn to associate certain characteristics of the proximal stimulus with information obtained by other means (mainly touch and motion). Thus, a cue is not meaningful in itself, it is a coded signal that is exploitable only if one possesses the knowledge needed to decode it. Note that a theory of cues is not necessarily restricted to depth. Note also that Berkeley's linking of cues with learning is not a necessary ingredient of a theory of cues to perception: one might hold that the knowledge needed to exploit visual cues is innate.

If one retains the Berkeleian link between cues and learning, one might want to say that what distinguishes normal images from M-images is that knowledge of a set of cues different from the one used in normal vision is needed to process M-images. In other words, although the set of cues learned for normal vision yields generally correct inferences concerning the distal layout, it would yield mistaken inferences in the case of M-images. For instance, M-images exhibit specific artifacts produced by the apparatus[14] and not encountered in normal vision. Thus, we need to acquire some special knowledge in order to be able to distinguish between the features of M-images that are artifacts and the one that correspond to real things. But is this a strong enough reason to deny that we see with microscopes? Anybody walking in the mountains or in the desert for the first time in his life will soon realize that he needs to revise his usual procedures for estimating distances. In the same way, it takes some learning for an underwater diver or an aircraft pilot to adjust to the special conditions created for vision by diving or flying.

But it would be rather counter-intuitive to say that the diver, the pilot, or the desert or mountain hiker do not really see.

One might nevertheless claim that there is a difference between the diver and the microscope user. The argument would go something like this: learning to see under water is just a matter of practice, but learning to interpret a M-image requires theoretical knowledge: it requires learning some optical theory. However, Hacking (1983) offers an interesting rebuttal of this argument. According to him, one should distinguish between what is needed to build a microscope and what is needed to use it. He acknowledges that some knowledge of optics, and more generally of physics, is needed in order to design new types of microscopes or to improve existing ones — although not as much as one might think. But, he contends that it is false that such theoretical knowledge is needed by the user of a microscope. Knowledge of optical theory might help the user understand why such or such an artifact is produced, but it is not needed to enable him to distinguish artifacts from real things. What is needed is practice: manipulation of specimens and familiarity with several types of microscopes. These, according to Hacking, are the microscope equivalents of the touching and the doing insisted on by Berkeley. In other words, it seems false to say that what one needs to learn in order to be able to use a microscope is different in kind from what one needs to learn in the case of unaided vision.

Another possible move for the indirect theorist might be to go nativist and to claim that what distinguishes the processing of M-images from that of normal images is that we are endowed with an innate store of knowledge of perceptual cues appropriate for the interpretation of normal images, but that we have to acquire the knowledge needed to interpret M-images. Yet, even if true, this would hardly justify a denial that we see with microscopes, unless one is also willing to deny that we see in any situation where our supposedly innate knowledge is inappropriate and where learning is necessary. This would mean denying that divers see in water, that aircraft pilots see when they are flying their aircrafts, and so on. One last move, similarly unlikely to succeed, would be to oppose the automaticity[15] of normal visual processing to the flexibility or plasticity of the processes involved in microscope perception. But then, once again we would be confronted with the unappealing alternative of either admitting that we see with microscopes despite the non-automatic character of the processes involved or denying that we do while also denying that divers see, that jet pilots see, and so on.

To sum up, assuming that a theory of indirect perception is correct, there are several differences between the processes involved in normal vision and the processes involved in microscopy that one might be tempted to exploit in order to deny that we see with microscopes. However, success is not warranted. On the one hand, although some of these differences are admittedly real, whether they would justify denying that we see with microscopes is problematic. Dependence on acquired knowledge or non-automaticity are characteristics also found in other cases that we would intuitively consider as instances of seeing. Whether we hold that we don't see with microscopes depends on whether we are willing to relinquish those intuitions. On the other hand, the only alledged difference on which one could hope to build a strong case, the difference between the theory-ladenness of M-observation and the atheoretical character of normal vision, looks more like an illusion of armchair philosophers than like a truthful depiction of what goes on in the laboratory.

Let us proceed to the last stage of our inquiry and see what we can expect from theories of direct perception. As we have seen, these theories assume that there is enough information in the proximal stimulus to unambiguously determine the distal stimulus that produced it: the information-to-object mapping is one-to-one. This mapping assumption goes usually on a par with an enlarged notion of proximal stimulus. The proximal stimulus is not defined as a static pattern of light intensity, but as a changing optic array. It is thus extended over time. What is generally agreed upon by theorists of direct perception is that, from the mapping assumption, it follows that it is not in principle necessary to appeal to other sources of knowledge for the processing of visual stimuli: perception is the result of the extraction of structural invariants[16] from the changing optic array, and perceiving is an endogenous process. Disagreement arises concerning the complexity of the operations necessary for the extraction of these invariants. According to Gibson, there is a direct pick up of information (hence a second sense of direct perception), and the visual system is so constituted that it automatically registers certain definite dimensions of invariance in the stimulus flux: "it *resonates* to the invariant structure or is *attuned* to it" (Gibson, 1986: 249). By constrast, according to theorists such as Marr, the extraction of invariants is a complex information-processing task the difficulty of which Gibson seriously underrated (Marr, 1982: 30). Visual processing is inferential, even though its inferences are both deductive and endogenous.

