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Reality as Persistence and Resistance

Abstract: This paper proposes a way to understand the meaning of reality (in science). It first supports the ontological view that reality consists of persistent potentialities, which resist being excluded from existence. A study of the cases of the Higgs boson and the hypothetical F-particle helps to illustrate how real entities persist and resist. The paper then suggests that, perceptually speaking, the results of ordinary perception or observational processes persistently appear under appropriate conditions, and they resist disappearance even when the conditions are not completely appropriate. It also argues that, epistemologically speaking, a truthful theory resists being falsified and persists across replicable observations and experiments. Overall, discussing the notion of reality in the context of the philosophy of science, science and technology studies, and phenomenology, the paper explicates the 'real' on the basis of these two concepts: 'persistence' and 'resistance'.

1 Introduction

The scientific realism debate concerns the question of whether or not scientific knowledge describes reality. However, (anti)realists usually begin the discussion without clarifying the answer to this central question: what is taken as the meaning of the notion of the 'real'? This leads to a general problem: reality is discussed, but its meaning is not clarified. Realists are faced with the issue more seriously since they advocate a realist interpretation of unobservables, the meaning of whose reality is unclear. This question cannot be adequately answered merely by providing a 'criterion' for reality. Also, using 'truth' does not help realists in determining the meaning of reality because of the existence of non-realist theories of truth. This paper aims to illuminate the notion of the real. I aim to conceptually analyze the meaning of the real at three levels: ontological, perceptual, and epistemological.

In addressing the question of 'what reality means' I do not offer a definition that presents the necessary and sufficient conditions for reality. It is unclear if one can define a basic concept like 'reality' in this way. I instead plan to explicate or clarify the 'real' by these two concepts that have close affinities with reality: 'persistence' and 'resistance'. This approach of mine is not unusual in philosophy. For instance, a logical definition of 'meaning' that presents its necessary and sufficient conditions is similarly unavailable, and instead 'meaning' is usually explicated by use of closely connected concepts such as 'reference' and 'representation'.

In this paper, persistence and resistance collaborate in explicating reality, and neither of them is reduced to the other concept. Sometimes persistence is central to my conceptual analysis of reality and sometimes resistance is. As I will explain, ontologically speaking 'persistence' is more basic than 'resistance' because it is the tendency to persist that explains the resistance to being annihilated or wiped out. At the same time, as I will further clarify, during actual investigations and before the thing under investigation is finally realized, resistance is the primary concept. Experimenters first encounter an entity's 'resistance' to being excluded (or to be made to disappear); then, under the appropriate conditions, the entity may show its 'persistence'. Overall, the paper remains balanced as to the dialectic between persistence and resistance of reality.

The objective of the paper is not to argue for or against realism, but to argue that 'persistence' and 'resistance' play a central role in what reality means. Still, I attribute my proposed notion of reality to unobservable entities such as neutrinos and Higgs bosons. In this sense, the paper is committed to realism, or, more precisely, to a modest realism that coheres with perspectivism (see also Khalili 2023b; 2022b; 2022a; 2021). Nevertheless, my principal aim in this paper is neither

to convert antirealists to my preferred form of realism nor to prove that certain unobservables are real.[1]

The paper proceeds as follows. It starts with Hans Radder's account saying that reality consists of human-independent, persistent potentialities or powers. It then explores the account of reality as 'resistance', which can be suitably complemented by a positive, potentiality-based ontology. After that, a study of the Higgs boson and the hypothetical F-particle illustrates the view that real entities resist being excluded from existence and persist in existing. At a perceptual level, the same view implies that real things resist disappearance by providing some effects and signs, and they persist in appearing by making possible experience or evidence under appropriate conditions. Finally, the epistemological implications of the concepts of resistance and persistence are discussed briefly. I conclude that 'persistence' and 'resistance' explicate the negative and positive meanings of the notion of 'real' at different levels of discussion.

[1] This paper follows Khalili (2023a) about why neutrinos and Higgs bosons may be taken as real.

2 Reality as Consisting of Human-Independent Persistent Potentialities

According to Radder, the real is independent of humans (see Radder 2012[1988], p. 82 and pp. 169-170), so he often employs the adjective 'independent' or 'human-independent' before the noun 'reality' (see, e.g., 1996, chapter 4). He introduces the ontological and epistemological theses of realism as follows.

> Ontological thesis of realism: "The existence of the world (of nature) and its general structure is … independent of the existence of human beings and the process by which they acquire knowledge."
>
> Epistemological thesis of realism: "concrete scientific propositions 'are about' this human-independent reality" (2012[1988], p. 82).

A key concept here is the term 'is about', which Radder uses in order to argue for his 'referential realism', according to which a scientific term 'is about' or 'refers to' elements in a human-independent reality, provided that the experimental episode that is described by the term can be materially realized in a reproducible way (2012[1988], section 4.4; 1996, p. 76). Apart from this, the term 'is about' appreciates that knowledge is intentional: knowledge is always *about* something.

According to Radder, the notion of the real is independent of human beings. This 'independence' explains that, ontologically speaking, *(natural) reality would exist if no human being existed*. The ontological thesis of realism implies that reality *does not* depend on humans. However, the thesis does not clarify the specific ontological features of this independent reality. Accordingly, we need a notion of reality that illuminates reality's nature. To fulfill this need, and in line with philosophers such as Roy Bhaskar (1978), Rom Harré (1986), and Nancy Cartwright (1989), Radder (1996, chapter 4) supports the following notion.

