Selective Scientific Realism: Representation, Objectivity and Truth

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Abstract In this paper I advocate a version of selective epistemological realism. I begin with analyzing the conditions in which a scientific model successfully and correctly represents an identified target. I stress that the realistic import of models rests on the truth of some predicative statements. I then examine the notions of objectivity and truth in order to be able to assess the reasons to believe in the existence of some unobserved objects posited by our best scientific theories and in the truth of some assertions about the properties that these objects possess. I distinguish between the properties that are observable in principle by means of instruments which enhance our perceptive capacities (the OP properties) and the properties that are beyond any possible observation by us, namely the properties which are purely theoretical (the PT properties), such as charm and strangeness in elementary particle physics. The OP properties are identical or similar to the observed properties of ordinary perceived things, such as velocity, volume and, admittedly more controversially, charge and mass. I propose four stringent requirements for rationally believing that an unobserved object posited by a theory possesses a specific property. Firstly, this property must be an OP property. Secondly, it must be measurable. Thirdly, it must play a causal role in producing the observed data. Fourthly, distinct independent methods for measuring this property must deliver concordant results. I then show that the generality and acceptability of these four criteria is grounded on a parallelism with the reasons we adduce for (rightly) believing in the existence of ordinary observable things which we don't immediately perceive such as mice, in some circumstances. However, an agnostic attitude is to be recommended with respect to the possession of PT properties by an object posited by an—even successful—scientific theory.

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1 Representation

According to a still popular belief, science represents the world and is an image of reality. Certainly, the model-theoretic view of theories, according to which theories are foremost classes of models, makes such a view more plausible than the statement view, for which theories are sets of sentences or better, propositions (which are the semantic contents of sentences) which are asserted, i.e. statements or assertions. Indeed, models are structures, namely sets of elements organized by some relations, just as images are. An image is a visual two-dimensional object composed of colored patches—its elements—which stand in spatial relations. Thus, a scientific model is a structured set which can be meant to *represent* something else —a target—which I will call its *referent*.[1]

In the last decades, representation has become a trendy topic in the philosophy of science, due to the increasing influence of philosophers such as Bas van Fraassen who promoted the model-theoretic view of theories. Such a view is the heir of the *representational conception of knowledge* which accompanied the birth of modern science. We all know that both 17th century rationalists like Descartes and empiricists such as Locke construed knowledge as a faithful correspondence between our mental representations—our ideas—with reality. However, the representational conception of knowledge is confronted with a serious problem, called the “bridge problem” (Agazzi 2014, 29). Surely, we are immediately present to our ideas and we can safely investigate the properties of the idea of triangle without worrying about its possible correspondence with real entities. But how can we justify the belief that some of our ideas or representations faithfully mirror—at least in some respects—something external existing independently of our minds? This is the *idealistic predicament* which plagues the representational conception of knowledge. No fully satisfactory solution has been offered to this ill-posed problem (Agazzi 2014, 245) so far and it is doubtful that such a solution will ever be found. Simply because I’m unable to ascent to an overarching or divine point of view from which I could contemplate my representation and at the same time enjoy a direct-non-representational—access to a real external entity in order to verify that my representation correctly represents such reality.

The anti-psychological turn at the beginning of the 20th century did little towards the solution of the bridge problem. Extracting ideas[2] out of the human mind and endowing them with flesh and blood in the external world does little to solve the problem. Granted, doing so localizes representations in representing artifacts—such as scientific models—which are accessible to a community of human subjects just as physical, as opposed to mental, images are. By this move,

[1] For more details on this see van Fraassen (2008) and Ghins (2002, 2016b).

[2] Mental ideas, whatever their status, exist as mental entities and can be the target of scientific investigation.

representations escape the privacy of our minds and do acquire an objective status, in the sense of intersubjectivity. Human subjects can immediately see a colored two-dimensional entity, and even come to an agreement in admitting that it is a portrait of someone in an appropriate context. But to resolve the bridge problem, we have first to muster arguments in favor of the belief that the person we aim at representing by the portrait is unambiguously identified and exists. In other words, we have to argue in favor of the existence of the particular target or the referent of the portrait. Furthermore, one must provide good reasons to believe that the portrait is faithful (or not) to its referent, always in some respects only (because a portrait is not a mere duplicate of its target). Such arguments and reasons cannot be gained from an examination of the internal properties of a possibly representing artifact, because the success in representing a target by means of a specific artifact depends upon factors which are *external* to it. No entity possesses internal properties that make it automatically the representor of a particular target, essentially because representing always implies the appropriation of an artifact by a user.

As van Fraassen rightly stresses, to represent is to act. To represent involves someone who represents (a user or subject S), a representing artifact (representor) R, something that is represented (a target T) in some context C. As in any action, we can succeed (or fail) in representing the target that we intend to represent. Success (or failure) can obtain with respect to three distinct aims: *identifying the target, representing it as such and such, and partially representing it in a correct way.*[3]

In representing, we must beforehand unambiguously identify our intended target, provisionally bracketing at this first stage the issue of its existence. The entity which we decide to employ as a representational artifact has some properties that we can ascertain. But this fact alone does not provide any clue for identifying the target. Anything, whether natural or artificial, can be used by someone to represent any target. The user must initially stipulate which properties of the representor are relevant for his purpose. These are the properties which are meant to convey some information about the intended target. In general, the cultural context suffices to determine the relevant properties since it contains some specifications or conventions implicitly agreed upon by a community. Cultural contexts are of course external to the artifact itself. Moreover, these contexts widely vary in space and time. The physical characteristics of maritime maps for example considerably differ among cultures. To find their way at sea, Micronesians use sticks and shells bounded with ropes whereas we use sheets of papers covered with patches and lines of different colors, forms and widths. When an entity is used to represent, it becomes a construct, our artificially fabricated representor. But this does not prevent our construct from actually possessing some definite properties, which are real and internal to them, whether they have been selected as relevant or even added by us. Only some, not all, of the properties of the representor are considered to be *relevant* for our representing action. In fact, only a few properties of the representor

[3] More on this in Ghins (2016b).

play a representational role. These are the properties which the user makes to correspond to the properties of interest in the intended target.

