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ORIGINAL PAPER

Extended Cognition and Constructive Empiricism

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Abstract
According to constructive empiricists, accepting a scientific theory involves belief only that it is true of the observable world, where observability is defined in terms of what is detectable by the unaided senses. On this view, scientific instruments are machines that generate new observable data, but this data need not be interpreted as providing access to a realm of phenomena beyond what is revealed by the senses. A recent challenge to the constructive empiricist account of instruments appeals to the extended mind thesis, according to which cognitive processes are sometimes constituted not just by brain activity, but can extend into the rest of the body and the surrounding environment. If this is right, scientific instruments may, in the right circumstances, literally become part of our perceptual processes. In this article, I examine this extended perception argument, and I find that it fails for the vast majority of scientific instruments. Even if the extended mind thesis is accepted, the constructive empiricist can draw a line between observables and unobservables that makes very few concessions to the realist.

1 Introduction

This article is concerned with the different accounts of observability given by scientific realism and constructive empiricism. According to scientific realism, we are justified in believing that our best theories provide approximately true descriptions of the world. To accept a scientific theory is to believe that it is true and that the entities and processes postulated by the theory really exist. A central commitment of realism is that the existence of such entities and processes can be confirmed through the use of instruments such as microscopes. Instruments are tools for detecting and

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measuring phenomena, and many instruments outstrip what is revealed by unaided perception. As the realist sees it, such instruments are, to use van Fraassen's metaphor, "windows on the invisible world" (2008, p. 96) through which we observe formerly hidden entities such as viruses and mitochondria. For the realist, there is no epistemically relevant distinction between human perception, and human perception with instruments.

By contrast, according to constructive empiricism, to accept a scientific theory involves belief only in its empirical adequacy, that is, belief that the theory is correct in its description of the observable phenomena. As van Fraassen summarizes the view:

> Science aims to give us theories which are empirically adequate, and acceptance of a theory involves as belief only that it is empirically adequate. … a theory is empirically adequate exactly if what it says about the observable things and events in the world is true – exactly if it "saves the phenomena." (van Fraassen 1980, p. 12)

Of course, we do not accept theories merely on the grounds that they accommodate the observable phenomena. If two theories T and T* make the same claims about the observable phenomena, we may accept T on the basis of other theoretical virtues: perhaps it is simpler, or it has greater explanatory scope, or we expect it to be more fruitful for further research. The constructive empiricist takes such theoretical virtues to be merely pragmatic virtues (van Fraassen 1980, pg. 87). The only criterion that indicates the truth of the a theory, and so the only criterion relevant to belief, is empirical adequacy.

How should empirical adequacy be understood? The constructive empiricist holds that the observable is that which can be detected by normal human senses unaided by instruments. We need not actually be in a position to observe something for it to count as observable: Nobody could currently detect the moons of Jupiter except with the aid of a telescope, but they still count as observable because normal humans would be able to visually perceive them unaided, if they were located close enough (van Fraassen 1980, p. 16). The important point is that the limits of observability are set by human perceptual capacities. Instruments are not windows on an otherwise invisible world, but are instead "engines of creation" (van Fraassen 2008, pg. 96) that produce new images that must be accommodated by scientific theories. The observable phenomenon is the image generated by the instrument, not the entity to which our theories take that image to correspond. When we peer through an optical microscope, we do not literally observe *Paramecia*; rather, the optical microscope generates *Paramecia*-images, and we may remain agnostic about whether these images correspond to any real objects.

A standard objection to constructive empiricism is that either there is no sense to be made of the observable/unobservable distinction, or that the boundaries of observability extend far beyond the unaided senses. There is a voluminous literature on this topic (see e.g. Maxwell 1962, Churchland 1985, Hacking 1985, Alspector-Kelly 2001, and Teller 2001), and it may seem that realists and constructive empiricists have reached something of a deadlock. Recently however, a new argument along these lines has been proposed by Toon (2014), who appeals to the extended mind thesis. The extended mind thesis claims that cognitive processes are sometimes constituted not just by brain activity, but can extend into the rest of the body and the surrounding environment. Toon makes the case for extended perception: there are many circumstances where scientific instruments do not simply augment the senses, as the traditional realist would argue, but can literally become part of a perceptual process. That is, we literally perceive the objects detected by these instruments. In the right circumstances, a human being plus a scientific instrument can form a unified cognitive system. This undermines the constructive empiricist account of instruments, which presupposes that instruments merely provide input to the human cognitive system: an instrument produces images, which are then perceived and interpreted by humans. If perception literally extends through instruments, this account is untenable.