An advocate of direct perception inclined to deny that we see with microscopes has the choice between two main strategies. He could insist that what is definitional of seeing is that it is a process of extraction of invariants from a changing optic array. He could then deny that in the case of M-images the information-to-object mapping is one-to-one and therefore deny that M-observation is a process of invariance detection. Or, he could concede that M-images are rich enough informationally to allow for invariance detection, but insist that what is definitory of seeing is not invariance detection *per se* but the particular procedures brought into play for this detection. He would then claim that we don't see with microscopes because invariance detection in this case involves procedures not found in normal vision.

Let us examine the prospects of the first strategy. The idea is to argue from the fact that M-images are not rich enough informationally to allow for invariance detection. But is this a fact? In direct theories of perception, the proximal stimulus is equated with the optic array at the station point at which the eye is placed. That the proximal stimulus be extended over time, allowing for both persistence and change, is an important factor of its informational richness. There are two ways in which the proximal stimulus can change: the pattern of light around a fixed point of observation can change or we can change the point of observation. One could argue that microscopy does not allow for such changes, that M-images are static and informationally impoverished, hence that in order to process them it is necessary that we supplement the information available at the image. Now, it is true that the microscope techniques have some drawbacks. For instance, most staining products used in biological microscopy are violent poisons, so that only dead and totally inert cells can be observed. However, such drawbacks don't seem to be fatal. Acoustic microscopy, for instance, allows for the observation of living cells. The microscopist is not a passive observer, he may manipulate in all sorts of ways the specimens he is studying. M-observation can also involve comparing micrographies obtained through different microscope techniques precisely in order to detect invariants. Hacking (1983) takes this to be our most natural and most important reason for believing that the features of M-images correspond to real things and are not artifacts. He notes that our faith in invariance as a criterion of reality rests implicitly on an argument of coincidence: it would be an extraordinary coincidence if the identical visual patterns on two micrographies obtained by technical procedures based on different physical principles were nevertheless artifacts. In a way, invariance detection goes even deeper in microscopy than in ordinary vision, since in microscopy detection is concerned not only with invariance over time or space — changes in observation points — but also with invariance over physical processes. Thus, it seems that if we allow for an extension of the notion of an 'image' in microscopy similar to the extension the theorists of direct perception demanded for the notion of proximal stimulus in normal vision, we might be able to claim that a M-image in this extended sense contains enough information to unambiguously specify the object that produced it. The first strategy seems, therefore, inappropriate. Its denial that M-images are rich enough to allow for invariance detection is based on an unduly restricted notion of an M-image. Thus, it commits towards M-images the same type of fallacy that the direct theorists of perception accuse the indirect theorists of committing towards proximal visual stimuli.

By contrast, the second type of strategy that a direct theorist could possibly adopt would not deny that M-observation is a matter of invariance detection. It would claim that what is definitory of seeing is not invariance detection *per se*, but the methods of detection employed. The reasoning would go something like this: since M-images are produced by physical principles different from those of normal perception, the methods used for detecting microscope invariants cannot be the same as the ones used for detecting invariants in ecologically normal conditions of perception. Hence, we don't see with microscopes. If one is partial to the Gibsonian theory of direct information pick-up, one can claim, for instance, that whereas our visual system is attuned to the invariants present in ecologically normal conditions of perception and resonates automatically to them, no such pre-established harmony is at work in M-observation. Or, if one is more computationally minded, one can claim that the algorithms used by the brain for the extraction of visual invariants are tailor-made for the invariants of normal visual perception and go astray when given microscope data as input.

Neither of these stories seem to provide convincing reasons for denying that we see with microscopes. Note, first, that they seem to imply that the perceptual processes behind normal vision are fixed and inflexible, something that Gibson at least would not accept, for he takes the process of information pick-up to be susceptible to development and learning. Second, they face the same dilemma as some of the strategies open to indirect theorists: if they deny that we see with microscopes, they will have to deny on the same grounds that we see whenever we find ourselves in non-ecologically normal conditions for visual perception.

I have reviewed a number of possible lines of argument for denying that we see with microscopes. There are clearly differences between unaided vision and M-observation both in the physical processes involved in the relation between the distal and the proximal stimulus and in the perceptual processes that lead to a perceptual representation of the distal layouts. The existence of these differences certainly allows for stipulative definitions of seeing that exclude microscopes. On the other hand, whether these differences provide compelling reasons for denying that we see with microscopes, is, whatever theory of perception one advocates, much more problematic. This survey seems to me on the contrary to have brought to light reasons for asserting that we see with microscopes. As a conclusion, we might briefly enumerate these. M-images are, as are normal visual images, maps of the interactions between a distal layout and the radiation producing the proximal stimulus. These maps have in common with normal visual maps the property of carrying information about the spatial and structural properties of the distal layouts. The point of M-observation, as well as the point of normal visual perception, is to make this information explicit and thus available for further cognitive processes. Finally, as in the case of normal vision, it is uncertain whether this process of information explicitation is best conceived of as a process of cue exploitation or as a process of invariance detection. In both cases, the answer seems to depend in part on how one understands the notion of a proximal stimulus.

