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Grounded empiricism

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Abstract
Empiricism has a long and venerable history. Aristotle, the Epicureans, Sextus Empiricus, Bacon, Locke, Hume, Mill, Mach and the Logical Empiricists, among others, represent a long line of historically influential empiricists who, one way or another, placed an emphasis on knowledge gained through the senses. In recent times the most highly articulated and influential edition of empiricism is undoubtedly Bas van Fraassen's constructive empiricism. Science, according to this view, aims at empirically adequate theories, i.e. theories that save all and only the observable phenomena. Roughly put, something is observable in van Fraassen's view if members of the human epistemic community can detect it with their unaided senses. Critics have contested this notion, citing, among other reasons, that much of what counts as knowledge for scientists, especially in the natural sciences, concerns things that are detectable only with instruments, i.e. things that are unobservable and hence unknowable by van Fraassen's lights. The current paper seeks to overcome this objection by putting forth and defending a liberalised conception of observability and an associated, and accordingly liberalised, conception of empiricism. 'Grounded observability' and 'grounded empiricism', as we call them, unchain themselves from the burdens of traditional conceptions of experience, while at the same time tethering themselves to the source of epistemic credibility in the senses, and, hence to the true spirit of empiricism.

Keywords Empiricism · Constructive empiricism · Realism · Observability · AI agents · Grounded empiricism

1 Introduction

Empiricism has a long and venerable history. Aristotle, the Epicureans, Sextus Empiricus, Bacon, Locke, Hume, Mill, Mach and the Logical Empiricists, among others, represent a long line of historically influential empiricists who, one way or another, placed an emphasis on knowledge gained through the senses. In recent

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times the most highly articulated and influential edition of empiricism is undoubtedly Bas van Fraassen's constructive empiricism. Science, according to this view, aims at empirically adequate theories, i.e. theories that save all and only the observable phenomena. Roughly put, something is observable in van Fraassen's view if members of the human epistemic community can detect it with their unaided senses. Critics have contested this notion, citing, among other reasons, that much of what counts as knowledge for scientists, especially in the natural sciences, concerns things that are detectable *only* with instruments, i.e. things that are unobservable and hence unknowable by van Fraassen's lights. The current paper admits the objection's judiciousness and, in reaction, investigates what gives sensory organs epistemic credibility. It turns out that their credibility can be traced to some principles that are also satisfied by certain instruments. On the basis of this work, a liberalised conception of observability is proposed and defended, along with a closely linked, and accordingly liberalised, conception of empiricism. 'Grounded observability' and 'grounded empiricism', as we call them, remain true to the spirit of empiricism, but acknowledge that epistemic credibility extends far beyond biological sensory organs to include scientific instruments.

The structure of this paper is as follows. Section 2 outlines the key ideas behind van Fraassen's notion of observability. Section 3 fleshes out some problems with those ideas, ultimately raising doubts about the feasibility of the notion itself. Section 4 identifies the real source of epistemic credibility in the senses, which takes the form of compliance with two principles M and T. Section 5 makes a case for the view that the same epistemic credibility can be found in some instruments and even in purely artificial agents, so long as principles M and T are satisfied. Section 6 presents the two key notions of this paper, namely grounded observability and grounded empiricism. Section 7 contrasts the proposed account of the source of epistemic credibility with an account due to Azzouni (1997). Section 8 returns to the broader scientific realism debate and asks where the emerging empiricism leaves the realist. Section 9 concludes with a summary of the main points.

A proviso is in order before we proceed. Examples of observations in the sections that follow are drawn mainly from biology. One reason for this choice has to do with the fact that astronomy and physics are overrepresented in discussions of empiricism, and, indeed, in our own work on how to defend the veridicality of observations against the theory-ladenness thesis (Votsis, 2015, 2020). Having said this, it should be clear from the discussion that ensues that this choice is otherwise inconsequential to the arguments advanced, and that examples drawn from any scientific discipline would work just as well.

2 Observability à la constructive empiricism

This section is exclusively concerned with an attempt to provide a faithful representation of the ideas behind van Fraassen's notion of observability, as well as some of the adjustments these ideas underwent over the years. We begin by laying out the key idea of observability as an ability to detect the environment with one's sensory organs.[1] We then proceed to articulate the bounds of this ability in terms of species-specific limitations. Finally, we examine an alteration of the notion of observability, which sees van Fraassen explicitly admit that the class of observables may be larger than he at first imagined.

Although Van Fraassen (1980) identifies phenomena with "observable processes and structures" (p. 3), he employs the adjective 'observable' to qualify a number of different ontological categories, including entities, objects and events (p. 14), things (p. 21), facts (p. 24), correlations (p. 26), regularities and reality (p. 32), factors (p. 33), quantities (p. 53), characteristics (p. 54), parts of the world (p. 59), physical magnitudes (p. 65), aspects of the world (p. 72), mechanisms (p. 80) and course of nature (p. 203).[2] It is fitting then that in his elaboration of the notion of observability he leaves the 'subject' of observability/unobservability unspecified: "X is observable if there are circumstances which are such that, if X is present to us under those circumstances, then we observe it" (1980, p. 16).[3] Van Fraassen goes on to explain:

> The human organism is, from the point of view of physics, a certain kind of measuring apparatus. As such it has certain inherent limitations – which will be described in detail in the final physics and biology. It is these limitations to which the 'able' in 'observable' refers – our limitations, qua human beings (1980, p. 17).

In other words, something is observable-to-us humans if, inherent limitations permitting, we are able to detect it with our very own sensory organs.[4] Thus fish in the Mariana Trench and rocks on Mount Everest are observable-to-us, but atoms and nucleotides are not. Instrument-mediated detection is sanctioned so long as there are also circumstances that allow for the detection of the same things using only our unaided senses. A crater on Jupiter's moon Europa is observable-to-us because, even though we currently rely on instruments to detect it, there are (arguably) circumstances where human beings can get close enough to detect it with their own sensory organs.

The last quote makes plain that for van Fraassen observability is drawn along biological lines. What is not so plain, though it seems to be suggested, is that observability is drawn along *species-specific* lines. Whatever the pertinent biological category, it is clear that the sensory abilities/limitations of one and the same such category are subject to evolution. Suppose, for simplicity, that the intended biological category is indeed species. Tethering observability to the species-specific abilities of sensory organs means that changes in those abilities bring about changes in

[1] The notion of detection is employed here in a neutral way to signify that the given apparatus, in van Fraassen's case the sensory organ, is registering some changes in its environment.

[2] In what is a confusing maneuver, van Fraassen systematically uses the adjective to qualify phenomena. But if phenomena just are "observable processes and structures", as he announces on p. 3, then it is redundant to call them 'observable phenomena'.

[3] For a critique of van Fraassen's attempt to define observability in non-modal terms see James Ladyman (2000). An ingenious attempt to save it is made by F.A. Muller (2004, 2005).

[4] Observability does not denote solely our visual sensory abilities, but also those concerning our other sensory modalities.

what counts as observable for that species. Moreover, and according always to the constructive empiricist manifesto, since what is observable for a species determines its epistemic abilities, changes in observability imply changes in epistemic abilities.

> At present, we count the human race as the epistemic community to which we belong; but this race may mutate… If the epistemic community changes in fashion *Y*, then my beliefs about the world will change in manner *Z* (1980, p. 18).

Observability for the epistemic community *homo sapiens* is relativised to the sensory limitations that community happens to possess for a length of time during which those limitations remain largely constant.[5] If we were asked to describe in theoretical terms the limitations of one of our sensory modalities at present, say vision, we would say that we can only see the world around us through its effects on light in the so-called visible spectrum which ranges from *about* 400 to *about* 700 nm in wavelength.[6]

The constructive empiricist conception of observability has a certain undeniable allure to it. Any organism that attempts to successfully navigate its environment needs to be able to read that environment. But to do that an organism relies on the particular interface evolution equipped it with, namely its sensory organs. Epistemic output, it may be argued, is only as good as the sensory input detectable by those sensory organs. That is, sensory limitations put a cap on the epistemic abilities of an organism. So, how well an organism reads its environment crucially depends on the limitations of those sensory organs. Observability à la constructive empiricism is alluring precisely because it heeds the sensory limitations that, over a given period of time, members of a biological category have in common. We are after all humans circa 2024, not axoltls.

An obvious worry with van Fraaseen's conception of observability concerns the inescapable fuzziness of the boundaries of sensory limitations. Not even 'normal' members of a given biological category, say a species, are likely to have identical sensory limitations. That's why we end up approximating their description like in the vision case above. But if the boundaries of sensory limitations are not clearly delineated, the corresponding notion and predicate of observability must itself be (somewhat) vague. What good is it then to base our epistemology on such a fuzzy notion? This is precisely the question that Maxwell (1962), a realist, posed to his logical empiricist rivals. If, as he assumed to be the case, "there is, in principle, a continuous series beginning with looking through a vacuum and containing these as members: looking through a windowpane, looking through glasses, looking through

[5] Two issues deserve quick mention here. First, how best to conceive of species is a subject much debated in the philosophy of biology. Second, to many realists the consequences of determining epistemic communities and observability along species-specific lines are puzzling. As Alan Musgrave notes, "even if we can draw a rough and species-specific distinction between what is observable by humans and what is not" the real question is "should any philosophical significance be attached to it?" (1985, p. 205).