Identification of a target thus depends on the correspondence, established by the user, between some properties of the representor, which are considered to be pertinent, and certain properties of the intended target. Such a correspondence fixes a *code*. The stipulated correspondence or the code is a matter of convention. However, the actual possession of specific properties by the representor and the intended target, especially if the latter exists, is *not* conventional.

Arrived at this point, I wish to introduce a distinction between two ways of proceeding when we perform representing actions. First, we could start from a given perceived entity, which is immediately and unambiguously identified, such as a pipe, and attempt to represent it in a certain way. Or, and this is the second way, we can construct a representor, which functions as an unambiguous representation of an intended target, such as a unicorn, and inquire about the existence of unicorns. Surely, representation as such is directed: we use representors to represent targets, and not the other way around. In fact, within the representational conception of knowledge the users proceed by starting from their representors. Then, they ponder the reasons to believe that they represent some entities, which may or may not exist. Such a manner of proceeding is characteristic of modern times. Descartes asked himself if some ideas in his mind had internal characteristics which immediately pointed to a definite target and at the same time warranted its existence as well as the conformity of the idea with its target. He believed that the idea of an entity having all perfections implied the existence of God and also the conformity of this idea to what it represents. No external argument was needed to ground the success and adequacy in representing God by the mental idea of a perfect entity. Kant (rightly) disagreed and criticized this a priori proof of the existence of God. But he also embraced the representational view of knowledge and forcefully defended what he called the Copernican revolution according to which the phenomenal content given in space and time, which are the forms of human sensibility, together with the categories innate to the human subject constitute the objects of knowledge. According to this view, the represented object and its representor are made to coincide and the issue whether the constituted object corresponds to something external—a "thing in itself"–becomes at the very least insoluble and perhaps even meaningless.

After representors have been expelled from human minds and became entities in the world, the success and adequacy of a representing action not only acquired the status of meaningful (and interesting) issues, but must be assessed on the basis of considerations which do not solely belong to the representors and their intended targets. In scientific theorizing about unobserved objects, at the beginning of the representational *demarche,* I (the user) have to start from a potential representor to identify its possible target, and not the other way around, in the same way as the modern thinkers started from their internal representations and not from things in the world. Thus, the identification of a target of a representation can only be achieved by taking my representor as an initial point of departure. Then, I select in it some relevant properties corresponding to some properties of the intended target, irrespective of its existence, as in the example of unicorns. After having tacitly or explicitly specified the code, in order to convince myself of the existence of the target, I must obviously somehow verify that there is something in the world which possesses some relevant properties. For example, to revisit one of van Fraassen’sexample, I must have reasons to believe that Bismarckdid have a moustache if this property has conventionally been associated with a patch of a certain form and color in a picture meant to be a representation of *him*, and not of someone else.[4]

Once the target has been identified, the second aim pursued when we perform representations is to represent the target *as* having certain properties, which are distinct from the properties used for its identification. For clarity, it is convenient to distinguish in the representing artifact the properties A relevant for the *identification* of its target from the properties B that we consider to be relevant to *convey interesting information* about the target. Again, success in this respect can be achieved whether the intended target exists or not and whether it possesses the properties B or not. Some codified internal properties of the representor, such as distortion of bodily features in a portrait, can be used to succeed in representing Bismarck *as* vainglorious. In Spott’s caricature, its referent is identified by means of pictorial elements internal to the representor associated with some properties of the intended target such as having a moustache, being bald etc. Additionally, Bismarck is represented *as* vainglorious since in the caricature his body is partially distorted in such a way that some of its parts resemble certain features possessed by peacocks. In our culture, peacocks are conventional symbols of vanity. Success in representing Bismarck as vainglorious is thus achieved independently of his being actually so (of course, he was…).

So far, we remained confined to the domain of our representations. Evidently, some ingredients *external* to our representors, such as conventions and selection of relevant properties, had to be mobilized in order to achieve success in identifying an intended target and in representing it as such and such. But the goal of *correctly* representing a target has not been sufficiently addressed yet. Obviously, the issue of correctness only arises for existing targets which may have properties corresponding to some properties of our representors according to the established code. Thus, we must have good reasons to believe that the intended target exists before raising the faithfulness issue. Such reasons cannot be extracted from the representor and the conventions adopted by the users only.

In the case of perceptual entities, actual perception can do the trick. We see a pipe which we compare with its representor, which could be Magritte’s famous painting *La trahison des images* http://collections.lacma.org/node/239578. The sentence written on the canvas *Cecin’est pas une pipe* makes clear that the existence of the pipe does not follow from the existence of the painting, since the word “ceci” refers to the painted pipe and not to a “real” pipe. But we can perceptually ascertain

[4]See van Fraassen (2008, 14) and Ghins (2010, 525) for a discussion of this particular example.

the existence of a pipe and verify that the brown area in the painting corresponds to a feature possessed by the real pipe which we see, e.g. the property of being brown.

In so doing we attribute a property to the pipe in an *act of predication*. In fact, acts of predication have been present, although tacitly, throughout the entire process which initiated with the identification of the referent and ended with the verification of the partial (i.e. in some respects) correctness of the representor to its target. To identify a target, I had to select or insert in the representing artifact some characteristics and assume that they do belong to the artifact. Further, I had to select or insert in the artifact elements which allow me to employ the artifact as a representor of the target in some of its respects. Given this, I (or another user) is able to represent the target *as* having certain properties. Irrespectively of its possible existence, those properties are predicated of the target or referent. Thereafter, an existing perceived entity is identified as a pipe, that is, as having the property of being a pipe. Finally, the faithfulness of the painting with respect to a specific feature of the target, its color for instance, is confirmed by observation and expressed in the act of predication of the property of being brown to both the real pipe and the painted pipe, provided we conventionally assume that the brown expanse in the painting corresponds to the property of being brown for the pipe (we could have decided that the brown expanse corresponds to being pink in reality…).

An act of predication consists in attributing a property to an entity. Such an act is equivalent to asserting that an entity possesses a property, by means of a judgement, a statement or an assertion. The word "judgement" has traditionally been associated with a judging subject. Nowadays, the terms "statement" and "assertion" are taken to be more neutral, or impersonal, in the sense that the truth of a statement or assertion transcends the particular idiosyncrasies of the judging subject. We will come back to the problem of objectivity below. As for now, it must be emphasized that the entire business of representing depends on the success of acts of predication and further, on the truth of statements.