> The Aristotelian notion of reality: the real consists of persistent potentialities or powers (or dispositions, tendencies, affordances, capacities, abilities).

To explain this notion, let us apply it to an ordinary object. A glass cup consists of potentialities, which means that the cup possesses certain possibilities that can be realized in (specific) circumstances. Only some of the potentialities of the cup are already realized in specific conditions (e.g., its transparency in the presence of light). Its other potentialities are non-actualized. For instance, the glass cup is break*able*, so it will be broken on condition that we put it under certain pressure. When it actually breaks and becomes pieces of glass, we know that the cup is breakable. However, the cup possesses the ontological potentiality of breakability apart from our knowledge of this potentiality. Similarly, scientific entities consist

of potentialities, which we know via experimental activities that 'realize' those potentialities. For example, we learn that salt is soluble by actually solving it in different solvents. But salt is ontologically soluble independently of whether we know this potentiality.

Radder does not employ the concept of 'property' to explain potentialities. However, in contemporary metaphysics of science, scholars usually define potential capacities, dispositions, and powers in terms of properties (e.g., see Cartwright 1999; Mumford 2003; Bird 2007; Chakravartty 2007). For instance, Anjan Chakravartty argues that properties, such as masses, charges, densities, and acidities, confer on the things that have them certain abilities (2007, pp. 41). Thus, a real thing enjoys properties that, under certain conditions, make it behave as it actually does. In the following, I presuppose that potentialities are indeed potential or dispositional 'properties' of things.

Radder argues that potentialities are human-independent. However, their socio-material realizations depend on conditions that are not, or not entirely, human-independent. He thus speaks of "a *persistent potentiality of reality*, which as such is independent of the existence and knowledge of human beings. The *realization* of this potentiality, however, essentially requires human (material and theoretical) work" (1996, p. 79). To realize an entity's potentiality, scientists actualize that potentiality. In this sense, the term 'realization' also implies a knowledge of the potentiality obtained through practical activities. The concepts 'realization' and

'creation' should not be confused. The former is "the mixture of discovery and production in scientific practice" (1996, p. 80). By realizing potentialities, humans do not create potentialities but humans actualize those potentialities to understand them. We learn that the glass cup is breakable by actually breaking it. In science, this kind of realization happens in an experiment or an observation, both of which depend on skillful activities of humans.[2] Indeed, the realization of potentialities through an experimental or observational setting depends on human activities and the theoretical interpretations that guide these activities. However, this does not mean that the existence of potentialities is human-dependent. Potentialities exist in nature whether or not human beings realize them: "The potentialities of nature persist independently of our existence and of our knowledge, even if they can be realized only if we cooperate and are able and willing to do the required material and theoretical work" (Radder 1996, p. 79).

According to this notion of reality, 'persistent' potentialities constitute reality. But could potentialities be non-persistent? I would think that, ontologically, potentialities are always persistent. In other words, entities that are not persistent

[2] On experimentation, see Radder (2012[1988], section 3.3) and (1996, chapter 2); on observation, see his (1996, section 4.7); see also his (2006, pp. 12-18) for a criticism of Bas van Fraassen's account of observability.

are not real potentialities at all. The adjective 'persistent' is used before the term 'potentialities' to emphasize that real things persist through changing human contexts (hence 'human independent'). Note that persistence does not necessarily mean long-standing.[3] Real things may appear in a very short period of time, yet they are real if they appear in *different contexts*. For instance, some elementary particles have short decay times, but they do have potentialities in particle interactions because they appear in different experimental contexts (I will further clarify this point in section 5).

Historically, different theories may describe a certain reality differently. For instance, 'mass' is defined differently from the Newtonian and Einsteinian perspectives. Likewise, the properties of an electron are different from Lorentz's and Dirac's perspectives (Radder 2012[1988], pp. 83-84). Radder's 'referential realism' suggests that the *persistence* of a potentiality secures a certain degree of *continuity* through different theoretical perspectives. This continuity is not

[3] The notion of persistence analyzed in this paper is rather different from that in the metaphysics literature, for instance in Theodore Sider's (2001) *Four-Dimensionalism*. In a future work, my project of reality as persistence and resistance could be compared with similar projects in metaphysics, for instance with Kit fine's (2001) account of grounding.

conceptual-theoretical but existential. Successive terms, such as 'Lorentz-electron' and 'Dirac-electron', are not described by compatible concepts and theories, so there is a conceptual-theoretical discontinuity between theories in the history of science. In spite of this, successive terms can 'corefer' to a certain (unobservable) entity in reality. According to this account of coreference, the separate terms refer to, and are different theoretical interpretations of, the same entity. For instance, the theoretical terms 'Lorentz-electron' and 'Dirac-electron' both refer to the same unobservable entity, namely the electron. These two terms are indeed two theoretical interpretations of the same empirical evidence, which is provided by means of scientific instruments.

To sum up, Radder defends an ontological account of reality in terms of *human-independent potentialities*, whose *persistence* enables a *continuity* between successive theories, hence 'referential realism'. The next section examines the views of Bruno Latour and Andrew Pickering, who employ the concept of 'resistance' to describe reality.