[6] Van Fraassen would obviously insist that any such theoretical description can be accepted, but not believed, for the very notion of light refers to something unobservable (see his 2001, pp. 151–153). Acceptance in his account is less committal than belief since it is a pragmatic, not an epistemic, attitude.

binoculars, looking through a low-power microscope, looking through a high-power microscope, etc." (p. 7), then we cannot draw an ontological line between what is observable and what is unobservable in a non-arbitrary way.[7]

Van Fraassen's answer to this question is not unreasonable. He points out that although 'observability' is a somewhat vague predicate, it is no different in this respect than most predicates in natural language. The usability of such predicates is determined by whether they possess "clear cases and clear counter-cases" (1980, p. 16). Since, under Van Fraassen's conception, many things clearly qualify as observable, and many as unobservable, it is fair to say that observability, as a predicate and as a concept, does not suffer from an exceptional form of vagueness, and, hence, that an epistemology based on it is not likely to be more misguided than those based on other natural language predicates.[8]

More recently, Van Fraassen (2001, 2008) amends his view of observability, opting to expand the class of observables so as to explicitly include images produced by instruments, though not the things that presumably 'stand behind' them (2001, p. 155). To motivate his claim, he posits a distinction between three types of images. Type one images imitate real things, and are themselves deemed to be real or "independent".[9] Examples include paintings and photographs. Type two images are "purely subjective". Examples include dreams, after-images, and private hallucinations. Finally, type three images are an in-between category. They are "publicly inspectable", and, therefore, not purely subjective, but they do not qualify as independent things. Van Fraassen calls them "public hallucinations". Examples include rainbows, shadows, and instrument-produced images. Why are these not independent? Take rainbows. They are not independent because they lack "certain crucial invariances". That is, observations and even photos do not locate them "in the same place in space, at any given time" (2001, p. 157). Though he does not explicitly assert this, the implication is that instrument-produced images also lack certain crucial invariances.

Public hallucinations are further subdivided into those that imitate real things, and those that do not. Shadows and reflections are imitative because they replicate, to some extent, the features of real objects. By contrast, rainbows and mirages do not because there are (presumably) no corresponding features of real objects to imitate[10]

[7] Strictly speaking, Maxwell draws the distinction in terms of observation and theory, but we simplify the discussion here for the sake of brevity. Another interesting approach can be found in Massimi (2007), where a case is made for saving unobservable phenomena on the basis of experimental practice.

[8] There is of course the issue of whether our epistemology should be based on natural language predicates/concepts or more refined scientific ones.

[9] He offers two conceptions of independence but does not really go into detail about how they relate. The first simply conceives of independence as the quality of not being dependent on "subjective experience" (p. 157). The second conceives of independence in terms of having "certain crucial invariances" (pp. 156–7). An instance of the second kind follows in the discussion below.

[10] Van Fraassen recognises that there are 'significant invariants' in rainbows if we consider a broader set of physical conditions, e.g. the subtended angle between the sun and the cloud is at all times 42 degrees. Such invariants allow us to represent rainbows as structures "independent of our subjective experiences" (2001, p. 157). Why such invariants are not enough to qualify rainbows as real things (as opposed to public hallucinations) is a question he does not address.

What about instrument-produced images? Van Fraassen suggests that the case is not so clear regarding these. We simply do not, and, in his view, cannot know whether they are imitative because, unlike in the case of a reflection, we cannot use our unaided senses to confirm the existence of those features they are meant to imitate (2001, p. 160). We should thus remain agnostic as to whether or not they contain any veridical information concerning the objects 'standing behind' them. To sum up, we are entitled to believe in the 'observable phenomena' created by instruments like electron-microscopes, though we should remain agnostic in the unobservables we posit to stand behind them.[11]

Before we draw this section to a close, it is important to note that since the early noughties, van Fraassen has stopped attempting to establish the superiority of constructive empiricism over scientific realism. Rather, he now merely wishes to defend the rational coherence of his view, which he calls a 'stance'. At the same time, he acknowledges that several other stances (including a realist stance) are also rationally coherent, and can be adopted instead of the constructive empiricist one.

3 Problems with constructive empiricist observability

In this section, we identify some problems with the constructive empiricist account of observability. We begin with problems that centre on van Fraassen's insistence that biological categories play a key role in fixing observability. To be precise, three related problems are identified in this context. We conclude with an altogether different problem, one that concerns an intriguing conventionalist move van Fraassen makes in a bid to create more inclusive epistemic communities.

Recall that the allure of circumscribing observability and epistemic communities along fixed biological (and potentially species-specific) lines was imputed to the idea that members of a biological category share roughly the same sensory abilities over a given timeframe. As a consequence, members of that biological category possess approximately the same epistemic abilities, and, therefore, can be grouped into the same epistemic community. If what really matters, however, is the (approximate) sharing of sensory abilities, then fixed biological categories are not the most suited for the circumscription task. This is because no matter what biological category the constructive empiricist settles on, it will be subject to a number of general problems. We will mention three here.

First, whether or not the biological category chosen is at a taxonomic level where one can find sufficient homogeneity vis-à-vis a given sensory ability is a contingent and variable matter. Take the species *Canis lupus* which includes dogs. Although most breeds of dogs have roughly equal olfactory abilities, some breeds, e.g.

[11] Van Fraassen may have also softened his stance on optical microscopes: "For optical microscopes don't reveal all that much of the cosmos, no matter how veridical or accurate their images are. The point of constructive empiricism is not lost if the line is drawn in a somewhat different way from the way we draw it. The point would be lost only if no such line drawing is considered relevant to our understanding of science" (2001, p. 163).

bloodhounds, are non-negligibly better at it than others. Thus, provided non-human animals can form epistemic communities, it would not be unreasonable to identify bloodhounds as a distinct epistemic community. But, clearly, a new sub-breed of bloodhounds possessing a markedly more acute sense of smell may emerge at some point. It would thus be just as reasonable to identify this new sub-breed as a distinct epistemic community. The main point, of course, being that the taxonomic level (e.g. species, breed, sub-breed, etc.) at which one can find sufficient homogeneity vis-à-vis a given sensory ability changes over time.

Second, the fact that not all the branches of the tree of life are equally diverse means that there is no single biological category across the entire animal kingdom that is appropriate for the circumscription task. For example, the *Insecta* class contains more than a million species in its ranks and is much more diverse than the *Mammalia* class. Provided this diversity manifests itself in relation to sensory abilities, epistemic communities in the class of insects are likely to be more narrowly demarcated than those in the class of mammals.

Third, some sensory abilities may be shared crosswise, horizontally so to speak, and regardless of which taxonomic method (phylogenetic, cladistic, etc.) is employed. This is the case, for example, with ultrasound perception in bats (order: *Chiroptera*), some mice and rats (order: *Rodentia*). Note that there are many biological categories in between bats, on the one hand, and mice and rats, on the other, that do not share this ability to sense ultrasound.

What the above problems show is that circumscribing observability and epistemic communities in terms of biological categories, although to some extent fruitful, is a blunt way of approaching the matter of shared sensory abilities. Why not place the spotlight directly on shared sensory abilities instead? This would allow one and the same epistemic community to have as members a jumble of different biological categories – such categories can range from a single individual to a superordinate class of great generality. So long as members can exchange empirical information, nothing should hold us back from allowing the conception of epistemic communities of this kind.

What do we mean by empirical information? A rather short detour into Dretske's (1981) and Kosso's (1988) theories of information will help explicate this notion. On Dretske's theory, "[a] signal r carries the [informational content] that s is F = The conditional probability of s's being F, given r (and k), is 1 (but, given k alone, less than 1)" (1981, p. 65), where 's is F' means thing s has property F, 'r' stands for the vehicle of the information, and 'k' stands for the relevant background knowledge possessed by the recipient of the information. As is clear from this characterisation, informational content is conceived of as the increase in the conditional probability of 's is F', whenever that probability reaches unity in the presence of r and k, but fails to reach unity in the presence of k alone. Kosso's theory is directly influenced by Dretske's but departs from it in two significant respects: (i) it is logical (as opposed to probabilistic), and (ii) it splits the notion of information into two mutually exclusive and exhaustive categories: new information and redundant information. The former covers cases where the proposition 'x is P' is derivable from state S (the carrier of the information) together with the recipient's background knowledge k, but 'x is P' is not derivable from k on its own. The newness of the information for the recipient is made clear by the last clause, since it asserts that ‘x is P’ is not derivable from k alone. The latter covers cases where ‘x is P’ is derivable from k alone, but it is also derivable from S and k*, where k* consists of k with ‘x is P’ removed. The information carried by S in such cases is thus superfluous for the recipient, since ‘x is P’ is derivable from k alone.