It is important to be clear about the scope of this critique. The extended perception argument concedes that acceptance of a scientific theory involves belief only in what it tells us about the observable, and it concedes that observability a matter of perceptual capacities. As van Fraassen has noted, what matters for constructive empiricism is that a line can be drawn between the observable and unobservable, and that this line is relevant to our interpretation of the aim of science. The extended perception argument, if successful, only shifts the line. Still, it is clear that the notion of observation as unaided perception, or something close enough, has played an important role in van Fraassen's philosophy. The extended perception argument raises a serious challenge to this, even if a more liberal form of constructive empiricism could be stated within the framework of extended perception.

This article has two goals. First, I will argue that for the vast majority of instruments, the extended perception argument fails. Many instruments function by producing new artefacts that are presented for inspection and interpretation; I argue that such instruments are not plausible candidate for extending perception. Second, in the course of this discussion, it will emerge that there is a sensible line to be drawn between the observable and the unobservable. This line is close to where van Fraassen initially placed it. The article is structured as follows. In the next section, I describe the extended perception argument. Then in Sect. 3, I outline an alternative way of thinking about scientific instruments that still respects the insights of the extended mind hypothesis, but on which we do not literally perceive things through most of those instruments. In Sect. 4, I explain why Toon's extended perception argument fails. Section 5 considers whether other approaches to the extended mind might support an extended perception view and finds them unsuited to this task. I conclude that the extended perception argument poses little threat to the constructive empiricist.

2 The Extended Perception Argument

There is clearly a close connection between instrumentation and perception. In particular, instrumentation and perception share an important feature: they are both means for detecting properties in the world by establishing a special kind of causal connection with those properties. Indeed, we might view our perceptual systems as being types of instruments. Humans are subjected to a certain type of input, and in the right conditions they produce an output, phrases such as "the ball is red", "the cube is orange", "*a* is darker than *b*", "*c* is bluer than *d*", etc. Just as we use instruments such as gamma ray telescopes, and link particular data produced by those telescopes to specific wavelengths of gamma rays, so we can link our colour reports to specific wavelengths of electromagnetic radiation.

So perhaps perception just is an instrument. But are all, or a significant number, of the instruments beyond the body also perceptual? As I will discuss later, there are many different types of extended mind hypothesis, which could allow different ways to defend the claim that instruments extend perception. Toon's argument appeals to the parity principle of Clark and Chalmers (1998). Clark and Chalmers introduce the parity principle with the famous example of Otto and Inga. Both Otto and Inga want to visit the Museum of Modern Art. Inga is a normal adult, and she simply remembers that the Museum is located on 53rd street, and heads off in the right direction. Otto has Alzheimer's, and carries a notebook with him in which he records important information.[1] He looks up the location of the Museum, sees that it's on 53rd street, and heads off in the right direction. Clark and Chalmers argue that the notebook is literally part of Otto's memory, and that whatever is written in Otto's notebook forms part of his set of beliefs. Inga and Otto both use similar information in similar ways; the only difference is that in Inga's case, the information is located in her brain, whereas for Otto, it is located in his notebook. According to the parity principle, location is not relevant to whether something is a cognitive process:

> If, as we confront some task, a part of the world functions as a process which, were it done in the head, we would have no hesitation in recognizing as part of the cognitive process, then that part of the world is (so we claim) part of the cognitive process. (Clark and Chalmers 1998, p. 8)

One way to apply the parity principle to the case of scientific instruments is to imagine an intelligent Martian with a mechanism in its head that functions just like the instrument used by the scientist. If we would judge this to be part of a perceptual process in the Martian, then by the parity principle, we should also conclude it forms part of a perceptual process for the scientist. So imagine a Martian with a mechanism inside its head that can detect what is detected by the human eye plus the optical microscope. In the case of a single-lens microscope, we can just imagine a Martian with a visual system that is essentially the same as the human visual system, except the lenses of its eyes have a far smaller diameter. Surely we would say that this Martian can literally see *Paramecia*. A similar story can be told for almost any other scientific instrument – or so it seems, at least. For most instruments, we can imagine a similar mechanism inside the head of an intelligent Martian, and in this hypothetical case, we are inclined to say that the Martian can literally see what the instrument allows it to detect. Toon summarizes the argument as follows:

[1] Smart (2018) gives a contemporary twist on the thought experiment: consider Otto++, a man with Alzheimer's who installs an app on his smartphone that allows him to rapidly access important pieces of information. The smartphone is linked to augmented reality glasses so that the information can be displayed in his visual field. The information retrieved by the app plays a functional role very similar to that of beliefs stored in memory.

(1) Object X is detectable with instrument Y but not with the unaided senses.
(2) When used by the scientist, instrument Y forms part of her perceptual process.
(2i) (By intuitive judgment) If Y were inside the head of a Martian, it would count as part of the Martian's perceptual processes.
(2ii) (By the parity principle) Y is part of the scientist's perceptual processes.
(3) Therefore, *contra* van Fraassen, X is observable. (Toon 2014, p. 415)

If this is right, then a variety of scientific instruments are already part of the scientist's perceptual system, and so the scientist straightforwardly observes things detected by those instruments. If, as the constructive empiricist argues, acceptance of a scientific theory consists in belief that it saves the observable phenomena, then we are committed to belief about a much broader range of entities than constructive empiricists usually allow. While this is similar to some previous realist objections to van Fraassen's position, Toon argues that it is superior. Unlike the arguments of Hacking (1985), for instance, the extended perception argument does not involve inference to the best explanation, an epistemic rule that van Fraassen rejects (Toon 2014, p. 419–420). The extended perception argument only requires the intuitive judgment about the hypothetical case of the Martian, in conjunction with the parity principle.[2]

3 An Alternative View of Instruments

There is an important distinction between scientific instruments that is obscured by Toon's extended perception argument. To explain this distinction, I will compare two types of microscopes: optical microscopes and atomic force microscopes. The optical microscope shows us an object in visible light, using a system of lenses to magnify the object. This is a very similar to the mechanism of the human eye, which uses a lens to refract visible light. Indeed, the simplest microscopes such as those of Van Leeuwenhoek were just single lenses. A spherical bead of glass acts as a mag-

[2] It might be worth noting that there is a step missing in Toon's argument. If his argument is successful, it shows that instruments can sometimes be part of the scientist's perceptual process. But from this alone, it's not obvious that entities detected with the use of that perceptual process count as observable. After all, as noted above, van Fraassen takes it that what's observable is that which is detectable through *unaided* perception. So the constructive empiricist could hold that some instrument is part of a scientist's perceptual process, while still resisting the claim that this process constitutes unaided perception. However, I do not think that this is a particularly significant problem for Toon's argument. Although van Fraassen could in principle adopt this position, it is unclear what the motivation for it would be, and in any case, I do not think it would be particularly appealing given his other commitments. The reason is that whether or not something is observable is, for van Fraassen, an empirical question, dependent on facts about our physiological and cognitive capacities. The limits of observation are the subject of empirical science: "The theory draws a picture of the world. But science itself designates certain areas in this picture as observable" (van Fraassen 19801980, p. 57). If we are to look to our best scientific theories to draw the limits of observability, then theories of perception are the obvious place to find a line that is relevant to van Fraassen's concerns. If you want to know what it is that humans can observe, look to our best theories of human perception. It's not clear how else we could draw that line in a non-arbitrary way. But in that case, if our best theory of perception involves extended perception, then we should accept that extended perception counts as a form of observation, even if extended perception is not strictly speaking "unaided".

nifier: the smaller the diameter, the greater the magnification. Van Leeuwenhoek's surviving lenses achieve a magnification of up to 275x; some of his lenses possibly achieved magnification of up to 500x, an exceptional magnification for the time (Bradbury 1967, p. 73). Modern compound microscopes containing more than one lens can magnify up to 800x with lenses alone, without the use of techniques such as oil immersion. Figure 1 shows the model of a compound optical microscope:

The diamonds are labelled: *a* is the object; *b* is the "real image", the focus points of light rays converging from *a*; and *c* is the enlarged virtual image seen by the viewer. In this case, the parity principle is straightforwardly applied. We can imagine a Martian with an optical microscope in its head – or just a Martian with lenses in its eyes of a smaller diameter than are found in humans. We would say that the Martian sees the *Paramecium*. Indeed, we need not even imagine this: Visual systems with similar resolving power to optical microscopes already exist in some small animals. A small fish may see a *Paramecium* that is invisible to the human eye, in virtue of the smaller

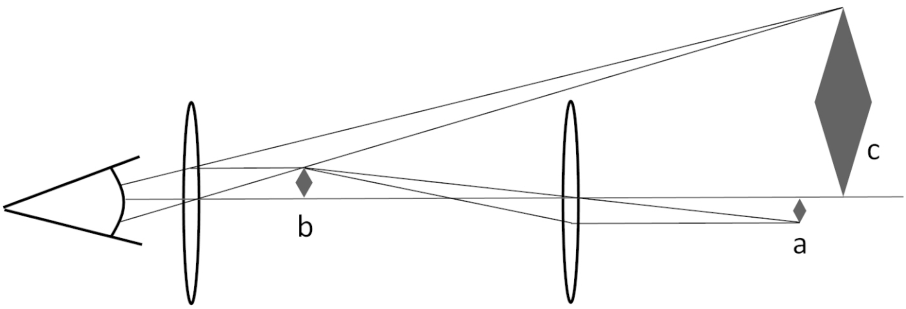

Fig. 1 Compound optical microscope

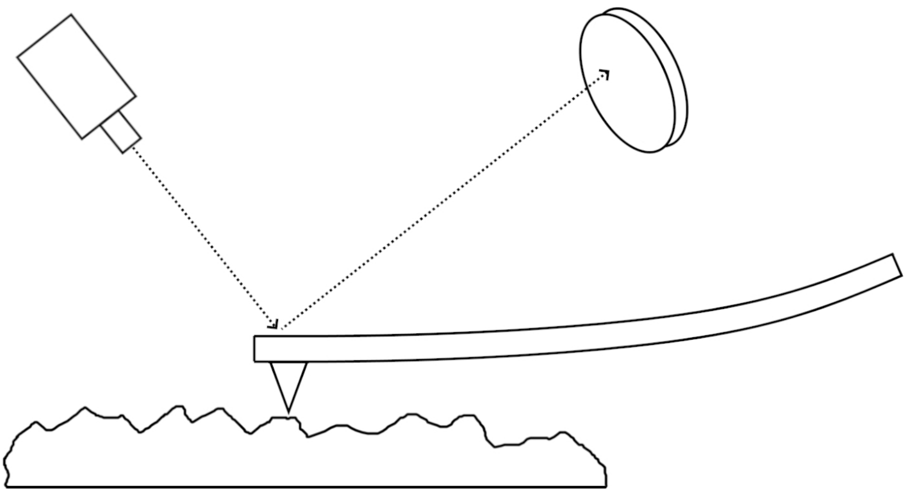

Fig. 2 Atomic force microscope

lens in the eye of the fish. So by the parity principle, we should say that the optical microscope literally extends vision. What about other instruments?

The resolving power of optical microscopes is limited by diffraction. We can achieve greater resolving power with different mechanisms. One such mechanism is found in atomic force microscopy. This is shown in Fig. 2:

The cantilever is a long rod with a sharp tip at the end; the point of the tip consists of just a few atoms. The cantilever is moved across the sample, and the forces between the tip and the surface deflect the cantilever up and down, depending on the topography of the sample. A laser beam is pointed at the top of the cantilever, and the beam reflects from the top of the cantilever into a detector. As the cantilever moves up and down, it deflects the laser beam; and by tracking how the laser is deflected, a computer can build up an image of the topography of the sample.