3 Reality as Resistance: Latour and Pickering

Latour states that "reality as the latin word *res* indicates, is what *resists*. What does it resist? *Trials of strength*. If, in a given situation, no dissenter is able to modify the shape of a new object, then that's it, it is reality, at least for as long as the trials of strength are not modified" (1987, p. 93). Apparently, an analogy with politics

underlies Latour's account of resistance. A political party exists insofar as it resists being wiped out through 'trials of its strength' by other parties. The ruling party is in power for as long as it successfully resists attempts to destroy it. A new party, as a 'dissenter', may enter the stage and gain power, and thus 'modify' the balance of power. Similarly, in the world of science, as long as an entity is actively referred to by scientists, it is real, or more precisely, it is considered to be real in a (scientific) community. If a putative entity (e.g., the ether) does not resist being *replaced by* another entity (e.g., the electromagnetic field), the old one is not considered to be real any more. The resistance an entity can offer depends on its position in the network of human and non-human actors. This relational account is based on Latour's famous 'actor-network theory'. An entity successfully resists change when other actors of the network, including tools, graphs, experimenters, and policy makers, support it (or are its allies, so to speak).

Another concept, similar to resistance, which Latour uses to describe the reality of objects is 'recalcitrance': "Natural objects are naturally recalcitrant; the last thing that one scientist will say about them is that they are fully masterable. On the contrary, they always resist and make a shambles of our pretentions to control. … [M]icrobes, electrons, rock seams are utterly *uninterested* in what human scientists have to say about them" (Latour 2000, p. 116). This view implies a kind of realism, because the resistance or recalcitrance of entities, rather than the mere interests or

expectations of scientists, has an effect on what we count as real in science.[4] On this view, an object is real if it resists being replaced (see 2000, p. 112).

In a similar manner, Pickering speaks of 'resistance'. He maintains that the outcome of scientific practice is "a *dialectic of resistance and accommodation*, where resistance denotes the failure to achieve an intended capture of agency in practice, and accommodation an active human strategy of response to resistance, which can include revisions to goals and intentions as well as to the material form of the machine in question and to the human frame of gestures and social relations that surround it" (Pickering 1995, p. 22). Accordingly, 'resistance' implies a kind of 'failure' of scientists to achieve what they want because it is not in agreement with reality. To illustrate this, Pickering puts forward the case of the physicist Giacomo Morpurgo, whose first observation of fractional electrical charge resisted to be in agreement with his expectations. Morpurgo then made several new 'accommodations'. That is, he altered the apparatus, revised his theoretical model of the apparatus, and modified his theory of the phenomenon. Finally, he observed

[4] Francisco Salinas interprets Latour's view of science as 'pragmatic realism', where "[r]esistance is what nourishes pragmata as the pillar of reality" (2014, p. 10). Matthew Watson (2015) confirms this interpretation. See also Latour (1999), where he depicts himself as a realist.

what he expected. According to Pickering, such processes constitute a 'dialectic' of resistance of the material reality and the accommodations to that world, including changes of experimenters' intentions and expectations, of their theories, and of the instruments they employ in the experiment. Pickering dubs his view 'pragmatic realism': It is realist because "*how the material world is* leaks into and infects our representations of it" (Pickering 1995, p. 183). However, it differs from 'traditional philosophical realism' in that scientific representations should not be considered as correspondence links: "Pragmatic realism specifies nontrivial links between knowledge and the world that are quite independent of relations of correspondence" (Pickering 1995, p. 183).[5]

Thus, Latour and Pickering explain why reality, in many cases, resists conforming to scientists' expectations and interests. As such, this is definitely a valuable view. At the same time, the notion of 'resistance' is a *negative* concept that can to be complemented by a positive one. Many cases of the 'failure' of scientists to achieve a theoretical aim or the fact that reality may be 'uninterested'

[5] We should not confuse Latour and Pickering just because both have been related to 'pragmatic realism', of which they may have different interpretations. Be that as it may, the two thinkers point to the significance of resistance in addressing what reality means and both incorporate realist attitudes in their accounts.

in what scientists say about it, can be explained by a positive feature of reality that (partly) results in the failure or dissatisfaction of the scientists. According to the Aristotelean notion of reality, potentialities are *power*ful, so they do not simply 'obey' what scientists expect or want. Instead, scientists have to 'pay careful attention to' reality (through what Pickering calls 'accommodation') to understand it. In a less metaphorical language, the potentialities of (natural) reality exist in a human-independent way. Experimenters/observers know them by actively realizing them through experimental/observational processes. Humans cannot fabricate those powers. Even if all experimenters assume that a certain power exists, it will not be real as long as it does not enjoy independent existence. The experimenters' beliefs may have real social implications. However, this does not introduce a new power to already existent potentialities of (natural) reality. Indeed, the resistances of reality to scientists' expectations and interests rest on human-independent potentialities, and those predictions and explanations are successful that respect the persistent potentialities of reality.

Latour and Pickering are sometimes blamed for discounting the role played by reality. For instance, it is claimed that the natural world "never seems to be decisive in any of Pickering's case studies" (Franklin and Perovic 2019; see also Hacking 1999, p. 91). To avoid this kind of criticism, the account of reality as resistance can

locate its *ontological* roots in a potentiality-based ontology.[6] Accordingly, the resistance to be replaced by 'dissenters' and to follow scientists' expectations and interests relies on the persistent potentialities or powers of real things. This view acknowledges the indispensable role of persistent reality in the production of scientific knowledge.