Both theories have strengths and weaknesses. The main strength of Dretske’s theory is that it aligns well with highly plausible views of the mind as a probabilistic predictive machine that updates beliefs based on perceptual signals (Clark, 2013). Its main weakness is that it does not cover cases where the increase in the conditional probability falls short of reaching unity, i.e. cases where r and k do not entail the proposition ‘s is F’. The main strength of Kosso’s theory is that it distinguishes between new and redundant information. Its main weakness is that it does not cover cases where redundancy comes in degrees. Needless to say, some strengths of Dretske’s theory are weaknesses of Kosso’s theory, and vice-versa.

In what follows, we attempt to combine the strengths of the two theories, while hopefully avoiding their weaknesses in three related definitions of empirical information. To be clear, we are not wedded to these definitions, but rather offer them as potential ways to supplement empiricist views with an affable theory of empirical information.

> O provides *entirely novel empirical information* to Φ that F iff (i) $P_\Phi(F|O, k) > P_\Phi(F|k)$ and (ii) $k \nvdash o$ for any o such that $O \vdash o$.

> O provides *partially novel and partially redundant empirical information* to Φ that F iff (i) $P_\Phi(F|O, k) > P_\Phi(F|k)$, (ii) $k \nvdash o$ for some but not all o such that $O \vdash o$.

> O provides *entirely redundant empirical information* to Φ that F iff (i) $P_\Phi(F|O, k) = P_\Phi(F|k)$ and (ii) $k \vdash O$.

As before, k stands for the agent’s background knowledge, and F stands for a non-trivial declarative statement about which the agent may update their belief. In addition to these, Φ stands for the agent, $P_\Phi(\cdot|\cdot)$ stands for the subjective probability function of Φ, O stands for an observational output that is expressed as a non-trivial declarative statement, and o stands for a non-trivial declarative statement derivable from O.

Intuitively, the suggested definitions encode whether there is content overlap between O and k via potentially common consequences o. Where overlap is absent, the empirical information O provides is entirely novel. Where overlap is present but not complete, the empirical information is partially novel and partially redundant. Finally, where overlap is complete, i.e. where O is derivable from k, that empirical information is entirely redundant.[12] The proposed definitions incorporate the strengths of Dretske’s and Kosso’s theories in that they: (a) align well with the predictive mind view as an agent’s beliefs are still probabilistically updated based on empirical information, and (b) preserve the distinction between new and redundant information. The proposed definitions also avoid the weaknesses of those theories in

[12] Note that the way entirely redundant information is defined above does not discriminate between cases where O is relevant or irrelevant to F.

that they: (c) cover cases where O increases the conditional probability of F without requiring its value to reach unity, and (d) support a graded account of redundancy and novelty. The upshot is a prima facie plausible theory of empirical information. On this theory, O provides information for Φ that some proposition F holds if and only if it is either entirely or partially novel in the ways specified above.

Going back to the discussion of epistemic communities, Van Fraassen would perhaps approve of the liberties we took in bending this notion. Our confidence stems from the fact that he himself takes an even bolder step in that direction. He doesn't just cite biological factors as playing a role in determining the composition of an epistemic community, and, by extension, the range of what counts as observable. He also, and rather unexpectedly, cites what might be described as 'conventional' factors to do the same. In his own words: "[our epistemic] community may be increased by adding other animals (terrestrial or extra-terrestrial) through relevant ideological or moral decisions ('to count them as persons')" (1980, p. 18). Alas, no well-articulated examples are offered, and we are left with no clue as to the extent to which such decisions are meant to gnaw at the determining power of biological factors.

This conventionalist move makes the attractiveness of constructive empiricism now wanting. For, if an epistemic community is to be adjusted at will on the basis of moral and/or ideological decisions, then it is no longer true that similar sensory abilities are the be-all and end-all of epistemic community circumscription. After all, such decisions, if left un-vetted, would allow in the same epistemic community individuals from biological categories whose sensory limitations are not even overlapping.[13] Let us stress that, at this time, we are not claiming that it is erroneous to include such sensorily diverse biological categories in one and the same epistemic community. Rather, we are simply pointing out a conflict between the idea that the only determining factor in the demarcation of epistemic communities is the sharing of sensory abilities and the idea that (seemingly un-vetted) moral and/or ideological decisions can also play a determining role.[14]

4 Epistemic credibility

We have yet to touch upon the most important question of all. What makes a sensory organ epistemically credible? In this section, we claim that credibility springs up from the satisfaction of two principles that we call simply 'M' and 'T'. A case for this claim as to the origins of epistemic credibility is made by carefully considering what would happen if the aforesaid principles were to fail.

For all the attention that constructive empiricism has received over the years, one would think that the source of a sensory organ's epistemic credibility would have

[13] Moreover, if moral and/or ideological decisions play an overriding role in determining the boundaries of observability, the plausibility of van Fraassen's view *as a form of empiricism* wanes, for the senses take a back seat on this view.

[14] Put less kindly, van Fraassen contradicts himself when, on the one hand, he insists that "the 'able' in 'observable' refers [to] our limitations, qua human beings", limitations "which will be described in detail in the final physics and biology" (1980, p. 17) and, on the other, he claims that our epistemic community and, hence, boundaries of observability may be expanded "through relevant ideological or moral decisions" (p. 18).

been front and centre in discussions of that view's plausibility. As it turns out, nothing could be further from the truth. Van Fraassen himself remains silent on this vital issue. That is, he does not attempt to justify or even motivate the epistemic credibility of sensory organs. We propose that this credibility can found in the satisfaction of something like the following principle:

> (M) It produces output that, under some types of actual background conditions, is likely to be (a) the same or sufficiently similar when targeting the same or sufficiently similar things and (b) sufficiently dissimilar when targeting sufficiently dissimilar things within a specific range.[15]

Let us break M down into easy-to-process parts. Take, first, the expression 'under some types of actual background conditions'. We demand that background conditions are actual (as opposed to merely possible) because, qua empiricists, we erect our knowledge on what comes to pass, not on what would come to pass if our universe were a certain way. The latter is at best empirically inaccessible and therefore out of bounds for the empiricist.

In the same expression, background conditions are restricted to *some* types. This qualification is there because it is unreasonable to expect that *all* background conditions are favourable toward a sensory organ. In a room with little to no light, for example, a human observer would not be able to identify and discriminate objects with their eyesight. Having said this, favourable background conditions do not guarantee that a sensory organ satisfies clause a or b. There are presumably no background conditions that would allow a completely blind individual to identify and discriminate objects with their eyesight. It is important to highlight that which types are pertinent is a matter to be determined a-posteriori. It depends on the sort of background conditions that interfere with the output of the sensory organ at issue. For example, ultrasound interference may affect bats' ability to detect obstacles, but will not affect ours, whereas visible light interference may affect ours, but is not as likely to affect theirs.

Now let us turn to clause a. Suppose, for argument's sake, that sensory organs were not in compliance with it. There would then be no reason to think that the output of sensory organs can tell us anything about the world, for it would not contain the requisite repetitions of characteristics that allow for the identification and re-identification of things in the world. For example, if, under some favourable type of background conditions (e.g. a clear sky, no city lights, etc.), naked-eye observations of the constellation of Orion did not produce a sufficiently similar sensation in us, we would be incapable of identifying and re-identifying it as one and the same constellation. The stakes become higher when one thinks about the identification/re-identification of things that matter to survival, e.g. food and predators.

Meeting clause a is clearly not enough. That's because output from a sensory organ may be invariant in the aforementioned way, without it being sensitive to any differences in its environment. After all, a sensory organ that produces only one output, no matter what the input, still satisfies clause a. That's why we need clause b. As before, suppose,

[15] Incidentally, this is a version of a principle, proto-versions of which go back to Locke, Hume and Mill among others (see Votsis, 2015).

for argument's sake, that sensory organs were not in compliance with it. There would then be no reason to think that the output of sensory organs can tell us anything about the world, for it would not contain the requisite distinguishing characteristics that allow for the discrimination of different things in the world. Once again, the stakes become higher when one brings to mind the sensitivity required in matters of survival, like, for example, the difference between a berry that sustains and a berry that kills. A final note is required to explicate the qualification 'within a specific range'. Quite simply, it is unreasonable to expect that *all* differences in the world are detectable by any one sensory organ.

A non-negligible complication in all of this is how to conceive of similarity. This is a tricky issue and one that cannot be adequately addressed here (but see Votsis, 2015, 2020). Suffice it to say the following. First, notice that sameness will clearly not do. This holds both at the level of sensory experience but also at the level of the things themselves. Many of our sensory experiences of even one and the same static thing, e.g. our sensation of a chair in the morning and our sensation of that chair in the evening, do not appear to be identical but have subtle variations. Also, many of the things we encounter, e.g. a tree in the morning and that tree in the evening, are not identical but at best similar or dissimilar. In other words, similarity, not just sameness, appears to be a *sine qua non* for any approach to empirically model the world.