Obviously, this is nothing like vision. Although the atomic force microscope produces an image that is visually perceived, we should not be misled by this into supposing that atomic force microscopy extends sight. After all, the information produced by an atomic force microscope could be communicated in some other way, such as via sound or touch. Unlike the optical microscope, it is not entirely clear which sense is extended by the atomic force microscope. In itself, this is no challenge to the extended perception argument; as Toon notes: "the extended perception argument does not rely on the claim that the aliens perceive objects using the same physical processes, or even with the same fine-grained perceptual psychology, as we do" (2014, p. 421). Consider the Martian with an atomic force microscope in its head. We don't need to claim that this is a form of sight. All that matters is that it counts as some sort of perceptual process. This is surely plausible: after all, we already recognize that different creatures may have perceptual processes very different from anything we find in humans, such as echolocation in bats, magnetoception in birds, and electroception in sharks. So the fact that most scientific instruments would have to be taken as producing new perceptual capacities rather than simply extending old ones does not in itself refute the extended perception argument. But I do think that this difference between the optical microscope on the one hand, and the atomic force microscope on the other, points to a serious problem for the extended perception argument.

As I see it, the significant difference between the optical microscope and the atomic force microscope is that when we use an atomic force microscope to detect some object X, the detection of X is necessarily *indirect*. The atomic force microscope produces a literal image on a computer screen, and we see X only via seeing the image. The information about X could of course be delivered in some other way, as the microscope could produce sounds or construct an object that could be touched; but our access to X will always be indirect in the same sense. We access X only via an artefact produced by the microscope.

In contrast, when we look at X through an optical microscope, we are not looking at an artefact that represents X. If I use a lens to view a paramecium, I can see that the lens is transparent, and that there is not a literal, material image of a paramecium inside the lens. Of course, we may talk about lenses creating "real images" and "virtual images", but these technical terms refer respectively to where light rays converge and where light rays appear to have converged. Real images and virtual images are not material objects. Van Fraassen (2008, p. 103–105) provides a useful way of thinking about this in his catalogue of different kinds of images. *Graven images* are images that are material objects, such as paintings, photographs, sculptures, and films. *Private images* are purely subjective experiences such as dreams, hallucinations, and after-images. Finally there are *public hallucinations*, which are images that are not subjective but are also not genuine objects: rainbows, shadows, reflections, mirages, and so on. Some public hallucinations are images of real things (the reflection of the tree in the lake); others are not images of anything (rainbows are not images of anything). Van Fraassen treats the appearances produced by optical microscopes as public hallucinations. The question is, should we take such appearances as images of real things?

The category of public hallucinations is questionable, but an evaluation of this category is not exactly my point. Let's say we hold that this category should be rejected. Then it seems we have no choice but to treat optical microscopes as "windows on the invisible world." There is nothing else they could be. They do not create graven images. There is not literally an image, a material object, inside the lens of an optical microscope; no more than there is a literal image inside the lens of a magnifying glass. In this respect a simple microscope is no different in kind from a powerful magnifying glass or even a window. We simply see through these things; they do not produce images. In these cases our perception of the object is direct. As Maxwell (1962) said, there is a continuous series from "looking through a window pane, looking through glasses, looking through binoculars, looking through a low power microscope, looking through a high power microscope, etc." – this is exactly right, provided we are considering only optical microscopes, no matter what their magnification. By contrast, many scientific instruments produce only graven images, which may or may not depict real things: the output of an atomic force microscope is a case in point. Other scientific instruments do not produce images at all, or at least their outputs are not usually interpreted as images: the white streaks produced by a cloud chamber do not *represent* charged particles, but according to our best theory are produced by charged particles much as a jet plane produces a trail in the sky, which supports inferences from what is seen in the cloud chamber to what is going on in the invisible world.

With this in mind, my key claim is this: In van Fraassen's terminology, only instruments that can be interpreted as creating public hallucinations are plausible candidates for extending perception. For such instruments, if we reject the hallucination interpretation, they must be treated as "windows" instead. But instruments that produce artefacts, even if these artefacts are graven images, as in the case of the atomic force microscope, are not plausible candidates. If I am right, the line between instruments that plausibly extend perception and those that do not is where the only access to the information provided by the instrument is via a graven image. In my view, the atomic force microscope has more in common with a cloud chamber than with the optical microscope. The atomic force microscope produces an image that we take to represent some unobservable structure. The cloud chamber produces phenomena that we could take as representational, but we do not. Now peer through an optical microscope. There is no image or artefact about which we can ask: what, if anything, does this represent? This is a question that may be asked about the output of an atomic force microscope. This is a significant difference, completely lost if we view scientific instruments in general as extensions of perception.