What I am suggesting here is indeed a way of capturing Latour's and Pickering's conception of resistance that at the same time includes the account of reality as persistence, powerful potentialities. In other words, the idea of reality as resistance is insightful, but its insights can be incorporated within the broader view of reality as resistance *and* persistence. A reviewer for *Perspectives on Science*, however, questions whether my endorsement of persistent potentialities is compatible with Latour's account:

> when addressing "persistence" you seem to agree … about natural things being already there as potentialities and, therefore, "discoverable". Nevertheless, this is incompatible with Latour's

[6] Latour's notion of 'plasma' may be compatible with the Aristotelian concept of potentiality. Thus, relying on a comprehensive reading of Latour, one could develop a more proactive argument in favor of the ontology of potentialities. I should like to thank one of the reviewers for offering this remark.

> account claiming that there were no microbes before Pasteur since he invented them as well as *they* invented him as a famous scientist. … [Latour] would never accept a strong distinction between the human world and that of nature: if you will, for him reality is "powerful" but never "independent" (the basis is always interrelated monads, so to speak). Therefore, it seems that you must take sides either for a "logic of discovery" (that also acknowledge some role to human practice) or a "logic of performativity" (where human intervention is a constitutive part of the reality of ever-changing actor-networks).

I would think that the ontology of potentialities is not in conflict with Latour's view unless we understand his claim that there were no microbes before Pasteur uncharitably as claiming that Pasteur created the ontological potentialities of microbes. The claim that microbes are ontologically created by Pasteur is as ridiculous as the claim that Pasteur, as a person with certain talents who was born in 1822 and died in 1895 was ontologically created by microbes. I understand Latour's claim about Pasteur and microbes not ontologically but in this conceptual-societal way, which is completely defensible: our conception of microbes as small living objects that may cause disease and our social recognition of Pasteur as a

famous scientist are constructed and human-dependent. Furthermore, Latour's view carries an epistemological implication insofar as it is concerned with truth claims. For instance, "when Latour accepts climate change is real in *Down to Earth* [(2018)], he is accepting that the current associations in favour of climate change being true (e.g., scientists, machines, gestures, textbooks, institutions and journals) are more robust—so *more* real—than the associations asserting something different" (Lawson 2020, p. 38). In other words, the position of 'climate change' in the network of human and non-human actors is supported by its associations, that is, by the other actors of this network. For this reason, we are justified to consider climate change to be real. This epistemological implication of Latour's view should not be confused with an ontological claim.

I should also clarify that I support neither the logic of discovery nor that of performativity, but the 'logic of realization'. This view is different from the other two logics but has affinities with them inasmuch as 'realization' is the mixture of 'discovery' and 'production'. Human intervention is not an ontologically constitutive part of potentialities, but rather the constitutive part of realizing them ('realizing' in both senses: 'actualizing' and 'knowing'). As a result, potentialities need to be *actively* actualized to be known, which requires a lot of human work (see section 2). Thus, Latour and Woolgar (1986, p. 176) are right that there was no reality "merely waiting to be discovered and that it finally became visible". A further implication of the realization logic is that the realizations of potentialities

depend on human problems, purposes, and inquires. It would be cumbersome to exhaustively list the properties of an object given its possible range of interactions. In practice, people try to know just those properties of an object that are somehow relevant to their problems and purposes. Accordingly, providing an exhaustive list of the properties of an object is pointless, and usually our ontological commitments are just given to those aspects of objects that are somehow relevant to our (scientific) inquires. What is more, the 'logic of realization' implies that the same object with certain potentialities may be manifested differently in different kinds of contexts or to different observers. One example that can be found in various phenomenological writings is this: a sponge is squeezable for a human with hands but is like a porous rock for an ant based on how the ant can interact with a sponge. Although the sponge's potentialities exist independently of humans and ants, it will be realized differently depending on the bodily features of the thing interacting with it. This results in a perspectivist view at the perceptual and epistemological levels of discussion. The manifestation of an object is perspectival in the sense that it may be perceived and known differently depending on the bodily and technological perspectives that make it possible to interact with the object and on the (theoretical) concepts that interpret it (see section 5; see also Khalili 2021; 2022b). As a result, the realizations of potentialities are always bounded by historically contingent instrumental and theoretical conditions, and thus an objective, non-perspectival knowledge of reality is unavailable. This perspectivist view is in agreement with

Pickering's assertion that there are 'nontrivial links' between knowledge and reality different from the 'relations of correspondence' and also with Latour's denial of "a one-to-one correspondence between an isolated statement and a state of affairs" (1999, p. 161). Finally, an implication of my perspectivist view is scientific pluralism: potentialities can be realized differently in different conditions (see Khalili 2022b, section 7).