Second, although judgments of similarity depend on the metric that underwrites them, and, on the face of it at least, there does not seem to be a unique similarity metric, there is surely considerable convergence, at least with respect to judgments made in specific domains. So long as there are many clear cases of things we count as similar, and many clear cases of things we count as dissimilar, the existence of grey cases need not be such a thorn in our backside.[16] Recall, from Sect. 2, that the very same manner of reasoning lies behind van Fraassen's defence of observability. We suspect that the reason why there is no universal metric of similarity has to do with the idea that in any given domain the relevant respects for a correct similarity judgment may be different.

One further complication concerns single-instance cases of observation. Suppose there is an event E_1 that occurs only once, and that, as it so happens, it is observed by a bystander, say a random human being with average sensory abilities. Is such a case covered by principle M? The answer is 'yes'. Clause a is trivially satisfied. That's because there is no way that the bystander's sensory organ does not produce the same or sufficiently similar output when targeting the same or sufficiently similar events, simply on account of the fact that E_1 is not repeatable. Similarly, clause b is satisfiable. That's because even though E_1 is not repeatable, all sorts of other events, which as we already stipulated cannot be the same or similar to E_1, are presumably within the specific range that makes the bystander's sensory organ produce sufficiently dissimilar outputs to the output produced when they observed E_1.

A final complication deserves contemplating. Principle M, as well as much of our ordinary and scientific talk, presupposes a distinction between outputs (in the case at hand, the observations produced via a sensory organ) and inputs (i.e. in the case at hand, the things targeted by that organ). The whole point about M

[16] This is especially true when we can give a cogent account of the reasons why some judgments diverge, e.g. by coming to know more about the criteria each person uses for a particular set of judgments.

is that its satisfaction enables us to map observations to things. But how do we know the two match up, if we cannot stand outside our heads, as it were, and verify that the things in question are indeed the same or different? We see no way of solving this problem other than through a success test like the following:

> (T) Other things being equal, the output (referred to in principle M) must be such that, when utilised, it helps us successfully interact with and predict the world.

Once again, it is instructive to suppose, for the sake of the argument, what would happen if this were not the case. There would then be no reason to think that the output of sensory organs can tell us anything about the world, for we would lose what appears to be the strongest obtainable hint for the potential veridicality of that output, namely its usefulness. When all is said and done, we are much more likely to successfully interact with and predict the world, if the sensory output at our disposal has a greater degree of veridicality.[17,18]

Note that for output to be utilised in successful interactions with, and predictions of, the world, it must carry information. That's where the notion of empirical information comes into play. Since the output under consideration is observational, and it allows its users to identify and discriminate worldly things, that presumably means that the probability of propositions about those things is justifiably increased by the presence of that output.[19] But that's another way of saying that such outputs carry empirical information.

5 Enter the artificial

Analogies between the observational capacities of sensory organs and of scientific instruments have been made ever since the latter were first constructed. Galileo, for example, explicitly draws an analogy between eyesight and telescopic observation. Indeed, he claims that telescopes correct certain illusions that our eyesight is prone to produce. Here's a quote from *The Starry Messenger*, as it appears in Brown (1985):

> When stars are viewed by means of unaided natural vision, they present themselves to us not as of their simple… size, but… as irradiated by a certain fulgor and as fringed with sparkling rays… [and hence] they appear larger than they would if stripped of those adventitious hairs of light [i.e. the illusory fulgor and fringe]… A telescope… removes from the stars their adventitious and accidental rays, and then it enlarges their simple globes… (p. 492).

[17] Successful interaction or prediction can of course be driven by non-veridical output. It's just that, other things being equal, the greater the degree of veridicality, the higher the chances that the given interactions or predictions will be successful.

[18] The claim is not that all instances of output produced by sensory organs satisfy M, e.g. think of sensory illusions, but that a randomly selected output is likely to do so.

[19] Modulo the nuances relating to the distinction between entirely novel and partially novel/redundant empirical information.

More recently, several philosophers have drawn similar analogies. Shapere talks of "learn[ing] about nature, by extending our ability to observe it in new ways" (1982, p. 522), and discusses at great length the observation of neutrinos, through an elaborate process that involves their interactions with isotope ^{37}Cl. Similarly, Kosso notes that "in the interest of open-mindedness", it is important to "consider the use of machines in observation" (1988, p. 452), and offers examples of observations from electron microscopy and biochemical testing. Continuing with this analogy, a natural question to pose is whether scientific instruments comply with principles M and T. In this section, we argue that various scientific instruments comply with those principles, and, as such, their credibility should be considered as secure as the credibility we attribute to various sensory organs.

It should come as no surprise that various instruments do indeed comply with principles M and T. Take electron microscopes. When properly calibrated these instruments produce output that, under certain background conditions, is largely invariant, exhibits sensitivity to a specific range of differences in the things it targets and, when put to use, contributes to successful interactions with and predictions of the world. Finding examples from electron microscopy is not difficult as these instruments are in wide use.

Take clause a of principle M first. Bushby et al. (2011) describe a three-dimensional imaging technique applicable in cell and tissue biology using focused ion beam scanning electron microscopy with a backscatter electron detector. In the case reported, connective tissue from the developing cornea of an embryonic chick is imaged. The procedure is carried out under specific background conditions, which involve, among other things, tissue preparation conditions, e.g. isolation, immersion into a specially prepared primary fixative (i.e. a solution), etc., as well as imaging conditions, e.g. setting up the working distance of the microscope, determining the contrast and resolution settings, etc. A sequence of images is produced, each image taken from a different ultra-thin slice of the same embryonic chick cornea. That means that in this case several samples from the same source are involved. The sameness of the source but also the sequentiality and ultra-thinness of the sliced samples make it plausible to believe that the samples stand in a relation of similarity to each other (at least in a sequential way) even before any imaging takes place.[20] This is confirmed by the imaging of the samples. Figure 1 consists of a sequence of six images that exhibit a close resemblance even though they were taken at ten slice intervals. An associated video, supplementary video 2, shows even more continuity as there are no slice intervals between the successive frames.[21] Needless to say, the case for similarity in output is strengthened when the images are taken from one and the same sample, e.g. one ultra-thin slice of the aforesaid cornea. In a nutshell, the instrument at hand, and for the same reasons electron microscopy more generally,

[20] Slicing a structure whose width, length and height vary continuously means that it is unlikely that similarity is preserved across many slices. In other words, distal slices, e.g. 1 and 30, are less likely to be sufficiently similar than proximal ones, e.g. 1 and 2.

[21] Another way to determine similarity between samples is by consulting samples coming from different sources, though in such a case we need some warrant for the claim that the samples are likely to have a similar morphology. This warrant can be provided by external clues. In the case at hand, one can compare samples taken from embryonic chick corneas that are in the same stage of development, e.g. 48 h old.

complies with clause a of principle M precisely because the same or sufficiently similar samples are imaged as the same or sufficiently similar.

Now take clause b of principle M. In the example just described, the backscatter electron detector is used to resolve differences at the sub-cellular level.[22] The results can be seen in each of the six images in Fig. 1 but, for a close-up, we can consult Fig. 2.[23] Several characteristics can be distinguished which are then associated with various details of cells and cytoplasmic organelles, including the nucleus, mitochondrion and collagen fibril bundles that reside in extracellular space. Having said this, the associations are not necessary for the purpose of establishing the satisfaction of clause b. Even a layperson can recognise that there are visible features in Fig. 2, and can presumably reproduce them with a fair degree of accuracy when called upon to draw them by hand and sparing no details. By the recognition of features, we *do not mean* that the layperson can describe these features in the same way that an expert would. Description depends on theoretical knowledge, something clearly not shared by experts and laypersons.[24] Rather, what we do mean is that a layperson can recognise simple things like darker vs. lighter patches, curved vs. jagged lines, textures and contours. Moreover, such a person can verify that features produced by one instrument match, sometimes in better and sometimes in worse ways, the features produced by other instruments. This kind of correspondence is especially telling when the instruments operate on entirely distinct principles and can therefore provide independent confirmation for the existence of the differences in the samples.[25] For example, Bushby et al. mention laser scanning confocal light microscopy as a method to produce images at the cellular level. These can be tested against images taken from electron microscopy. To sum up, the focused ion beam scanning electron microscope and, for the same reasons, electron microscopy more generally comply with clause b of principle M because the images produced are sensitive to a certain range of differences in the samples.

The importance of independent confirmation is stressed by several philosophers, including Hacking (1985), Kosso (1988), and Azzouni (1997). As we discuss Hacking's and Azzouni's work below, we focus on Kosso here. Kosso stands out in that he seems to think that independence is sufficient for the purposes of establishing the existence and properties of a thing. In his own words, "An inference that x is a source of information [i.e. that the information we acquired from our detector is of the target thing x] is a good one insofar as the inference ticket is issued by an independent source" (1988, p. 465). Although this might be generally true, the independence of a source is no guarantee that the information obtained is veridical.