This difference is presupposed by our models of these instruments. Recall the instrumental model of the optical microscope shown in Fig. 1. Notably, this model includes the human eye at the left. The model must depict a “receiver” at the left; without this, it would not properly represent how the optical microscope functions. This receiver need not be a human eye, but it can be. Contrast this with the instrumental model of an atomic force microscope, where no parts could be replaced with a human sensory organ. These models are given by the sciences. If we are using our best scientific theories to delineate our perceptual capacities, this suggests an important sense in which the optical microscope is an extension of vision, so there is genuine perception through an optical microscope. This is not the case for the atomic force microscope.

Perhaps the realist could grant that there is an important difference here, but still insist that I have not dealt with the extended perception argument. After all, everybody recognizes that there are differences between different perceptual processes. So if we must recognize differences between perception with an optical microscope and perception with an atomic force microscope, this is no matter. We can accept that perception with an atomic force microscope occurs via the production of a graven image; this differs from other kinds of perception, but if the parity principle is accepted, it’s still perception. I grant that so far I have only presented an alternative view; I have not yet dealt with the appeal to the parity principle. So let’s turn to this.

4 Why the Appeal to the Parity Principle Fails

In this section, I aim to undermine the use of the parity principle in Toon’s extended perception argument. Toon asks us to imagine a Martian with an atomic force microscope in its head: surely, despite what has been said in the previous section, we would still say that this is part of the Martian’s perceptual process. Hence, by the parity principle, the atomic force microscope does extend perception! I am not convinced. I suggest that when the thought experiment involving the Martian is analysed more carefully, with attention to how the instruments in its head functions, we are not tempted to take this as a perceptual process. There are two ways in which the Martian thought experiment is seriously misleading.

First, what we are tempted to imagine when we imagine the atomic force Martian is that the output of the atomic force mechanism in the Martian’s head is not an artefact that is then made available for the Martian’s examination, but is simply immediate sensory data, in the same way that the output of the human visual system is immediate sensory data: I see the greenness of grass, not an image of the greenness of grass. But to interpret the Martian’s perceptual system this way is to ignore the features of atomic force microscopes that I have outlined in the previous section. When we adjust the thought experiment to account for these features, I suggest that we do not have the intuitive judgement that the Martian is perceiving anything with its atomic force mechanism.

Consider photography. A photograph creates an image of a scene that is highly realist. In the ideal case, we could have a photograph looks exactly like the original scene looks, if you are viewing the scene from the same vantage point as the camera. When we look at a photograph we know that it accurately represents what it depicts, provided it hasn't been retouched. So this is a case where questions about realism and antirealism do not arise; we all agree that photography can augment our perceptual capacities since we could in principle perceive the objects depicted in a photograph without the aid of the photograph. Yet Walton's (1984) claim that photographs are transparent, that we literally see through a photograph to the object it depicts, at least initially seems bizarre. Why? What photographs lack is a certain kind of directness. When we see a photograph of an object, we see the object only via seeing another, completely different object. The photograph is a graven image.

Does the extended mind thesis support the Waltonian view of photographs? I don't think so. Imagine a Martian that has in its head a mechanism that functions just like a camera. This mechanism produces an image of whatever the Martian is looking at – a literal image, a graven image, that is stored inside its head in a file of images that it can flick through when it wants to revisit them. One day the Martian witnesses a crime, and it creates several images of the crime, which later it revisits in order to answer questions about the crime. Intuitively, this is some sort of cognitive process. But is it perception? Surely it would more naturally be classed as a kind of memory: literally a photographic memory! What this thought experiment establishes, if it establishes anything, is that there are circumstances where a file of photographs can count as an extended memory. *Perception* through a photograph seems no less bizarre when it's going on in the head of a Martian than under normal circumstances. The moral for the atomic force microscope should be clear: if even a photograph, which we all agree accurately reveals the genuine structure of the world, does not extend perception, then an image produced by an atomic force mechanism doesn't either.