As we saw, the user must specify at least implicitly a correspondence between some properties of the representor and some properties of the target. The faithfulness of a representor to its target in some respects cannot be conveyed by some feature intrinsic to the representor. Suppose a specific mark, such as a cross or a green dot, in the representing artifact is to signify that it is faithful to its target in some respect. Here, we inserted a property of the representor which does not correspond to a property of its target, and which consequently does not play a representational role. Success in representing presupposes a correspondence, a matching, between the representor and its target. What is called a *representative function* (Da Costa and French 2003, 49) has to be constructed by the user. Such a function must be an isomorphism or a homomorphism[5] which preserves the form,

[5]A homomorphism is a function which preserves the form or the structure but is not necessarily bijective. As a particular case of homomorphism, an isomorphism is a one-one correspondence between two sets. See Suppes (2002, 56).

or the structure, common to the representor and its target. An established *structural similarity* is a *necessary* (not sufficient) condition for the success of representation. If we add a mark to the painting of the pipe to indicate that it correctly represents existing pipes in some respects, we have constructed *another* representing artifact and the problem of correctness has been pushed one step back (van Fraassen 2008, 31; Ghins 2010, 527) .

In the example of the painting of a pipe (without Magritte's sentence), it seems that the bridge problem has been solved. On the one hand, we have a representing entity, the painting, and on the other, a represented entity, the pipe. Both are immediately perceptible and we can compare them to assess the partial correctness of the painting to its referent. The idealistic predicament has been dissolved by objectifying mental ideas into real perceivable entities and thereby making representors and their targets inhabitants of the same perceptual world in which the relevant comparisons can be performed.

This is an illusion. The initial modern defenders of the representational conception of knowledge claimed that we have direct cognitive grasp of our *mental* ideas or representations *only*. Thus, they deny that representing artifacts and perceived targets can be immediately known. The replacement of mental ideas by worldly representing artifacts has not been achieved at all. The comparison between the representor and its target is nothing else than a comparison between two mental representations. There is no warrant whatsoever that we have hit upon external real entities.

Even if we avoid any recourse to mental representations and defend some version of direct realism about paintings, pipes etc., we must concede that the cognitive content does not belong to representing artifacts per se but pertains to facts which are extrinsic to them among which the truth of some predicative assertions certainly is the most important. Representors are not the primary vectors of knowledge. What we originally know is that some perceived entities, representors and targets, possess some properties because we are immediately perceptually present to them. Such knowledge provides the ground for the success of our representing activity. I insist that the predicative statements which express this knowledge do *not* trade on representation. To assert that an entity possesses a specific property is not to say that the property (adequately?) represents the entity *albeit* partially and much less that the predicate term represents that entity as having such property (Ghins 2010 533; van Fraassen 2010, 553).

In science we often deal with theoretical models which are meant to represent targets which lie beyond our possibility of perceiving them. In such instances, the perceptual comparison between the model and its purported target cannot be carried out. The epistemological debate of scientific realism hinges on the cogency of the reasons which the realist can adduce in favor of belief in the existence of unobservable referents or targets. But before addressing this issue, a discussion of objectivity is in order.

2 Objectivity

In his latest book Agazzi (2014) introduces an illuminating distinction between *things* and *objects*. So far, I mostly used the generic and encompassing term "entity" to refer to things, objects, events, processes etc. A *thing* is an entity in the world which possesses a large, perhaps infinite, number of properties. An *object*, according to Agazzi, is a structured set of properties (Agazzi 2014, 284). Properties are *encoded*—a term borrowed from Zalta (1988), *albeit* in a different sense[6]—by the object. By abstraction, we select some properties of *things* and thereby construct *objects* which are "clipped out of things" (Agazzi 2014, 89). An object can be an abstract object, or an object of thought only, a *noema.* But, in a predicative statement, we attribute, correctly or wrongly, some property to a thing. For Agazzi, when an object is instantiated by a thing, the thing does possess all the properties which make up the concrete object.

"Scientific objects exist as abstract objects (i.e. as intellectual constructions) that encode certain properties, while not being purely abstract since they are exemplified (within certain margins of accuracy) by concretely existing objects" (Agazzi 2014, p. 104, n. 48)

But a thing cannot be reduced to an object, since a thing also has properties which do not belong to the object it instantiates. Moreover, the instantiation of an object by a thing need not be exact in the sense that a property of an object might only approximate a property of a thing. An object is thus constructed by adopting a certain point of view, some perspective on a thing. An object cannot encode all the properties of a thing. The predicative statements that attribute the properties of an object to a thing only convey a *partial* knowledge of the latter.

When we attempt to represent some observed targets, we similarly clip out some relevant aspects of those targets and connect them with some properties of our representors. In doing so, *what we represent are objects* and *not* things.[7] In what follows, to clarify the notion of objectivity, my starting point will be our perceptual presence to things. Thus, I will not conduct the discussion by beginning from our representing artifacts as I mostly did above. Contrary to Kant and the exponents of the representational conception of knowledge, I adopt a direct realism with respect to ordinary perceived things. Such a direct or common sense realism is also embraced by an empiricist such as van Fraassen (2008, 3) although he significantly refers to "observable phenomena" instead of things.[8] From these phenomena, we

[6]Zalta's abstract objects are individuals which both encode *and* exemplify properties. They aren't Agazzi's abstract objects. For Zalta, when a concrete object has all the properties encoded by the abstract object, it is a physical "correlate" of the abstract object (See Ghins 2016a).

[7]Although the targets of our representations are things, we represent only some aspects of them, that is, structures or objects (see Ghins 2010).

[8]The word «phenomenon» inevitably suggests something that appears to me or us, whereas the word "thing" immediately makes us think of something in the external world.

extract what van Fraassen calls "appearances" (2008, 8). Appearances present some analogy with Agazzi's objects since they are constructed by adopting a certain *perspective* on observable phenomena.