Let me finish this section by explaining that my use of 'resistance' in this paper coheres with two points Martin Heidegger makes in *Being and Time* about Wilhelm Dilthey's and Max Scheler's notions of *resistance*. Heidegger maintains that "*if* 'Reality' gets defined as 'the character of resisting', we must notice two things: first, that this is only *one* character of Reality among others; second, that the character of resisting presupposes necessarily a world which has already been disclosed" (1962[1927], p. 254). Concerning the first point, my discussion in this paper is not restricted to 'resistance'. In addition, the ontological feature of being persistently potential and powerful is considered. Furthermore, the present paper addresses the notion of 'persistence' and 'resistance' at ontological, perceptual, and epistemological levels, whose distinction clarifies the question of what reality means. Heidegger's second point is also the case. Resistant reality is disclosed through our engagements, when we actively experience things in the world, that is, in our realm of possible, interrelated things. In Heidegger's words, "*[t]he experiencing of resistance—that is, the discovery of what is resistant to one's*

endeavors—is possible ontologically only by reason of the disclosedness of the world. The character of resisting is one that belongs to entities with-the-world" (1962[1927], pp. 253–254). I agree with this statement and should like to add that this is correct both about ordinary objects and about scientific entities whose resistance (and persistence) shows itself by means of embodied or instrumental perspectives and is interpreted by (theoretical) concepts in the 'world' of scientists and experimenters (see section 5).

This section has argued that the account of reality as resistance is a negative view, which can be complemented by a positive, potentiality-based account. The following section illustrates the concepts of 'persistence' and 'resistance'. Sections 5 and 6 discuss the relevance of these concepts to the perceptual and epistemological levels.

4 Persistence and Resistance: Higgs Bosons versus F-particles

I start this section with a conceptual analysis. 'To persist' may literally mean 'to continue existing'. Real things persist in the sense that they continue to exist through changing human contexts. When a thing continues to exist, it 'resists being excluded from existence' as well. After all, 'persistence' and 'resistance to be excluded from existence' are two sides of the same coin. Two related statements can be made at the ontological level thus: real things 'resist' being excluded from existence, and real things 'persist' in existing. The former provides a negative view

of reality; the latter presents a positive one. Conceptually, both point to the same reality. However, *in practice*, the former is more suitable to describe a thing to be realized, or in other words, a thing whose existence is under investigation. The latter, in contrast, better describes a thing that is already realized in the appropriate conditions. My approach here is not limited to the final realization but also addresses the processes that precede these final results. Adding this process dimension is an important feature of understanding scientific practice.

Persistence is not unconditional. Real potentialities only demonstrate their persistence in the appropriate conditions, where appropriate observational/experimental setups are prepared. The presence of the appropriate conditions is contingent and may not always occur. Nor do observers/experimenters know from the beginning the characteristics of the appropriate conditions. They make use of theories and models and of other observers/experimenters' practical experiences, and they also attempt to provide appropriate observational/experimental setups by heuristic methods or sometimes even by trial and error. As a result of their attempts, a significant correlation may be established between the outcomes of observational/experimental instruments and the behavior of an entity, and therefore a property of the entity is being realized. In this process, precluding possibly disturbing external influences is a substantial part of the observational/experimental work (see Radder 2021, section 2). Accordingly, a lot of work needs to be done so that the appropriate conditions, which are necessary

for the display of 'persistence', are prepared. That said, entities may resist being excluded from existence even when the appropriate conditions are *not fully* prepared. This may be the case when these conditions are only partly prepared for different reasons: observational/experimental settings are not perfectly arranged, the conditions are not completely appropriate for that specific entity under investigation to be realized, not all disturbing influences are prevented, not all possibilities for the observation/detection of the entity are as yet investigated, or for other similar reasons. In these cases, the real entity may still resist being considered as non-existent, which accounts for why unsuccessful experimenters/observers are still reasonably hopeful that by providing *better* conditions they may observe/detect the supposed entity in their future attempts.

In the following, I study two experimental endeavors regarding the Higgs boson and the hypothetical F-particle ('F' is a Greek letter, which is pronounced 'digamma' and whose shape is a little different from the English letter 'F'). The Higgs boson is an elementary particle and plays a unique role in the Standard Model of particle physics. It explains why elementary particles such as W and Z bosons are massive, while photons and gluons are massless. This boson was predicted by François Englert, Robert Brout, Peter Higgs and others in the mid-1960s and it was finally detected in 2012. In contrast, the F-particle was a hypothesis supposed to explain an unexpected anomaly in data collected in 2015 (at CERN in Geneva). However, further analysis and the data collected in 2016 combined with the

previous data showed that the anomaly was a statistical fluctuation rather than the evidence of a new particle.

The central claim is that before its detection in 2012, the Higgs boson was resisting being excluded as non-existent, mainly because not all the masses it might have had been investigated. After its detection in 2012, it persisted in reproducible experiments. In contrast, the putative 'F-particle' has not even resisted its exclusion. Its failed detection was not caused by imperfect experimental conditions; the probable reason was rather that the supposed particle did not exist.

Let me start my discussion of the Higgs boson with an ordinary example. Suppose that one thinks that there is a beetle in one's home, and then one starts examining different rooms in search of the beetle. If it really exists in the home, and indeed because of its very 'existence', the beetle resists being considered non-existent (despite its desire not to be found and killed!). Therefore, probably after one's active attempts to find it, the beetle will eventually be found in a room. In this case, the beetle resists being excluded from existence in the home. When it is trapped, one understands that it exists. Similarly, and providing that we disregard other complexities, there are different search probes into the Higgs boson. Each probe investigates whether the boson with a *specific mass* exists. Certain masses for the Higgs boson were excluded but the Higgs particles resisted being excluded from all possible probes. Finally, when the particles are realized, their persistent existence shows itself in experiments that reproduce the appropriate conditions, as

the consideration of the correct mass is a condition for its persistence in the experiment. Below, this example is further explained.