I have claimed that what is missing in photographs and in images created by atomic force microscopes is a certain kind of directness, since the object is perceived only via perceiving another object. What exactly do I mean by *directness*? Unfortunately, I do not know how to define this for perception in general.[3] To begin developing the notion I suggest that visual perception of an object requires the detection of light that has interacted with an object and/or its surroundings. I see a mountain by detecting light that has been reflected by the mountain. Light hits the mountain: some is absorbed, some is reflected back and hits my retina. Perhaps we would say that an object is seen when it blocks light, as when we see a silhouette; here we detect the object by detecting the light around it. Either way, what hits our eyes is light that has interacted in some way with the object or its surroundings. This condition holds for objects seen through optical microscopes: viewing a *Paramecium* through an optical microscope, the light that hits my eye is light that was reflected off or transmitted through the *Paramecium*. Hence we have a direct connection to the *Paramecium*.

[3] The issue of directness in extended perception parallels a similar problem with the original arguments for extended beliefs in the case of Otto. In normal cases, we have a kind of privileged access to our own beliefs, but if information in his notebook is partly constitutive of Otto's beliefs, then Otto's access to his own beliefs is not privileged. I might attribute beliefs to Otto in the same way that he will attributes beliefs to himself: by looking in his notebook. See Schwengerer (2021) for discussion,

However, looking at a graven image of a *Paramecium* created by a photograph or an atomic force microscope, I am not detecting light that was reflected off or transmitted through the *Paramecium*.

The second problem with the Martian thought experiment is that given how instruments such as atomic force microscopes actually function, it is implausible to suppose that they could ever be part of the head of any organism. Of course, philosophers often appeal to thought experiments, sometimes quite outlandish, and I do not want to argue against this practice in general. The problem in this case is that it's not at all clear what we are being asked to imagine. We are tempted by the image of a Martian with atomic force microscopes in place of its eyes; as it wanders around the world it points its atomic force microscopes at things and then receives information about them. Intuitively, this is a perceptual process. But of course, this is simply a fantasy. Since this is not how atomic force microscopes work or could work, it is illegitimate to use this example to conclude that such instruments in fact extend perception. They only seem to extend perception in the thought experiment because the thought experiment prompts us to conceive of atomic force microscopes in a way that is contrary to how they actually operate. This is an instance of a more general problem in the extended cognition literature, which Aagaard (2021) calls the "dogma of harmony". When writers on extended cognition describe human-technology interactions, there is a tendency to overemphasize the smooth, harmonious integration of minds and technology, and downplay the difficulties.

Although atomic force microscopes are now standard laboratory equipment, there are several complications in their use. One important point is that you do not simply point an atomic force microscope at anything; rather, you place a sample under the cantilever. Such samples must be carefully prepared: first the sample must be cut to an appropriate size; then it must be fixed to an appropriate substrate to prevent any movement during scanning, which would otherwise interfere with the measurements made by the cantilever; chemicals may need to be applied to make certain features more salient; etc. Sample preparation usually takes place in a vacuum to prevent contamination. Similar points hold for other types of sophisticated microscopy. When using such instruments we first have to create an artefact that can interact with the microscope in the right kind of way so as to produce a usable image.

Even after the sample is installed into the microscope, several other steps must be taken. Since atomic force microscopes are highly sensitive, there are numerous potential sources of interference. I will briefly describe two; see Eaton and Batziou (2019) for a much more extensive list. A common problem is mechanical vibration. The microscope must be maintained in a low-noise environment, such as inside a wooden box lined with foam; and before scanning the sample, the microscopist must employ damping tools are used to ensure that the microscope is isolated from vibrations. Another common problem is thermal drift, where a sample expands or contracts during scanning due to a thermal gradient. For high-resolution imaging, the equipment may need to be prepared and then left alone for several hours to allow it to move into thermal equilibrium, before scanning occurs. It is in cases like this that the "window on the invisible world" metaphor breaks down. Even if there were a way of getting an atomic force microscope inside the head, such a creature could not use it in its interactions with the world in anything like the way any perceptual process – or any other mental process more generally – is used by real creatures.

When we imagine a Martian with an optical microscope in its head, we are imagining an organism that is much like organisms that we are familiar with. For this thought experiment, we can simply imagine an organism with lenses of a smaller diameter in its eyes. But when we try to imagine a Martian with an atomic force microscope in its head, or some other mechanism that magnifies as much as an atomic force microscope, what would this organism actually be like? It is far from clear how to fill in the details. I conclude that the parity principle does not support the claim that instruments such as atomic force microscopes extend perception.