In what sense can my representations be objective? When users agree that a representor adequately or correctly represents its target in some respects, we get objectivity in the 'weak' sense of intersubjectivity (Agazzi 2014, 51ff.). But such agreement does not guarantee per se that there is something in the world that instantiates the relevant properties, i.e. the aspects selected when constructing the object of the representation. Intersubjective agreement fails to substantiate the claim that there is a thing "out there" possessing properties which conform to those encoded by the object of the representation. Such conformity is what Agazzi calls 'strong' objectivity. Surely, I concede that we can collectively be wrong in attributing properties to things. I thus endorse fallibilism.

Now, van Fraassen is quite aware of the importance of reaching strong objectivity. However, he subscribes to a representational conception of knowledge, albeit not in the classical, psychological, sense which took representations to be mental ideas. Then, he must propose a solution of the bridge problem, which he baptizes "the loss of reality objection" according to which our representors, our scientific models, do not hit on something external.

"*How can an abstract entity, such as a mathematical structure, represent something that is not abstract*, something in nature?" (van Fraassen 2008, 240)

The answer he gives is *pragmatic* and amounts to a "dissolution" of the loss of reality objection. When I claim that my representation is adequate to the phenomenon I also claim that my representation is adequate to the phenomenon *as represented by me* (van Fraassen 2008, 253–261). I cannot assert that my graph is adequate to the evolution of the deer population in Princeton as represented by me and at the same time deny that it represents such evolution in a correct way. If I do this, I fall into pragmatic inconsistency.

I'm happy to concede that the indexical ingredient in the activity of representing, which is performed by me or us, prevents from positioning myself at a God's eye point of view and enjoying an overarching view of my graph and the deer population. Yet, such a difficulty arises only when knowing is identified with representing. Such epistemological posture entails that the loss of reality objection must be overcome by resorting to a pragmatic move.

Moreover, even if we grant, as I do, that *within the representational conception of knowledge*, the loss of reality objection is pragmatically dissolved, doubts can be raised about our capacity of knowing real things by means of our representors, above all if we adopt what I will call a *predicative conception of knowledge*. According to the latter conception which I favor, knowing is attributing to things properties which they exemplify and to have good reasons for doing so. Such acts of predication are expressed in statements such as "At t_0, the deer population in Princeton is n_0". Within the representational conception of knowledge, strong objectivity collapses into weak objectivity and the bridge problem vanishes or "dissolves" as van Fraassen aptly says. Since we can't ascend to a godlike pedestal, we are forever confined to the domain of intersubjectivity or weak objectivity. Yet, such confinement is a consequence of the erroneous philosophical thesis according to which to know is to represent.

Notice that adequacy in van Fraassen's sense is not to be confused with truth, and certainly not with truth in a correspondence sense. Adequacy for him amounts to weak objectivity, that is, the invariance of some aspects of targets with respect to the particular points of view or perspectives of the various users of the same representors. For van Fraassen a representation is adequate or objective if it correctly represents its referent, in the sense that the usually agreed upon verification procedures have been implemented and consensus has been reached on their outcomes. Contrary to van Fraassen, I insist that the correctness of a representation rests on the truth of some predicative statements which attribute properties to things.

3 Truth

I maintain that truth is a property of statements[9] and I defend a correspondence *view* of truth. Now, I wish to stress the distinction I make between a *theory* of truth and a *view* of truth.[10] A theory of truth attempts to articulate in a precise way the correspondence between the statement and what makes it true, its truth maker (as in Wittgenstein's *Tractatus*). Granted, no fully satisfactory *theory* of truth as correspondence has been proposed so far. Yet, this is no sufficient reason to reject a correspondence *view* of truth according to which the truth maker of a statement is a *real fact*. In the case of a predicative statement, its truth maker is the fact that a given entity possesses a specific property referred to in the assertion. Such correspondence view of truth can be briefly advocated by pointing to the possibility of error when a statement "clashes", as Popper said, with reality. Then, we are constrained to admit that we are mistaken.

Thus, I sustain that truth is a relational property of statements. However, I submit that truth is absolute and not relative. Surely the truth of a statement is relative to the existence of the fact that makes it true (Agazzi 2014, 229). But truth is not relative to what we may believe or agree upon, nor does it depend on the arguments adduced in support of belief. This latter view of truth is epistemic, and thus relative to what we might judge to be a good justification. On the contrary, the existence of facts is independent of arguments or reasons. It would be wrong to object that the absoluteness of truth contradicts the fallibilist attitude. We may believe that a given

[9]See Agazzi (2014, 194).
[10]See also Ghins (2010, 527).

statement is true even when there is no fact which makes it true, and therefore the statement is false. Absolute truth is not to be confused with absolute certainty. The absolute character of truth is part and parcel of a correspondence view of truth. Absolute certainty on the other hand reflects the state of mind of a dogmatic person who pronounces that some beliefs are irrefutable. But he is not necessarily unable to provide arguments in favor of their truth. Famously, Descartes attempted to specify criteria which would guarantee that some of our ideas would be faithful representations beyond any possibility of doubt. It is significant that the criteria proposed by Descartes, namely clarity and distinctiveness, are *internal* to the ideas themselves. Indeed, dogmatism can only be supported by internal arguments.

On the contrary, a correspondence view of truth makes dogmatism quite difficult to maintain since resorting to any kind of external definitive authority would lead to an unstoppable regress. How can we justify that it is true, in a correspondence sense, that a given authority is an incontrovertible warrant of truth?

The correspondence view of truth may be considered to be a *realist view* of truth, because what makes a statement true must be real. Moreover, it is an essential component of any realist position. Any genuine realist must claim that there are things which exist independently of our language, our minds etc. and that some such things are cognitively accessible to us. As a consequence, a realist must be both an entity realist, who believes in the existence of external independent entities, and a statement realist, who believes that the predicative statements about things are true or false in virtue of the properties actually possessed by those external things.