[22] Incidentally, the most powerful electron microscope, a type of transmission electron microscope, can resolve spacing less than 50 pm wide (Erni et al., 2009).

[23] Because of compliance with a, the distinguishing characteristics remain largely invariant across images.

[24] Patterns depend on theoretical knowledge. That's why 'pattern' talk has here been replaced with talk of features. The latter are thought of as involving more instinctive stimuli responses than the former.

[25] What about cases where the observation is indeed valid but has been produced with a single instrument (i.e. without the benefit of the aforementioned convergence between instruments that operate on entirely distinct principles)? Such cases are accommodated by what we said above, as the said convergence is not necessary, but simply offers additional confidence in the outputs.

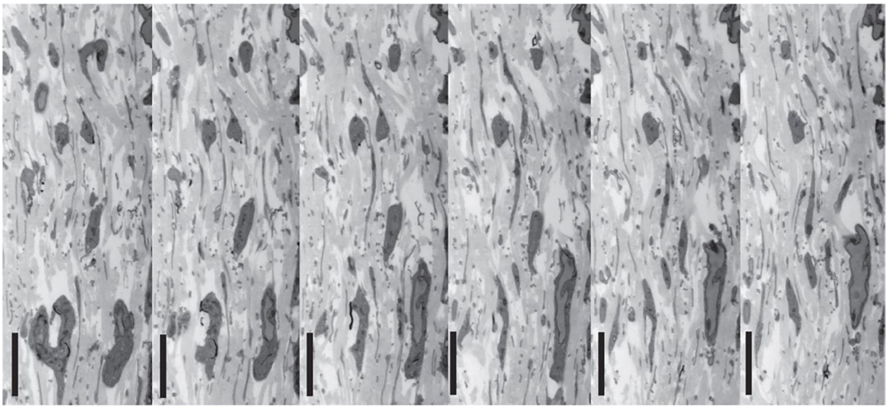

Fig. 1 This appears as Fig. 11 in Bushby et al. (2011). It is here rotated 90 degrees clockwise to save space. Although there are some differences between the six images, these can be accounted for by the fact that each image represents a different slice plus the fact that the images were taken at ten slice intervals

After all, two instruments that fail to satisfy principles M and T, and, hence, are not veridical may still operate on entirely distinct principles of each other, and, hence, satisfy independence with respect to some observations.

Finally, take T. The maps produced through electron microscopy help us diagnose, or at least reinforce existing diagnoses of, disease as well as its evolution. This is evidenced by an analysis (Collan et al., 2005) of the diagnostic utility of electron microscopy in kidney disease using biopsy samples. In this analysis, a transmission electron microscope (Jeol 1200 EX) provided output that was evaluated as being either (1) essential, (2) influential or (3) non-influential for diagnoses. It turned out that in around three quarters of all cases, the output provided was either essential or influential for the successful diagnosis of patients. Even in the cases where the output was non-influential there is no indication that it contradicted the existing diagnoses. And where there is a successful diagnosis a successful intervention to provide some form of curative effect is not that far behind. For example, minimal change nephropathy, one of the diseases for which electron microscopy is essential for diagnosis, can be treated via corticosteroids and other drugs. To sum it all up, the transmission electron microscope utilised in this study, and presumably various other types of electron microscopes (see, e.g. Miyazaki et al., 2012), complies with principle T, for the simple reason that their output helps us to successfully predict (e.g. diagnose a disease and predict its evolution) and interact with (e.g. cure a disease) the world.

Beyond electron microscopes, a host of other instruments, e.g. from Geiger counters and MRIs to radio telescopes and gamma-ray spectrometers, comply with principles M and T. Thus, if compliance with principles M and T is what grants sensory organs their epistemic credibility, then it is reasonable to conclude that a number of instruments including the above are deserving of the same epistemic credibility. Crucially, the resolution of many of these instruments surpasses that of our inborn sensory organs. Thus, contrary to the edicts of the constructive empiricist manifesto,

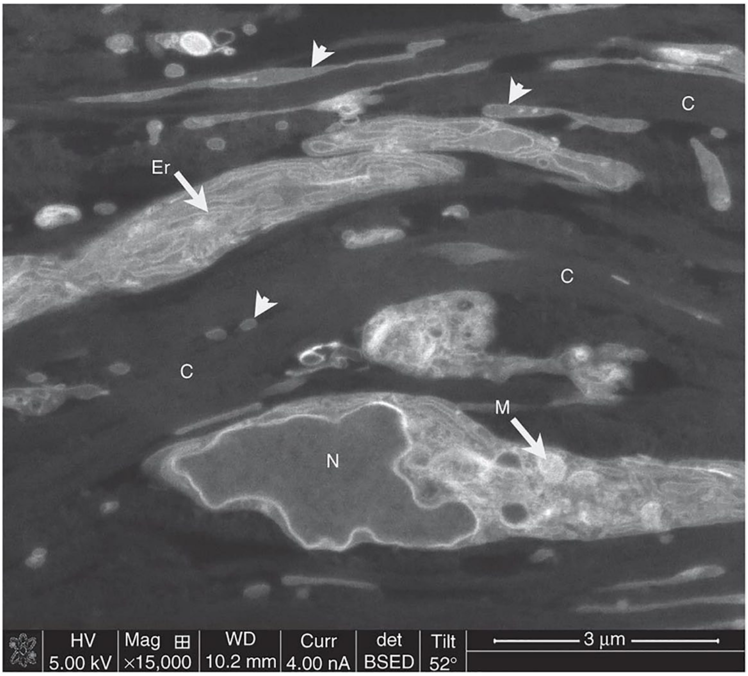

Fig. 2 This appears as Fig. 9 in Bushby et al. (2011). The legend there reads as follows: "A backscattered electron (BSE) image of the imaging face shows details of cells and cytoplasmic organelles (including nucleus (N), endoplasmic reticulum (Er) and mitochondrion (M)), filopodial cell processes (arrowheads) and collagen fibril bundles (c) in the extracellular space" (p. 857)

instrument-mediated detection is sanctioned even when there are no circumstances that allow for the detection of the same things using only our unaided senses.[26]

Note that we have *not* taken sensory organs entirely out of the equation. Employing an electron microscope, or some other M- and T- compliant instrument, does not sever the contact between a sensory organ and a target system, but simply adds another node right bang in the middle. We can think of such detectors as *amplifiers* and/or *transformers*, for they make more things accessible to the members of an epistemic community by converting them into something they can detect with their unaided senses. Kosso (1988, p. 461) calls detectors that do this kind of work 'transducers'. In this respect, the unaided senses still play an extensive and decisive role.

But even the extensiveness and decisiveness of this role can, and indeed has been, progressively questioned by technological advances. In recent years, for example, cochlear implants and bionic eyes have taken over some functions from their biological cousins allowing people with auditory and visual disabilities to make some progress toward the kind of detection levels considered normal for human beings. A future where such bionic devices bring along detection abilities that are significantly

[26] Another albeit more limited attempt to liberalise an associated notion, that of evidence, has been made by Bueno (2008, 2011).

superior to the ones a ‘normal’ human being inherently possesses is increasingly becoming a reality.[27] The acid test for the epistemic creditworthiness of any such device remains the same: compliance with principles M and T. In this respect, there is nothing special about biological organs. It is therefore important to disengage the biological yoke from empiricism. Needless to say, we are not here advocating for the removal of biological sensory organs from the empiricist worldview. Rather, we are advocating for the addition of non-biological scientific instruments in that worldview. Indeed, the biological and non-biological should be thought of as continuous.

On the basis of the aforesaid, we can synthesise a requirement from M and T, one that provides some much needed regulation of what would make an adequate conception of observability and related notions.

> (MAP): Detectors (biological or artificial) must produce output that under some types of actual background conditions, is likely to be (a) the same or sufficiently similar when targeting the same or sufficiently similar things, (b) sufficiently dissimilar when targeting sufficiently dissimilar things within a specific range and (c) helpful, when utilised, in successful interactions with and predictions of the world.

Note that this requirement seeks to ensure that the detector tracks things in the world, i.e. it creates a (partial) map of the world. That’s the purpose of any detector worth its salt. As Kosso rightly notes, “[t]he final apparatus-state can be correlated to the object-state… and in this way the observing apparatus [i.e. the detector] has information about the object-state, information which comes from the object” (1988: p. 454).

The disengagement or unchaining from biology can, in fact, be pushed even further. Artificial devices are not only able to take over detection functions from biological devices, but also long-term storage and inferential processing functions, i.e. functions that fall under the aegis of the brain. Instruments that perform all these functions on their own make biological life-forms unnecessary in matters observational. What we have in mind here are artificial epistemic agents, i.e. agents endowed with artificial intelligence as well as the ability to detect their environment. The notion of a biological epistemic community is thus too narrow. It must be replaced with the notion of a potentially mixed community:

> (PMC): A potentially mixed epistemic community is one whose population may consist of purely biological, purely bionic, purely artificial members or various combinations thereof.