The Large Electron-Positron (LEP) Collider operated from 1989 to 2000 at CERN in order to measure the properties of Z and W bosons and also to search for the Higgs boson. Direct searches for the Higgs boson at the LEP set a lower bound on the mass of the Higgs boson: If there is such a particle, its mass must be more than 114 GeV/c^2 (Abbiendi et al. 2003). Until 2001, the Higgs boson hypothesis was neither confirmed nor rejected. The Tevatron, a proton-antiproton collider at the Fermilab in Chicago operating in the years 1986 to 2011, had probed masses of 100-200 GeV/c^2 in searching for the Higgs boson but couldn't find any evidence that could be a conclusive indication for a Higgs detection. However, physicists could not completely reject the existence of the Higgs particle either. The Tevatron only excluded Higgs masses between 162-166 GeV/c^2 (Aaltonen et al. 2010; Buehler 2008). Although different searches might exclude the existence of the Higgs boson, it could also have some other mass. Up to this point, although the Higgs boson was not detected, it resisted being considered non-existent.

The Large Hadron Collider (LHC) was subsequently designed at CERN to reach higher energies in order to further constrain the parameter space for the mass of the Higgs boson. Only if the total parameter space would have been probed and nothing would have been found, then physicists could conclude that the Higgs particle does not exist. All experiments before 2012 succeeded in excluding certain masses for

the Higgs boson, and thus in those experiments the Higgs bosons were in fact excluded. However, the particle resisted being entirely excluded from existence. Finally, ATLAS and CMS collaborations at CERN using the combined LHC data, at the energies of 7 and 8 TeV, reported the detection of the Higgs boson with a high statistical significance (Aad et al. 2012; Chatrchyan et al. 2012). The proton-proton collisions at the LHC (with an energy of 13 TeV) were also in agreement with the previous results at 7 and 8 TeV (Tao 2018).

The Higgs experiments in proton-proton collisions at different collision energies, including 7, 8, and 13 TeV, confirm the reproducibility of the experiment. Since 2012, physicists have also collected further data at the LHC and measured the mass of the Higgs boson with unprecedented accuracy (Sirunyan et al. 2020). In sum, the Higgs boson has resisted being excluded while experimenters were probing it, and after its detection in 2012 it manifested its persistent existence in reproducible experiments.

The so-called ‘F-particle’ has had a different fate in comparison with that of the Higgs particle. In December 2015, ATLAS and CMS collaborations at the LHC reported an excess of mass in the di-photon spectrum (Aaboud et al. 2016; Khachatryan et al. 2016). In the first half of 2016, over 500 papers were written to examine the excess and offer possible explanations for its nature. The signal at first showed a rather high statistical significance (bigger than 3.4 sigma), which could be considered as an indicator of a possible, new particle, the so-called ‘F-particle’

with a mass of about 750 GeV/c^2, which decays into two photons. However, accumulating data and further analysis excluded the possibility that the 'F' particle exists. Unlike the Higgs boson, the putative F-particle has not put up enough resistance to being excluded. Nor has it entered into the class of entities showing persistence in reproducible experiments.

Thus far, I have argued that real entities resist being excluded from existence and they persist. This ontological view has a 'perceptual' parallel, which the next section clarifies. The perceptual level addresses the experiential or evidential characteristics of real things.

5 Persistence and Resistance in Perceptual Processes

This section explains what 'persistence' and 'resistance' mean at the *perceptual* level. The main question is how we *perceive* reality if it ontologically consists of powers or potentialities that persist in existing and resist being excluded. To answer this question, I use the phenomenological account of perception, according to which the perceiving subject is both *active* and *passive*. The active dimension implies that things manifest themselves through *our bodily or instrumental engagements* with them. The passive (or receptive) side acknowledges the fact that perceptual "experience is shaped by the *insistence* of the

world" (Gallagher and Zahavi 2012, p. 111, emphasis added).[7] I employ the concepts of 'persistence' and 'resistance' to explain the passive feature of perceptual experience of reality. I first put forward the account and then clarify its terms and support it.

> The perceptual account of persistence and resistance: veridical experience persists in appearing and resists disappearing across several modes of our bodily or instrumental engagements.

The passive or receptive side of perception, the persistence and resistance of perceptual experience, and its active dimension, that perception is a kind of active human involvement through embodied or instrumental engagements, are both included in this account. 'Appearance' includes the occurrence of mere appearances and of veridical experiences. The claim is that only veridical experiences persist and resist. Experience comprises ordinary perception (perceived by embodied

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[7] My account of perception in this section is also akin to the predictive mind approach, which says that the brain is a hypothesis-testing mechanism that minimizes the error of its predictions about its received input from the world. The theory implies that, although what we perceive originates in the world, its content depends on our action and attention. See Clark (2013) and Hohwy (2013).

organisms) and observational and experimental evidence (obtained through instrumental engagements). Thus, the terms ‘experience’ and ‘perception’ should be understood broadly to cover not only ordinary perception but also the evidential results of scientific observation and experiment.