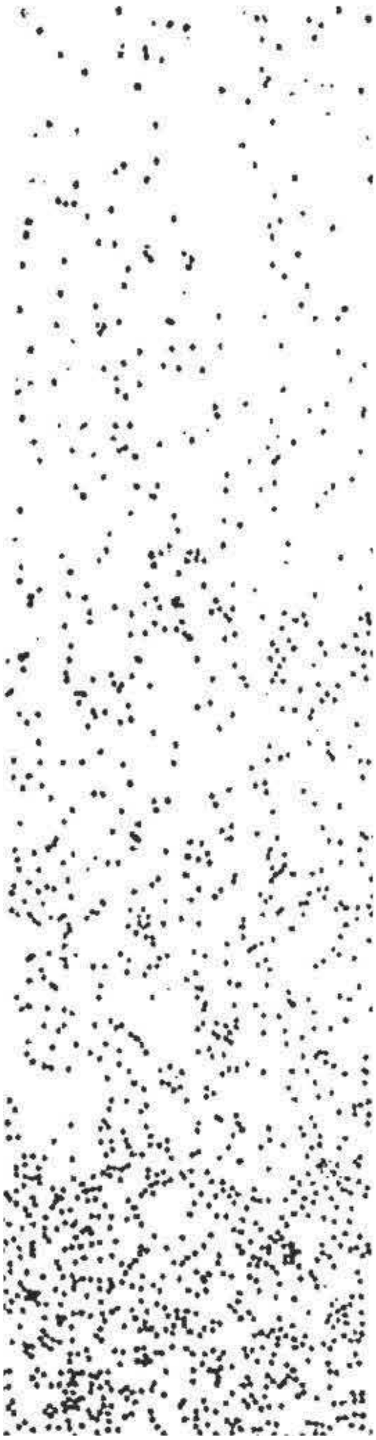
4 Scientific Realism

As I conceive it, selective scientific realism maintains that some non-observational statements belonging to scientific theories are true or false in virtue of the existence of external things and further that we are at times in a position to provide good reasons to believe in the truth of these statements even if they speak of things whose properties are accessible only by means of instruments. Thus defined, scientific realism involves two main claims. At the ontological level, the scientific realist is committed to the existence of external things, i.e. things whose existence is independent of our language and internal states of mind such as thoughts, beliefs, representations, wishes and so on. At the epistemological level, the scientific realist contends we have good reasons to believe in the reality of some unobservable objects which actually possess some of the properties attributed to them by our theories. The challenge for the realist is to formulate criteria for selecting the objects posited by our theories which deserve to be called "real".

I broadly construe theories as having two major components: models and statements. Scientific models are artifacts. They are possible representors of concrete objects. Typically, models are mathematical structures composed of a set of elements which make up the domain of the structure and the relations which stand between the elements of the domain. Given some conventions, a two-dimensional curve functions as a representation of a specific object. Its elements are points which are meant to correspond to couples of properties specified by the coordinates, such as the number of deer in some area at some time, instantiated by the target, like the deer population in a defined area around Princeton. Here, the relations between the points of the curve are spatial and its shape provides some information on the variation of the deer population in time.

In order to construct the graph, we have to measure some selected properties of the object clipped out of the targeted thing. Generally, we manage to construct data models by means of measuring operations with the help of instruments. These instruments deliver data, that is, observable items such as digits on a screen, coincidences of a needle with black lines associated with numbers on a screen, colored surfaces (e.g. microscope images) etc. These data must be interpreted such that they might provide information on the properties possessed by the targeted thing. In the process of measurement, we can distinguish four steps, at least: the identification of the target, the observational interaction with the target, the production of a data model and finally the information the data model delivers about the target. Let us briefly discuss these four steps through the example of the determination of Avogadro's number by Jean Perrin.

In Perrin's experiments, the targeted things are emulsions, which are mixtures of liquids and small grains in Brownian motion. The realist at this stage presupposes that the grains and the liquid exist. The grains are identified by—indirect—observation by means of an instrument: the microscope. Once the target has been identified, we collect the data, which are the microscope images at different heights of the emulsion. Here, the interaction obviously is optical. Then, and this is the third step, we must select the properties which will be measured. We aim to give an answer the following question: is the liquid continuous or is it composed of discrete particles, namely molecules? (Molecules are considered to be indivisible, i.e. atoms in this context). More precisely, we want to measure the concentration of those grains in function of their height in the recipient. The distribution of the grains and their height are properties which are both observable by us (through a microscope) and measurable. We are then in a position to produce a graph (as in the case of the deer population) which represents the variation of the concentration of the grains in function of height. This graph is an exponential function which expresses in a precise way how the concentration of the grains decreases with height (the figure below (Perrin 1913, 144) shows the decrease in concentration of the grains with height). At this stage, we have a data model, namely a set of measurement results organized by an exponential function.



What does this data model teach us about the emulsion, and crucially about the nature of the liquid? Making a long story short (see Psillos' papers (2011) and (2014) for a detailed reconstruction of Perrin's reasoning), the data model permits to determine the value of Avogadro's number, which is a *finite* number. Consequently, the liquid is composed of molecules which can be counted. Matter is not continuous and the atomic hypothesis has been vindicated.

But what is so special about Perrin's experiments and arguments? What is it that makes them so convincing? Does Perrin rely on the inference to the best explanation (IBE) which is the favorite lever used by realists to boost our confidence in the existence of unobservable concrete objects? Yes, but not only, as I'm going to argue. The existence of molecules certainly *explains*, together with additional other hypotheses, why the data are organized by an exponential function. But what is more, the explanation is *causal*. The distribution (and the motion) of the grains is *caused* by the collisions with the molecules of the liquid. The presence of such a causal link is certified by showing that there is no other reasonable explanation of the distribution of the grains, because the alternative explanations have a very low degree of probability. Why? Because the value of N obtained by Perrin *concords* with the values obtained by different, independent, methods of measuring Avogadro's number. Perrin speaks of the "miracle of concordance": it is very unlikely that these methods would give roughly the same result if matter were continuous.

However, objections have been addressed by antirealists and realists alike against the force of IBE (of which the "no-miracle argument" NMA is a particular instance) even in its stronger—causal—version.[11] Some of these objections are a direct consequence of a staunch empiricist position, such as van Fraassen's, which eliminates from the domain of knowledge any statement about entities unobservable by our unaided senses. Perrin was quite aware of this kind of objection:

"Sensation is the only reality provided all *possible* sensations are adjoined to the actual sensations" (1903, p. X)

Since the word "sensation" habitually refers to internal mental items, I will rephrase Perrin's advice thus: we are entitled to believe in the existence of objects only if they are in principle accessible to observation or perception. Such constraint is in line with rather strict empiricist requirements. It implies that we can rationally believe in the existence of an entity only if it possesses at least one perceptible property: *it is not enough that the existence of this entity is an indispensable ingredient of the only possible explanation of some data*. Even if we have somehow managed to prove that a proposed explanation is the only acceptable one (and *a fortiori* the best available one…), this is not sufficient to ground our belief in the existence of unobservable entities and true statements about them. Those entities must possess properties which are the same as—or at least similar to—the properties possessed by ordinarily observed things. Otherwise, it would be impossible to

[11]For a discussion of the strengths and weaknesses on the NMA, see for example Alai (2012).

make, as Perrin contends, molecular agitation visible. Visible, but not actually seen through the microscopes available at Perrin's time. As he says, the behaviour of grains observed through the microscope makes molecular agitation visible in the same way as a floating cork follows the motion of sea waves better than a ship (1909, 353).