It is worth clarifying what we mean here by such a community. How could such a community be made up of members that form combinations of the abovementioned groups? How do they decide on what is observable for their community? The answer is simple: So long as one member of that community possesses a detector, either inbuilt or external, biological or artificial, that satisfies MAP, then any objects

[27] Another way to improve the detection abilities of human beings is to genetically modify our sensory organs. It is highly unreasonable to suppose that the detection abilities of the sensory organs we are currently equipped with are at the limit of what is biologically possible.

registered with that detector count as observable for the whole community. This is not so different to the way we intuitively understand how human epistemic communities function at this very moment. The vast majority of people do not have access to the James Webb Space Telescope, yet the images it produces make the vast depths of space epistemically available to us all.

6 Grounded observability and grounded empiricism

Taking MAP and PMC into consideration, we can at last construct some key notions and a corresponding empiricist view. Let us begin with the notion of observation. In our view, observation is an act that targets real or fictional things (e.g. objects or properties) via some physical process (e.g. a sensory organ or an instrument), and whose aim is to produce output that is truthful about at least some aspects of those things. Needless to say, the aim may not be achieved. That happens in cases where the MAP requirement remains unsatisfied. When it is achieved, we may take those outputs and utilise them in successful interactions with, and predictions of, the world.

How is observability determined? There are two relevant notions to consider here: 'observability vis-à-vis a potentially mixed epistemic community' and 'grounded observability'. Let us start with the former:

> *X* is *observable to a PMC* roughly when members of that community have access to a detector that is such that when it targets *X* it produces output in compliance with MAP vis-à-vis *X*, i.e. output that allows the identification, re-identification and differentiation of *X*.

According to this new conception, atoms and nucleotides now count as observable for human beings and our various detection methods. By contrast, the jury is still out on dark matter, whose existence is posited solely on a theoretical basis.[28]

The reason for having a relativised notion of observability is that only such a notion does justice to the idea that, no matter how hard we try in our quest to free observability from its shackles, most (if not all) epistemic communities, including the one we belong to, are still bound to some such shackles. The shackles we are referring to are the limitations of the biological, bionic and/or artificial detectors an epistemic community happens to possess.

To compare how much progress each epistemic community has made toward the common pursuit of science, we need a non-relativised notion of observability, i.e. one that transcends the limits of individual epistemic communities:

[28] Even this may be changing. A recent study centering on quasars, which act as a kind of celestial flashlight, may have yielded the first images of dark matter structures (Cantalupo et al., 2014).

> *X* is *groundedly observable* roughly when there are members of some epistemic community who have access to a detector that is such that when it targets *X* it produces output in compliance with MAP vis-à-vis *X*.

Everything that is observable relative to a specific PMC is also groundedly observable but not vice-versa.[29] Note, moreover, that grounded observability does not entail that everything is observable, as there may very well be things that no detector ever registers. Kosso (1988, p. 455) calls these things 'unobservable in principle'.[30] Finally, the output of detectors belonging to different epistemic communities must be roughly corresponding, if each such detector is, in fact, in compliance with MAP vis-à-vis *X*.

The notion of grounded observability calls for a new kind of empiricism:

> **Grounded Empiricism**: *Science ought to produce, and, depending on the given epistemic community, may have made some progress in producing, observationally complete theories, i.e. theories that save all and only groundedly observable things.*

The aim of the above discussion is to offer more modern and defensible conceptions of observability and empiricism. Regarding the last-mentioned quality, it is worth pursuing a brief comparison of how grounded empiricism fares against constructive empiricism when one of the most compelling objections to the latter is taken into account, namely Hacking's 'argument from the grid'. In microscopy tiny grids are used to identify and keep track of the relative position of a sample's features. What is illuminating about these grids is the way they are constructed. As Hacking notes:

> The tiny grids are made of metal; they are barely visible to the naked eye. They are made by drawing a very large grid with pen and ink. Letters are neatly inscribed by a draftsman... Then the grid is reduced photographically. Using what are now standard techniques, metal is deposited on the resulting micrograph... Then we look at the tiny disc through almost any kind of microscope and see exactly the same shapes and letters as were drawn in the large by the first draftsman. It is impossible seriously to entertain the thought that the minute disc, which I am holding by a pair of tweezers, does not in fact have the structure of a labelled grid. I know that what I see through the microscope is veridical because we *made* the grid to be just that way (1985, p. 146) [original emphasis].

Hacking's argument triumphs over constructive empiricism precisely because that view denies what could not be more obvious, namely that the features present in the images mirror the features of the microscopic grid we constructed.[31] Grounded empiricism is not afflicted by this argument for it allows instrument-mediated detection even in cases where no unaided sense detection can be made. To be precise, it

[29] Not unless such a community has access to all the detection abilities afforded by the universe.

[30] He contrasts them with things that are 'unperceivable in fact' (i.e. observable but only with a non-human detector) and 'perceivable' (i.e. observable by human beings, which is another way of saying observable in van Fraassen's sense).

[31] Van Fraassen's reply to Hacking's argument from the grid is baffling. He complains that it is disputed whether "we *successfully* made the object to be that way" (1985, p. 298) [original emphasis] but does not provide any grounding for that disputation.

allows the detection of things so long as the instruments utilised are MAP-compliant. In the case at hand, the microscopes produce images of one and the same microscopic grid (or sufficiently similar ones) whose features remain largely invariant, e.g. the structure consistently appears grid-like. The images also exhibit sensitivity to a certain range of differences in the microscopic grid, e.g. horizontal vs. vertical lines. Finally, the images help us to successful interact with and predict the world. For example, using images from a microscope we can guide a tiny needle in real time to fertilise an egg with greater accuracy and then based on feedback from the microscope we can select those fertilised eggs that are likely to develop into healthy embryos.

What about van Fraassen's suggestion that instruments such as electron microscopes are *merely* creating new phenomena, i.e. not revealing or mirroring the structure of a world standing behind them? Let us stress that we do not have an issue with cases where instruments create new phenomena. The question is whether the phenomena, new or naturally occurring, can tell us something about the target system 'standing behind them'. The problem with van Fraassen's suggestion is that it cannot account for the systematic convergence one finds in the output of instruments that operate on entirely distinct principles, e.g. an optical microscope vs. an electron microscope, *and* distinct methods of preparing one and the same sample, e.g. 'dry' vs. 'wet' methods. To maintain that each different type of instrument coupled to a different sample preparation method is merely creating new phenomena even though the phenomena they end up creating are structurally identical or nearly so makes constructive empiricism sound delusionally conspiratorial.

The conspiracy theorists may stretch their fanciful story further by appealing to the complexities involved in sample preparation, measurement and calibration. The topic of calibration is rich in nuance, and, given the limited space afforded to us here, we cannot do it full justice. Even so, it is worth saying a few things about it. First of all, what do we mean by 'calibration'? Although the term is used variably in all sorts of related contexts – for an overview see Tal (2017) – what we mean by it here is a process whose aim is to ensure that the output of the calibrated instrument agrees with some standard. Following Franklin, we may say that the standard involves "the use of a surrogate signal [i.e. a well-understood signal that resembles the signal the instrument being calibrated is ultimately intended to detect]" (1997: 31). Often, new instruments are calibrated against existing ones, meaning that the outputs of the former need to agree with the outputs of the latter, at least with respect to the range of values where the latter are considered valid. The question then immediately arises whether calibration just propagates mere artifacts that emerge when measurements are first made by the calibrating instrument, i.e. without the real targeted signals playing any role whatsoever.[32]

[32] This question is closely tied to the *experimenter's regress* (Collins, 1985): an instrument is certified as properly functioning because it produces acceptable measurements, and the measurements are certified as acceptable because they are produced by a properly functioning instrument. Franklin (1997) replies that the circularity is not vicious, since the given instrument A could be calibrated against another instrument B, whose theoretical underpinnings are independent from those of instrument A. An altogether different approach is taken by Perovic (2017), who fends off the regress not by appealing to independence but rather by highlighting the iterative nature of calibration and its dynamic relation with measurement.

Although at first sight plausible, this accusation has at least two significant weak points. First, it overlooks the crucial fact that during sample preparation, measurement and calibration, outputs cannot be made to look like anything we desire. There is usually a certain stubbornness in the range of outputs an instrument produces. Take an instrument that always outputs concentric circles no matter the input – hence an instrument that does not comply with MAP – and attempt to calibrate a microscope with it. That microscope would not, in all likelihood, produce images of concentric circles when presented with a microscopic grid. Calibration may affect the output of instruments to some extent, but it does not strong-arm them into producing any output whatsoever. As such, one cannot simply assume that convergence is a by-product of calibration, largely independent of the real targeted signal themselves.