5 Beyond the Parity Principle?

There are, of course, other arguments for extended perception that do not rely on the parity principle. Toon points out (2014, p. 416) two other arguments for the extended mind that appeal to the notion of close coupling (Clark 2010) and to phenomenological considerations (Clark 2003). Might we use these to attack van Fraassen's conception of observability? These can be dealt with swiftly. Close coupling, where brain, body, and external instrument are tightly integrated, is not possible for sophisticated instruments such as atomic force microscopes. Perhaps it would be possible for a person to carry a simple optical microscope everywhere and to employ it enough in their dealings with the world that it counts as part of their cognitive system, but few instruments are so user-friendly.

As for phenomenological arguments, these appeal to the experience of using certain tools, and how those tools may become part of a person's body image: for instance, when a blind person who is proficient with a cane takes the cane as an extension of their body. In such cases, technology becomes phenomenologically transparent: "where external technology is used in a skilled and hitch-free manner, that technology disappears from the conscious apprehension of the user" (Wheeler 2019, p. 858-9). The blind person does not direct any conscious attention to the cane, just as I do not usually direct conscious attention to the operation of my eyes. However, as I have noted in the previous section, users of atomic force microscopes must perform several, sometimes tedious tasks before even scanning a sample, and must constantly be wary of artefacts and interference. Moreover, looking at the final image created by an atomic force microscope is phenomenologically like looking at any other image such as a photograph. It does not have the different phenomenology that would be expected of a new perceptual process.

There is another option that is not discussed by Toon, enactivism (Ward et al. 2017). Enactivism proposes that perception does not involve the mind mirroring or representing the world, but is instead a relational process arising from the interaction between the organism and its environment, from the organisms exercising various skills and abilities in the environment. Perception is tied to action; we perceive the world in order to do various things in it. In particular, perception involves exercising our knowledge of "sensorimotor contingencies", which are regularities in the way that sensations change as a result of bodily movements (cf. Noë 2004). As I move towards a black object, for instance, my visual sensations will change in regular, predictable ways: blackness will increasingly fill my visual field, and blackness will occlude more objects previously in my visual field. In general, I know that an object will appear larger as I approach it, I know how its apparent angles will change as I move around it, I know how it will feel if I pick it up and how much force to use when doing so, I know how moving will reveal things occluded by the object, and so on. In Gibson's language, we see the environment as *affording* various possibilities for action (Gibson 1979).

Enactivism provides no comfort for the extended perception argument. If anything, my claim about the fundamental difference between perceiving X and perceiving a graven image of X is especially well-suited to the enactivist view. On my desk is a cup and a phone. I know that as I move, different parts of the cup and phone will be revealed; that at times the cup will occlude the phone; that some parts will be in shadow and others in light. The cup and the phone both afford various possibilities for action, in that I could throw the cup and use it to smash the window. Now suppose, by contrast, I look at a photograph of the same scene. As I move around the photograph, the image of the cup doesn't occlude the image of the phone. I can't use the image of the cup to smash the window. The affordances of X and the affordances of a graven image of X are very different. The output of an atomic force microscope is merely an image; the sensorimotor contingencies are just as they would be for a photograph or a painting. I conclude that none of the alternative approaches to extended perception can support the claim that a wide range of scientific instruments form part of our perceptual processes.

6 Conclusions

This article has not challenged the extended mind thesis, or even the extended perception argument in principle. There may well be a few scientific instruments, such as optical microscopes, that literally extend perception. This does not raise a significant challenge to constructive empiricists; as noted in the introduction, what is important for the constructive empiricist is that there is a line between the observable and unobservable, which is close to unaided human perception (cf. van Fraassen 2001, p. 162–163). The question, then, is how broadly the extended perception argument applies. I have argued that it fails for the vast majority of scientific instruments. Instruments that produce graven images, new objects that are presented for inspection and interpretation, are not plausible candidates for extended perception; in moving from an optical microscope to an atomic force microscope, we lose the direct connection with the objects that are apparently revealed by the instrument. This provides a straightforward criterion of observability: the observable is that which is detectable by the senses, unaided by the production of new material objects. The appeal to the parity principle for instruments such as atomic force mircroscopes loses its force when the examples are considered in any detail, and when we consider how these instruments actually function. So, even granting the extended perception framework, there is not yet any good reason to think that instruments in general extend perception.

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