The passive feature of perception ultimately relies on the *power*ful nature of reality. An experience persists in appearing and resists disappearing because the thing to which the experience belongs exists independently of the perceivers. Note that the passive side of perception implies that *perceivers* are (partly) passive in perception. It does not mean that reality is passive. A powerful reality is active in this respect, and for this very reason perceivers are and should be (partly) passive in their perceptual experience of real things.

Despite the connection between the ontological and perceptual levels, persistence and resistance have different implications at the two levels of discussion. Persistence and resistance are relations: A ‘persists in’ B and ‘resists’ B'. At the ontological level, A is the ‘potentialities of a thing’, B is ‘existing’ and B' is ‘being excluded from existence’. Accordingly, the potentialities of a thing persist in existing and resist being excluded from existence. At the perceptual level, similarly, A ‘persists in’ B and ‘resists’ B', but A, B, and B' are different. A is ‘the results of ordinary perception or observational/experimental processes’, B is ‘appearing’, and B' is ‘disappearance’. Accordingly, the results of ordinary perception or observational/experimental processes persist in appearing (by making

possible experience or evidence under appropriate conditions) and resist disappearance (by providing some signs or effects). In addition, the difference between 'persisting in appearing' and 'resisting disappearance' is similar to what was said earlier: when we start engaging with a new thing, it may not be manifest persistently right from the beginning, while it may resist disappearing by displaying some signs, indications, or traces. After its manifestation under appropriate conditions, however, the thing's appearance persists in appearing.

'Engagement' here entails being significantly involved with something to *experience* it. Specifically, I- ordinary perception, II- scientific observation, and III- experimentation are cases of our engagement with things. The ordinary perception of an object or the empirical evidence of a scientific entity resists disappearing (before its realization) and persists appearing (after its realization). This is the case when we actively engage with an object by means of bodily interaction or with an entity by the mediation of technological instruments.

Veridical experiences can appear across *several modes* of our engagements. That is, the engagement with a thing, in ordinary perception or scientific observation and experimentation, should be possible once again in a replicable way. In the following, I first explain the veridicality of our ordinary perception, and then, I extend it to scientific observation and experimentation.

Human beings enjoy embodiment, so they can bodily engage with things to distinguish veridical perceptions from mere appearances, illusions, and

hallucinations (see Merleau-Ponty 1962, pp. 296–297). For instance, we can approach a mirage and see it from different angles to become confident that its appearance is different from the veridical experience of an actual lake. My main point here is that a veridical experience involves *several modes* of perception. Suppose that one thinks to see something in a dark area, but one is sure neither if there is something there nor what the properties of that supposed thing are. One can perform different actions to check if what is seen is a veridical experience. One can look at the thing from other positions, flash a torch on it, throw a small piece of grit to it to detect its reaction and to listen to the sound made. One can also collaborate with one's friends in order to share what is perceived. These and similar practices constitute several modes of engagement with the thing. If the experience of the thing itself first 'resists disappearing' and finally 'persists in appearing', and different modes of our engagement with the thing are in agreement, then the experience of the thing is veridical. The experience of the thing's *properties* may also resist and persist. For example, if there is a car in that dark area, first, one's experience displays the signs of the car. Even if one initially supposes that the thing must be, say, a wild animal, that thing resists being experienced as anything but a car. And sooner or later, after several active engagements with it, it finally appears as a car. The more our experience is based on several modes of active engagement with it, the more veridical the experience of the thing and its properties are.

In similar ways, scientists devise several practical methods to engage with entities. These engagements, mainly through technological instruments, help scientists check if the evidence of a supposed entity (and its properties) is veridical (cf. Vallor 2009). Scientists can never be *completely* confident that observational/experimental results are veridical because it may always be the case that what has appeared to them is a stubborn, tenacious illusion or hallucination rather than a piece of veridical evidence. However, such a perfect level of confidence is not necessary; to the extent that their results rely on different processes of obtaining scientific evidence, they can be confident that the evidence is veridical.

In the remainder of the section, I clarify some further details of the perceptual account of persistence and resistance. The first point is that perception is a result of *collaborative* activities. In ordinary perception, perceivers share their experiences to recognize a veridical experience. Likewise, scientific observation and experimentation, which is made in a community of observers or experimenters, the empirical results should be confirmed by a broader scientific community. To emphasize this characteristic, I have stated in the perceptual account of persistence and resistance that 'our' [in the plural] bodily or instrumental engagements enable us to have veridical experiences.

Another point is that we may experience a thing only for a very short time. For example, soap bubbles quickly disappear upon most of our bodily engagements

with them, but we do not doubt that they are real. Why? Because anytime we blow in soapy water, with a pipe or a straw, bubbles rise. Soap bubbles appear only for a short period. Similarly, in particle physics unstable particles undergo quick decays. However, (the evidence of) an unstable particle keeps reappearing in different experimental contexts, although within a very short time period. The fact that the duration of the appearance is short does not mean that it does not appear. Every time appropriate experimental conditions are replicated, the evidence of the particle appears persistently, even though shortly, because persistent appearance in experience is based on the persistence of human-independent potentialities that can be realized (even if shortly) under the appropriate conditions. For example, although they are very elusive because they easily pass through ordinary matter, neutrinos are real, and thus their evidential effects persist every time appropriate experimental settings are prepared. Accordingly, 'persistent' does not mean 'long-lived'. Real entities may appear in different experimental contexts even for a short time.