Second, although there are precedents where artifacts have resulted from the specific sample preparation, measurement or calibration process adopted, e.g. the case of mesosomes comes to mind (Hudson, 2014), such cases are neither clearly the rule nor is good science obviously defenceless against them. Moreover, even when they do appear, the artifacts are often detected rather early. Mesosomes took a little longer to be dismissed (about two decades), but they were eventually expunged when a distinct sample preparation method, i.e. freeze-fracture (vs. chemical) fixation, was employed.

If the instruments, the ways in which we calibrate them and the methods we employ to prepare samples do not account for the aforesaid convergence, that leaves only one suspect in the line up, i.e. the input from the underlying target. That's just another way of saying that the target makes the most substantial and telling contribution to the output. And another is that the images of microscopes are veridical. The same reasoning, of course, applies to a multitude of instruments.

Note that the structure of this last argument is a simple inference by elimination, not an inference to the best explanation (IBE).[33] There are four different sources for the convergence – the instrument (as it is independently of any calibration), the calibration of the instrument, the method of preparing the sample and the sample itself. The first three are eliminated, thus the last one must hold. No murky appeal to obscure concepts like 'best explanation' is required to make the inference work.[34] The argument cannot thus be said to beg the question against the constructive empiricist in particular and empiricism more generally.

[33] Van Fraassen (1985, p. 298) suggests that Hacking's argument from the grid is an instance of inference to the best explanation. If this is true, it is not good news for Hacking for he wishes to dispense with such inferences.

[34] Of course, structurally speaking, IBE can be described as a form of inference by elimination. Crucially, however, elimination in IBE-type arguments is effected by appeal to some, at best semi-understood, concept of explanation. In the case at hand, the elimination is effected simply on probabilistic and/or deductive grounds that take facts into consideration – e.g. it is an empirical fact that a given instrument cannot be calibrated to produce any output we desire.

7 Grounded observation vs. thick epistemic access

In this section, we explore how our account of epistemic credibility compares with a rival one, namely Jody Azzouni's account of thick epistemic access. We first identify a non-exhaustive list of similarities and differences between the two accounts. We then make the case that our account is more attractive.

In an influential paper, Azzouni (1997) argues that four aspects make observation 'special'. They are: (1) that it "operates, more or less, independently of what we believe", making it "quite robust under a broad range of circumstances", (2) that "[w]e have means of adjusting and refining our observational means of access to the thing being seen", (3) that "[o]ur sensory access to something often enables us to 'track' properties of it" and (4) that "[w]e can connect certain properties of the objects seen with our capacity to *know* about their properties" (pp. 474–476) [original emphasis]. Together these aspects constitute what he calls 'thick epistemic access' to the things being observed. Crucially, Azzouni extends this notion to instruments, thereby endorsing thick epistemic access to theoretical posits, such as sub-atomic particles and molecules.[35]

Let us begin with some similarities between Azzouni's account and ours. Both identify some epistemically critical properties (i.e. 'principles' M and T in our account and the four 'aspects' in Azzouni's account) that are behind the reliability, or as we call it 'the credibility', of observation.[36] Moreover, both argue that these properties can be exhibited by scientific instruments. In addition, both accounts employ this claim to establish the existence of posits that are not endorsable by the constructive empiricist, or, indeed, other empiricists. Finally, both accounts emphasise the importance of consistency between observations (Azzouni's account via robustness, and our account via principle M and requirement MAP) – more on these below.

There are also some differences between the two accounts. Azzouni insists that theoretical posits like viruses can be instrumentally accessed (i.e. instrumentally detected), but not observed: "These things, in my view, cannot be observed… But something almost as good as observation is available… [namely] instrumental access" (pp. 476–477). To motivate this distinction between (sensory organ) observational access and instrumental access, he ends up driving a wedge between them at the level of thick epistemic access: "the four aspects of thick yet nonobservational instrumental access (to something) contrast with the four aspects of observation" (p. 477). We here consider one of the points of contrast he offers. As he puts it: "[t]he robustness of any instrumental process is only achieved by linking it to the robustness of observation" (p. 477). The reason why is not entirely clear. Perhaps he thinks that we can only check and verify the robustness of instrumental access (or of instruments), say when we are calibrating

35 A major preoccupation of his paper is with mathematical posits. We set this discussion aside, as we do not at present wish to engage with issues in the philosophy of mathematics.

36 Strictly speaking, Azzouni imposes his epistemically critical properties to sensory organ *observations*, whereas we impose ours on the sensory organs themselves. For simplicity, we ignore this difference.

them, via the robustness of observation (or of sensory organs). On this reading, the former depends on the latter, and, as such, there is presumably some kind of epistemic priority that sensory organs hold over instruments, one that justifies driving the aforementioned wedge between them.

Is this dependence *necessary*? Of course, not! In modern science, much checking and verifying is performed by (other) instruments and computers because it is virtually impossible to do so otherwise. The sheer complexity of instruments like the Large Hadron Collider at CERN snuffs out that possibility. Note also that, as we explicated in the previous sections, even though human beings may still be able to sensorily observe something downstream of such complex instruments, e.g. a bubble chamber photograph on a computer screen, those observational outputs (and the associated robustness) can be epistemically substituted by the outputs of some functionally identical, or, at least functionally sufficiently similar, instrument. Indeed, such substitutions may happen not just piecemeal, but all at once. A proof of concept for the latter kind of substitution can be found in the AI-powered Robot Scientist, an actual machine that autonomously performs experiments, interprets results and tests hypotheses (see King et al., 2009). On our account, there is no such dependence relation between the robustness of instrumental access (or instruments) and the robustness of observations (or sensory organs). As such, our account does not insist, and, in fact, denies that sensory organ observations are somehow epistemically prior to instrumental outputs. It is, after all, just an accident that we have the kinds of sensory organs we do have, as opposed to other sensory organs that may be more like artificial instruments.

Another related difference between the two accounts concerns what is needed to secure genuine robustness. Azzouni's characterisation of robustness seems akin to our characterisation of principle M, particularly the first clause. But his characterisation and our clause are still markedly distinct. That's because in articulating robustness in terms of "whether or not… something … can be seen again under similar circumstances" (p. 475), Azzouni (unlike us) does not specify what should happen in cases where the two things are *similar* but not identical to each other. Moreover, Azzouni's account doesn't touch upon the second clause in principle M, i.e. the clause whose purpose is to deal with things that are *dissimilar*. To remind the reader: output must be produced that, within a specific range of circumstances, is likely to be sufficiently dissimilar when the targets are sufficiently dissimilar things. The satisfaction of this clause guarantees that the detector, sensory organ or instrument, is sensitive to differences in the environment. Without this commitment to sensitivity, there cannot be the kind of robustness and tracking of things that Azzouni and we deem takes place in science and beyond.

Beyond these up-to-now fairly narrow differences between Azzouni's account and ours, there are also some rather broad differences. One such difference is over whether the epistemically critical properties required of sensory organs and those required of instruments are the same. On Azzouni's account this is denied by the explicit contrast he draws between 'observational access' and 'thick non-observational instrumental access'. On our account, they are indeed the same, as principles M and T (which are embodied together in requirement MAP) are applied to one and the same class of things, namely detectors, and regardless of whether these are artificial or biological. That's why we extend the term 'observation' to cover the outputs of not just sensory organs, but also instruments. This decision is endorsed by many philosophers working in this area, e.g. Shapere (1982), Hacking (1985) and Kosso (1988). It is also a decision that follows scientific practice.[37] More crucially, it is a decision that reflects an important fact about the relationship between biological sensory organs and artificial instruments: What is epistemically significant about both is their ability to register things in their environment, something demonstrated by the satisfaction of requirement MAP.[38] Without this ability, there is nothing of epistemic note about biological sensory organs and artificial instruments. Our account, but not Azzouni's, offers a unified treatment of both types of detectors in terms of that ability, and coheres with scientific practice to boot.

Another broad, and potentially even more important, difference between the two accounts concerns the available pathways in establishing the existence of physical things, including theoretical posits. Although our account revises traditional forms of empiricism by calling for the uncoupling of the notions of observation and observability from the biological yoke, it remains wedded to the traditional empiricist tenet of taking observation and observability as the only pathway towards the establishment of existence claims regarding the physical world. Azzouni's account, by contrast, allows for other pathways beyond those that take us through sensory organ observations or instrumental detections. In his own words, "a theoretical item can be one we think exists, even if we do not have appropriate instrumental access to it, provided that we can tell a decent story, in terms of its properties, about why we cannot have such instrumental access to it" (p. 480). Alas, what exactly that story would involve is not made clear. And without criteria for what would count as a decent story, as well as sufficient motivation for the criteria chosen, this gambit is likely to open the floodgates to all sorts of undesirable theoretical posits. This consequence is not something our account needs to fear, as adherence to the foregoing empiricist tenet keeps the ontological floodgates firmly closed.[39]

Although the comparison pursued in this section is far from exhaustive, we hope to have provided sufficient discussion of some of the similarities and differences between our account and that put forth by Azzouni. Arguably, our account is superior to Azzouni's because it: (a) denies the necessary dependence of the robustness of instruments on the robustness of sensory organs, which as we have argued, can be thwarted with considerations from recent science, (b) provides more details about what is needed to secure genuine robustness and tracking, including sensitivity

[37] Both of these points, by the way, are conceded by Azzouni.