To avoid confusion I introduce a distinction between two categories of unobserved properties. The first category contains properties which are identical or similar to the perceptible properties of everyday things, but which cannot be observed because of the unavailability of appropriate instruments or other obstacles. Let's call them "observable in principle" (OP). Indeed, molecules are supposed to have properties such as size, velocity, acceleration etc. which were in principle perceptible at Perrin's time and also possessed by observable things such as billiard balls. Such properties are observationally accessible and measurable nowadays by means of more powerful scientific apparatuses. The second class of properties, which I will call "purely theoretical" (PT)[12] is composed of properties which are beyond the reach of any possible perception, even with the aid of the most powerful instruments, such as the properties of strangeness and charm in elementary particle physics. They might be measurable, but they are too remote from our ordinary perceptual experience.

Such version of scientific realism seems quite restrictive. The existence of unobservable objects can be defended only if they possess some (though not necessarily only) properties which are of the same *type* as the properties of ordinary observable things, namely the OP properties. Scientific realism is defensible with respect to objects which are unobservable only if their unobservable character results from the fact that the reach of our direct perception is limited *and* that we don't have today apparatuses sufficiently powerful to bring these properties within perceptual access. I'm aware that such a position casts a doubt upon the existence of properties such as strangeness, charm, baryonic number, internal spin etc. since those properties have no analogue in ordinary experience. Yet, the scientific realist is still allowed to rationally believe in the existence of such objects to the extent that they possess some OP properties. Thus, the existence of quarks with a specific mass can be defended since (as I will argue) mass is an OP property. But one may remain sceptical about their having some exotic properties such as charm, strangeness etc. which are PT properties. If this is correct, the version of scientific realism I advocate is not that restrictive after all. In physics, which is the discipline that postulates explanatory objects endowed with properties most distant from ordinary experience, the vast majority of posited objects do have one or more OP properties.

To conclude this section, let's summarize the philosophical lessons drawn from Perrin's experiments and reasonings by stating four conditions or requirements that

[12]The OP properties attributed to molecules certainly are theoretical, since they belong to objects posited by a theory. This is why I use the adjective "purely" to refer to theoretical properties which are beyond any possibility of indirect observation.

a solid argumentation in favour of the existence of unobservable objects must satisfy:

1. *Requirement of observability in principle*: objects that are not directly perceptible must possess some OP properties (at least one…) which are identical or similar to the immediately observable properties of commonly perceived things (such as the velocity of a billiard ball) and as a consequence are in principle amenable to observation with the help of suitable scientific instruments.
2. *Requirement of measurability*: the OP properties must be quantitatively measurable by means of adequate instruments (such as the microscope).[13]
3. *Requirement of causality*: the OP properties of these objects are causally responsible, and thus provide an explanation, of the observed data.[14]
4. *Requirement of concordance*: distinct and independent experimental methods of measuring these properties must deliver results that are concordant (within acceptable approximation).

Taken together, these four requirements are a necessary and sufficient condition for the justification of the belief that a scientific object possesses a given property. They are jointly satisfied by Perrin's argumentation in favor of the existence of molecules and the truth of the atomic hypothesis. One might first object that some properties taken to be observable in principle, such as having a mass, cannot be considered to be so. True, the history of science teaches us that scientists came to agree on a precise definition of mass with much difficulty. However, once mass has been defined (and also before that…), it is easy to empirically ascertain that it is more difficult to set in motion a ball made of lead than a ball made of wood. Such difference is manifest because a ball made of lead has a larger *inertial* mass than a ball made of wood (with equal volumes). Such immediate observations allow to defend that the property of inertial mass is a OP property. Moreover, we observe that a ball exerts a stronger pressure on the hand if it is made of lead rather than wood. This shows that they have different *gravitational* masses. From these simple experiences, we can immediately conclude that there is a relation between the inertial and the gravitational mass without getting into an elaborate theorizing about gravitation.

The four requirements mentioned above provide grounds for a defensible version of selective scientific realism. How can we go beyond Perrin's experiments and establish the generality of these four requirements? The answer is straightforward: on the basis of our ordinary perceptual experience. Our next task is to show that these four requirements form the backbone of any argumentation in favor of the reality of commonly observable entities, but which have not been observed yet.

[13]Mario Alai (2010, 672) mentions a method of measurement used by Perrin to determine the upper limit for the size of molecules, which relies solely on an inductive inference.

[14]Admittedly, an OP property often plays a causal role together with some PT properties. Each requirement is necessary but none of them is sufficient in isolation.

5 The Parallelism with Ordinary Experience

Empiricists philosophers are quite right in stressing the epistemic role of observation or perception as warrant of our assertions of existence. In order to justify the belief in the existence of objects inaccessible to our immediate perception, we are only allowed to resort to arguments analogous to the ones used to comfort our beliefs in the existence of things immediately perceptible in the context of our everyday experience. In ordinary practice, we increase our degree of confidence in the reality of perceived things by augmenting the number of our observations, by repeating them, and also by relying not only to our sense of vision but to the other modalities of perception. We judge that our belief in the existence of a thing such as a rose is more assured when we have managed to look at it in satisfactory perceptual conditions and when we have witnessed an agreement between our perceptions, that is, when we have noticed that some properties remain constant, invariant, e.g. that the stem of the rose is covered with thorns. We increase our degree of belief in the existence of the rose by touching it, smelling its perfume and perhaps by tasting its petals as the ancient Romans did before mixing them with wine. By trusting our five senses, or at least several of them, that is, by resorting to various modularities of perception, we enhance the degree of confidence in the truth of an assertion of existence (Ghins 1992), without however reaching absolute certainty. We understand now why scientists give much importance to the concordance between measurement results obtained by means of *independent* methods, which corresponds to the fourth requirement mentioned above.