NOTES

[1] I thank Roberto Casati, Adriano Palma and Joëlle Proust for helpful discussions and comments.

[2] My attention was drawn on microscopes by the reading of Hacking's stimulating book on the philosophy of experimental sciences, *Representing and Intervening* (1983). I was struck by the similarities between some of the questions dealt with by Hacking in his discussion of microscopes and the issues concerning perception I was then and am still interested in.

[3] Gibson (1960, 1966) and his followers consider as fundamental the concept of the optic array, the spherically projected geometric pattern of ambient light around a station point. The optic array exists objectively independent of the existence of an observer. It is a potential stimulus that becomes actual when an eye is placed at the station point.

[4] "Direct" here does not mean that no physical events mediate between the interaction and the image, which would be nonsense, but that no "intentional" mediation is involved as it would be the case if, for instance, one were looking at a hand drawing of an object.

[5] In his 1990 paper, Dretske does not draw a distinction between causal and informational accounts of perception. Elsewhere, however (Dretske, 1969, 1979), Dretske is careful to distinguish between a causal account of sense perception and the information-theoretical account he himself endorses. The latter account insists that it is the delivery of information, not the causal connection, that is essential to our seeing things — even though this information is usually delivered by causal means.

[6] By constrast imagining or remembering, say, a bottle does not generally involve experiencing the bottle as actually being out there now. However, as Roberto Casati pointed out to me, imaginings and rememberings can have indexical contents. For instance, one can imagine or remember a bottle on t*hat* table or even imagine or remember *that* bottle being on *that* table. It seems that imaginings or rememberings of this kind involve experiencing the object(s) referred to by the indexical(s) as actually being out there now. Yet, there remains this difference with perception that the state of affairs imagined or remembered — the being on that table of that bottle — need not actually be realized nor experienced as realized.

[7] Note that I *don't* claim that exteriority or spatiality are distinctive of *visual* perception. I simply want to emphasize that they are important characteristics of it. I take it that exteriority is distinctive of perception in general by contrast to other kinds of mental processes. Besides, I am perfectly willing to admit that spatiality is also a feature of, say, tactile experience.

[8] Indeed, Marr (1982) acknowledges that it is the discovery of this fact, well documented in the neuropsychological literature on patients with left parietal lesions, that prompted him in part to go against the then prevalent trend in computer vision and to propose his own, now well-known, theory of vision.

[9] A similar distinction between perception and mere discrimination can be found in Evans (1985), who argues, following Bower (1974), that it is not sufficient for an organism to perceive spatially that it be capable of discriminating stimuli whose differences we describe in spatial terms.

[10] Note that this assumption is about information on spatial properties not on spatially-dependent properties. Thus, it does not deny the possibility that normal visual images and microscope images carry information on different spatially-dependent properties. Acoustic microscopes, for instance, are sensitive to the density and viscosity of objects, properties on which normal images do not usually inform us.

[11] This label can however be misleading in at least two ways. First, direct perception is nowadays often associated with Gibson's work on perception, which he himself describes as a theory of direct perception. However, Gibson's theory rests on several, not necessarily non-dissociable, assumptions, and it is not always clear which of these is meant when one speaks of direct perception. Second, philosophers have traditionally used those labels to refer to another distinction, namely the distinction between theories that claim that we are directly aware of objects and facts in the world (theories of direct perception) and theories that claim that what we are directly aware of are our subjective states — sensations or mental representations of some sort — and that our knowledge of the external world is indirect and derives from our knowledge of our subjective states (theories of indirect perception).

[12] Cutting (1986) himself argues in favor of a third possibility, directed perception, that involves a many-to-one information-to-object mapping. For him, then, information in the proximal stimulus overdetermines the distal layout. The name "directed perception" refers to the fact that, given this abundance, we have to select what information to use.

[13] Berkeley used the term 'sign'. According to Cutting (1986: 261, n. 15), William James may have been the first to use the word 'cue'.

[14] As pointed out by Hacking (1983), there are no less than eight main types of aberrations in the simplest optical microscope.

[15] Note that automaticity does not necessarily go together with innateness. To use the terminology of computer science, a process can be automatic either in the sense of being hard-wired or in the sense of being compiled.

[16] It is important to note that the invariants we are concerned with here are the invariant features of a persisting thing, not the invariant features that make different things similar; they are invariants over time, not invariants over things. There is a close relation between this distinction, underlined by Gibson himself (1986: 249) and the distinction I myself drew between intermediate and cognitive perception.

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