[38] This ability is a contingent matter. For example, and as van Fraassen concedes (attributing this idea to Maxwell), there could have been evolutionary circumstances under which humans developed "different sense organs – electron-microscope eyes" (1980: p. 17). Kosso similarly asserts that "it is a contingent property of the world that the human body does not have bubble chambers as eyes and that it is not sensitive to electron information in some other way" (1988: 455).

[39] At the very least, it should be clear that each account sanctions different ontologies under it.

towards differences in the environment, (c) offers a more unified and scientific practice-based treatment of biological and artificial detectors in terms of their ability to register things, and (d) avoids opening the floodgates to all sorts of undesirable theoretical posits by holding firm the empiricist tenet of taking observation and observability as the only way to establish the existence of physical things.

8 What about realism?

No view or claim says anything substantive or non-trivial unless it excludes something. Empiricist views are no exceptions. For example, by insisting that we should remain agnostic about things that cannot in principle be verified by our unaided senses, constructive empiricism excludes realist views since the latter are happy to endorse knowledge of such things. It is easy to see how constructive empiricism is in direct conflict with realism. But what about grounded empiricism?

If grounded empiricism claims that anything detectable by a MAP-compliant instrument is as likely to be real as anything detectable by our unaided senses, then what is there to differentiate between realism and grounded empiricism? The process of liberalising the notion of observability clearly inches the ensuing empiricism closer towards realism, at least weak forms of it. Perfect convergence, however, may be out of reach. The reason for this is that realism, at least as it is traditionally conceived, holds that various theoretical posits can earn support via purely theoretical means, e.g. the coherence between theories.[40] This is so even if the posits under consideration are impossible to detect with any instrument. It goes without saying that grounded empiricism does not lend credence to such posits. In fact, the epistemically unimpeachable grounds proposed by this view can be utilised as the basis of an ominous form of underdetermination: Any body of evidence, consisting of claims about the structure of groundedly observable things, is insufficient to uniquely determine the reality of all the posits theories make, and, hence, the truth-value of any claims about those posits. Whether this form of underdetermination is surmountable depends on whether some posits can in fact earn support holistically, even though the things that correspond to them are not groundedly observable.

Suppose some philosopher, who identifies themselves as a minimal scientific realist, ends up constructing a view that makes exactly the same epistemic and ontic commitments as grounded empiricism. What is the correct way to label their view? Is it a form of realism or a form of anti-realism? There is a certain element of conventionality in how the line between realists and anti-realists is drawn. So, the correct reaction to have is that it doesn't really matter how we label the view. Furthermore, none of the main views currently being discussed in the scientific realism debate are exclusively realist or anti-realist. Rather they are all either selectively realist (e.g. Chakravartty, 2007) or selectively anti-realist (Rowbottom, 2019). At the end of the day, all that matters is that a view puts forth the most defensible selection of what we should be realists about and what we should be anti-realists about.

[40] We do support some limited form of confirmational holism but not in the complete absence of groundedly observable evidence.

9 Conclusion

We hope to have given the reader a good glimpse of an ongoing project to formulate a version of empiricism that is more defensible than the constructive variety so prominently espoused by van Fraassen. Grounded empiricism, we argued, allows us to unchain ourselves from the shackles of traditional conceptions of experience, while remaining firmly tethered to what is the true source of epistemic credibility in the senses: the production of output satisfying the MAP principle. As such, grounded empiricism transcends the limitations of individual epistemic communities, regardless of whether their members are biological, artificial or hybrid, and, in so doing, provides a more promising account of scientific knowledge that aligns better with actual scientific practice.

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References

Azzouni, J. (1997). Thick epistemic access: Distinguishing the mathematical from the empirical. *The Journal of Philosophy, 94*(9), 472–484.

Brown, H. I. (1985). Galileo on the telescope and the eye. *Journal of the History of Ideas, 46*(4), 487–501.

Bueno, O. (2008). Visual evidence at the nanoscale. *Spontaneous Generations: A Journal for the History and Philosophy of Science, 2*(1), 132–138.

Bueno, O. (2011). When physics and biology meet: The nanoscale case. *Studies in History and Philosophy of Biological and Biomedical Sciences, 42*, 180–189.

Bushby, A. J., et al. (2011). Imaging three-dimensional tissue architectures by focused ion beam scanning electron microscopy. *Nature Protocols, 6*(6), 845–858.

Cantalupo, S., et al. (2014). A cosmic web filament revealed in lyman-α emission around a luminous high-redshift quasar. *Nature*. https://doi.org/10.1038/nature12898

Chakravartty, A. (2007). *A metaphysics for scientific realism: Knowing the unobservable*. Cambridge University Press.

Clark, A. (2013). Whatever next? Predictive brains, situated agents, and the future of cognitive science. *Behavioral and Brain Sciences, 36*(3), 181–204.

Collan, Y., et al. (2005). Value of electron microscopy in kidney biopsy diagnosis. *Ultrastructural Pathology, 29*(6), 461–468.

Collins, H. M. (1985). *Changing order: Replication and induction in scientific practice*. Sage Publications.

Dretske, F. (1981). *Knowledge and the flow of information*. MIT Press.

Erni, R., et al. (2009). Atomic-resolution imaging with a Sub-50-pm electron probe. *Physical Review Letters, 102*(096101), 1–4.

Franklin, A. (1997). Calibration. *Perspectives on Science, 5*(1), 31–80.

Hacking, I. (1985). Do we see through a microscope. In P. M. Churchland & C. A. Hooker (Eds.), *Images of science: Essays on realism and empiricism, with a reply from B.C. van Fraassen* (pp. 132–152). University of Chicago Press.

Hudson, R. (2014). *Seeing things: The philosophy of reliable observation*. Oxford University Press.

King, R. D., et al. (2009). The robot scientist Adam. *Computer, 42*(8), 46–54.

Kosso, P. (1988). Dimensions of observability. *British Journal for the Philosophy of Science, 39*(4), 449–467.

Ladyman, J. (2000). What's really wrong with constructive empiricism? Van Fraassen and the metaphysics of modality *British Journal for the Philosophy of Science, 51*, 837–856.

Massimi, M. (2007). Saving unobservable phenomena. *British Journal for the Philosophy of Science, 58*(2), 235–262.

Maxwell, G. (1962). The ontological status of theoretical entities. In H. Feigl & G. Maxwell (Eds.), *Scientific explanation, space, and time: Minnesota studies in the philosophy of science* (Vol. 3, pp. 3–15). University of Minnesota Press.

Miyazaki, H., et al. (2012). Application of low-vacuum scanning electron microscopy for renal biopsy specimens. *Pathology - Research and Practice, 208*(9), 503–509.

Muller, F. A. (2004). Can a constructive empiricist adopt the concept of observability? *Philosophy of Science, 71*, 637–654.

Muller, F. A. (2005). The deep black sea: Observability and modality afloat. *British Journal for the Philosophy of Science, 56*, 61–99.

Musgrave, A. (1985). Constructive empiricism and realism. In P. M. Churchland & C. A. Hooker (Eds.), *Images of Science: Essays on Realism and Empiricism, with a Reply from B.C. Van Fraassen* (pp. 196–208). University of Chicago Press.

Perovic, S. (2017). Experimenter's regress argument, empiricism, and the calibration of the large hadron collider. *Synthese, 194*, 313–332.

Rowbottom, D. P. (2019). *The instrument of science: Scientific anti-realism revitalised*. Routledge.

Shapere, D. (1982). The concept of observation in science and philosophy. *Philosophy of Science, 49*(4), 485–525.

Tal, E. (2017). Calibration: Modelling the measurement process. *Studies in History and Philosophy of Science Part A, 65*, 33–45.

Van Fraassen, B. C. (1980). *The scientific image*. Clarendon Press.

Van Fraassen, B. C. (1985). Empiricism in philosophy of science. In P. M. Churchland & C. A. Hooker (Eds.), *Images of science: Essays on realism and empiricism, with a reply from B.C. van Fraassen* (pp. 196–208). University of Chicago Press.

Van Fraassen, B. C. (2001). Constructive empiricism now. *Philosophical Studies, 106*, 151–170.

Van Fraassen, B. C. (2008). *Scientific representation: Paradoxes of Perspective*. Clarendon Press.

Votsis, I. (2015). Perception and observation unladened. *Philosophical Studies, 172*, 563–585.

Votsis, I. (2020). Theory-ladenness: Testing the "untestable." *Synthese, 197*(4), 1447–1465.

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