In the case of direct perception, it is evident that the first requirement is also satisfied, because the relevant properties are observable and perceptible. The second requirement is not, since in ordinary experience, it is not necessary to perform quantitative measurements to confirm the concordance between perceived properties in different circumstances, in accordance with the fourth requirement. The second requirement is a prerequisite for the satisfaction of the fourth. In most ordinary contexts there is no need to be in a position to determine if a rose is crimson, scarlet, purple or amaranth to truly state that it is red. Observations of this kind can be taken to be rough measurements, which are sufficient to establish the presence of a property in most cases. In science however, precise measurements are required to verify the accuracy of the predictions of a theory as well as to comply with the requirement of concordance.

The third requirement is also satisfied since it is easy to convince oneself that causal processes are at work in perception by verifying the systematic variation of some perceived properties in function of the changes in the observing conditions. Also, we can see that these properties vanish when the thing is removed. This is just a crude application of Mill's methods. Full knowledge of the laws and the causal mechanisms at work in perception is not indispensable because the immediate perceptual contact doesn't necessitate to resort to causal laws to guarantee that the perceived thing exists.

How do we infer the existence of a perceptible thing, which is not actually present in perception? In a by now famous example, van Fraassen (1980, 19–20) discusses the clues which permit to conclude that a—unobserved—mouse has come to live with me. Nobody has seen the mouse (which is observable…) yet, but some gray hair lies on the ground, cheese disappeared, tiny noises have been heard etc. Such evidence makes me believe that a mouse is living in the house. How is such belief justified? Well, we have seen mice before and we know that they have grey hair etc. We suspect that several causal links obtain between the existence of a mouse and the observed clues. Each causal relation points toward a particular property, such has loosing grey hair or eating cheese. The set of these properties and the awareness of the context allow to identify the thing which is causally responsible for their presence. Past experience is sufficient to make sure that the specific causal relations are in place without having knowledge of the causal laws. It is not mandatory either to perform precise measuring operations on the clues. (In other instances, a detailed quantitative inquiry is sometimes required, when for example the identification of a murderer is at stake.)

At this point, we come to grips with the justification of the belief in the existence of *unobserved* objects which are typically postulated by a theory to causally explain why some phenomena occur. The existence of molecules was asserted by Boltzmann because he wanted to causally explain the properties of gazes, such as pressure, temperature etc. I distinguished above between two kinds of properties that can fulfill an explanatory role, the OP properties which are observable in principle and the PT properties which are purely theoretical and escape de dicto any possibility of observation, even by means of instruments. With respect to objects which possess PT properties only, an agnostic attitude is to be recommended until perhaps some theoretical investigations lead us to attribute OP properties to them.

Thus, the selective realism I defend can give credence to observable properties only, but these properties are not limited to directly observable ones: they include OP properties, that is properties which could be observed through adequate instruments. OP properties are eligible candidates for membership in our ontology. As regards the sense of sight, which enjoys a privileged status in the sciences, observation instruments are extremely varied. First, we have the banal glasses commonly used by short-sighted, farsighted and presbyopic people whose eyesight is mildly deficient. Who will dare to claim that the observations made by someone who uses appropriate glasses are less reliable because they were not performed directly with the naked eye? Next,[15] we have the different kinds of microscopes and telescopes which make visible entities such as viruses, remote stars and galaxies. Notice again that it is not necessary to know the causal laws or the underlying mechanisms for these instruments to trust them. Polished glasses were already dependably used by the ancient Romans even though they didn't know anything

[15] See Maxwell (1962, 7).

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about the laws of refraction and electromagnetism. Galileo and his contemporaries ignored the working of the rudimentary telescope they used to explore the sky. Yet, Galileo's contemporaries rapidly came to agree on what was seen through the telescope. (Although they disagreed about the impact of telescopic observations on issues such as the immutability of celestial bodies…)

Moving further away from ordinary perceptual experience, we can mention the cause of the light rays directly observed in the cathode ray tubes. These light rays are produced by the interaction of unobservable particles—the electrons—emitted by the cathode, which interact with the molecules of the rarefied gas filling the tube.[16] J.J. Thomson succeeded in determining the values of the charge and the mass of an electron without knowing how the cathode rays were produced. However, knowing the laws permit to manufacture instruments, such as wire and drift chambers to detect and measure the properties of charged particles. These devices make visible the trajectories of charged elementary particles, such as protons. In order to be justified in claiming that the lines immediately observed on photographs or computer screens represent the trajectories of protons, we must know the causal mechanisms, i.e. the causal laws[17] which describe the interactions between the protons and the molecules of a gas such as argon. Typically, the protons remove electrons from the molecules of the gas. These electrons are instantly captured by the wires in their vicinity, which detect them and make visible the trajectories of protons.

This case is analogous to the emulsions studied by Perrin. The molecular agitation is rendered visible by the movements of the grains of mastic which collide with the molecules of the liquid, in the same way as the trajectory of a proton is made visible by the electric discharges resulting from the interactions of the protons with the molecules of the gas. These discharges then produce luminous spots on a screen. For molecules as well as for protons, the knowledge of the laws which govern their interactions is necessary to comply with the requirement of causality and justify our existence assertions.

Whether we look at directly observable entities, like a rose or a mouse, or indirectly observable, such as the grains of an emulsion or galaxies, or at entities whose existence can only be inferred, such as atoms, electrons, protons or gravitational waves, our reasoning is grounded on the attested presence of causal relations (how we attest such presence is examined in Sect. 6). The working of causal mechanisms, the laws of which can be known or not, is crucial to justify our belief in the existence of entities, whether directly or indirectly observable, or inferred only. Surely, actual perceptual presence in adequate conditions is what guarantees the truth of the assertion that an entity possesses directly observable properties. But perception is supported by causal mechanisms that we have reasons to believe to be present even if we might still ignore the details of their action, if only because when

[16]See Nola (2008).

[17]A causal law is a mathematical law containing a time derivative which refers to the effect, whereas the other terms refer to the cause(s). (Blondeau and Ghins 2012).

we intervene on an object in a certain way, systematic variations in the perception of its properties occur. In the same way, if we have a complete knowledge of the functioning of a measuring instrument, we have reasons to believe that the causes of certain observed effects are objects with specific OP properties. As a consequence, nothing prevents that these objects might be (indirectly) observed someday. Molecules can now be seen through instruments which were not at Perrin's disposal: the electronic microscopes.

My vindication of selective—local—realism is grounded on a parallelism between the reasons to believe in the existence of an ordinary thing and the reasons why we are rationally entitled to assert the reality of some concrete unobservable object and some true statements about it. Most scientists resort to such arguments to sustain the existence of objects which have properties which are de facto—but not de dicto—unobservable, namely the OP properties. We resort every day to inferences to the best explanation, for example when we infer the presence of a mouse from some directly observed clues. But such a way of reasoning rests on previous observations which warrant the reality of a causal link between the presence of a clue and the existence of a thing which has some specific properties. We can thus rely on *several* inferences to the best causal explanation. Each inference justifies the belief in the existence of a concrete object with a particular property such as having gray hair or eating cheese and so on. Thus, my vindication of selective scientific realism is explanationist (Psillos 1999, 78). But causal explanation is a particular—very restrictive—case of IBE. Moreover, at the end of the day, the existence of the mouse is established by means of a variety of IBE. In fact, the mouse is the only animal which has all the properties causally responsible for the observed clues.

The concordance of the results obtained by the various independent methods of measuring Avogadro's number is comparable to the concordance of the various ways of observing the *same* property of a mouse. One could say that the finiteness of Avogadro's number is the best explanation of an obtained value. The same holds for the other *finite* values obtained by other methods. It is this concordance that certifies that the measured values are finite and approximately correct. In an analogous manner, several perceptual accesses to a property of a thing, whether seen, touched etc., can attest that a perceived thing such as a tabletop is rectangular. The presence of the rectangular form explains, via various causal processes, the agreement between the various perceptions. But we know that each individual perception is immediate evidence that the tabletop is rectangular, irrespective of a possible knowledge the underlying causal processes. In the same way, when we deal with OP properties, whether of mice or electrons, we must have reasons to suppose that causal processes are at work and that they furnish the basis for the causal explanations of our direct or indirect observations.

For each theory and each posited object, we must examine if causal chains connect specific phenomena to some specific OP properties and if independent measuring operations generate concordant results for the same property. Every existence assertion deserves a special justification, as we saw for the determination of the Avogadro number and the masses and dimensions of molecules. Yet, the philosopher aims at universality. For this reason, I tried to show that each particular argumentation articulated by the realist must obey the four requirements that I formulated and motivated above.

6 Causal Link and Causal Law

It remains to be shown how we can certify that causal links obtain or, eventually, that some causal laws are true. This is an important task. The justification of our assertions of existence hinges on the reliability of the supposed causal connections between what we observe and what exists. When perception is immediate, no causal link need to be invoked. The actual presence of a glass of beer immediately evidences its existence beyond reasonable doubt in a normal context of perception. Direct or immediate realism is the indispensable ground for epistemological realism about external things.

By reflecting on our perceptions, we are in position to ascertain the invariance as well as the orderly variation of some properties of the perceived thing, e.g. when our spatial points of view are modified. If we alternatively shut and open our eyes, we perceive the same properties, provided the perceptual environment remains unchanged. These banal observations provide sound reasons to believe that some causal connections are in place between the perceived concrete objects and the perceptions of their properties.

To discover and mathematically formulate causal laws, thorough empirical investigations and in-depth theoretical work are necessary. As a first stab, we can fall back on the well-known methods of agreement—and above all of difference—of John S. Mill. Think of Newtonian dynamics. If we have reasons to believe that forces exist, it is in the first place because of our bodily experience. Weighty things exert a force on our arms when we carry them. An impressed force also produces variations of velocity. A body at rest can be put in motion by exerting pressure on it. When no net force acts, there is no acceleration. In science we must denote a force by a mathematical symbol, namely a vector. Moreover, we must be able to measure forces with accuracy. In order to measure the gravitational force, for example, we can use a scale. When it is horizontally in equilibrium, we can conclude that the forces, called "weights", exerted on the arms of the scale are equal. This static way to measure certain forces can be generalized to measure the values of different forces in some unit.

Accelerations can be measured by means of various experimental devices, such as the Atwood machine. In numerous cases, we can measure the forces and the accelerations they cause in order to verify that accelerations are proportional to forces, in conformity with the fundamental law of Newtonian mechanics. The proportionality factor—the inertial mass—can be measured by the method of

Huygens' collisions, independently of Newton's second law. When the vectorial sum of the forces is (approximately) nil, the velocity of the mobile is (approximately) constant in magnitude and direction. This is the inertial motion. Numerous observations and measurements give excellent reasons to believe that the law of inertia holds for all bodies.

Perrin's argumentation for the existence of the molecules can then rely on the fundamental laws of mechanics, which can furthermore offer a causal explanation of the property of gas pressure. We must therefore distinguish several levels in a causal explanation. The first hinges on the mechanisms described by a theory when Perrin relies on the kinetic theory and the laws of collision to explain what is going on in an emulsion. The second level consists in the causal interactions between our apparatuses, such as a microscope, and some observed properties, like the distribution of grains in an emulsion. Ii is not necessary to know the laws which govern the interactions of the second level to be entitled to believe that some objects having not directly observable (OP) properties exist.

7 Conclusion

A defensible version of scientific realism can only be fallibilist and selective. In order to be in a position to claim that a concrete object with particular properties exists, a specific argumentation in favor of the presence of each property must be provided. I have attempted to show that any such convincing argumentation must jointly satisfy four requirements: the requirement of observability in principle, the requirement of measurability, the requirement of causality and the requirement of concordance. The justification of these requirements is based on the fact that they are satisfied by everyday arguments in favor of the existence of ordinary objects, whether actually perceived or not. The requirement of measurability however, doesn't always have to be satisfied as far as ordinary objects are concerned. But in the sciences, the requirement of measurability is a prerequisite for the satisfaction of the all-important requirement of concordance. I submit that this version of epistemological selective realism on top of being forceful is also in compliance with a moderate empirical philosophy. AQ3

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