I would finally like to clarify that our observational engagement with reality is bounded by the mediation structure that makes available the interaction with the world. In other words, we engage with reality through our bodily apparatus and scientific instruments, both of which are perspectival. That is, humans ordinarily experience the world from a colored perspective (Giere 2006, chapter 2). And similarly, a scientific instrument is always conditional on what it is sensitive to. For

example, a gamma telescope is responsive only to gamma rays and a CAT scan only shows the structure (rather than the function) of the brain (Giere 2006, chapter 3). We can experience neither ordinary objects nor scientific entities without the mediation of bodily or technological instruments. Moreover, our experience of things is always conceptual. In ordinary perception, our perception is concept-dependent. In science, observational and experimental results are interpreted by theoretical concepts. Therefore, in addition to bodily or technological instruments, theoretical perspectives should also be considered. As a result, engaging with things without the use of any perspective, is beyond the human condition. As section 3 briefly explained, the resistance and persistence a thing shows are likewise perspectival in the sense that they are consistently demonstrated through bodily or technological perspectives and are interpreted by (theoretical) concepts. According to the account of perceptual persistence and resistance, we may rely on our experience when several modes of engagement successfully contribute to it. However, this does not imply that our experience can be non-perspectival or from no-where. That is, even when multiple perspectives are available, engagements with a thing (and therefore the persistence and resistance that we experience from that thing) are still conditional on those multiple perspectives – these engagements are not perspective-less (see Khalili 2023b, subsection 3.1). The perspectivism I am defending here concerns the perceptual level of human experience, which can imply a perspectivism at the epistemological level. Ontologically speaking, nevertheless,

powers or potentialities are human-independent. Therefore, at the ontological level my view is realist, and at the perceptual and epistemological levels it is perspectivist in the sense that we cannot experience or know things in themselves. We only experience and know the realization of powers within the conditions of our instrumental and theoretical perspectives.

6 The Epistemology of Persistence and Resistance

The epistemological thesis of resistance, which concerns the truthfulness of theoretical beliefs, entails that good theories are capable of withstanding efforts to refute them. But this description of good theories is 'negative'. All it can say about current, successful theories is that they have resisted falsification up to now. 19th-century ether theorists would have claimed the same about the ether theory, but the fact that a theoretical posit has not been falsified so far is not enough to conclude that the posit refers to something real. The posit may be falsified in the near future. An extra reason is necessary to accept that the theoretical posit is really about something real and that the posit's description of that something is truthful. The conception of resistance discussed in section 3 encounters the same problem. It presents a retrospective thesis that attributes reality to those entities that have so far resisted being replaced in 'trials of strength'. However, the (putative) entities may lose their power in the future when other actors of the network, including tools, experimenters or policymakers, no longer support them. Accordingly, a criterion is

needed to prospectively determine what will probably remain a justified part of the scientific image of reality.

As the positive side of resistance, the concept of 'persistence' is promising in providing a prospective criterion. At the epistemological level, persistence leads to the criterion that a thing may be taken to be real, and our knowledge of it will probably remain in the future, if it is detectable/measurable in a variety of independent ways. A real thing is obtained by means of 'replicable' experiments or observations, which is a specific case of 'reproducible' experiments and observations. Replicability implies the reproducibility of empirical *results* using (possibly radically) different processes (Radder 1996, pp. 18 and 22-24). For instance, a gas and a mercury thermometer each measure the temperature of an object, utilizing independent processes. For another example, consider the case of the Higgs boson, whose production mechanism at the LHC has always been the same. So far, physicists have been able to produce the Higgs particle only in reproducible proton-proton collisions. The boson has been detected in a 'reproducible', but not in a replicable, way. Thus, our level of justification for the Higgs boson, as well as our knowledge of its properties, is still bounded by a specific set of experiments. Our justification in the boson will increase inasmuch as it is realized in 'replicable' experiments, whose results are obtained through several independent processes.

'Replication' is one of the epistemological concepts that are used in the philosophy of science literature. A closely relevant concept is 'robustness'. Robust evidence is provided for an entity if it can be detected/measured in a variety of independent ways (see Eronen 2015).[8] Note that the concepts of 'persistence', 'replication', and 'robustness' are distinct yet also closely related. They are distinct as they describe reality, experiments/observations, and evidence, respectively. Still, they are closely related: 'persistence' is a concept that explicates what *reality* means, and 'replicable' *experiments/observations* provide 'robust' *evidence* that can justify one believing in an entity. As a final note, replication provides a sufficient, rather than a necessary, condition for reality. That is, those things that manifest themselves in replicable observations/experiments may justifiably be taken as real. However, all real things cannot be known through replicable observations/experiments (see also Khalili 2023a).

7 Conclusion: What Reality Means

This paper has been interdisciplinary. By building on the work of Radder, Latour, Pickering, and Giere, I have tried to discuss the philosophy of science and STS

[8] Khalili (2023b) argues that the robustness version of realism is complimentary to perspectivism.

debates on the notion of reality. Further, I have studied the cases of the Higgs boson and the F-particle to analyze the meanings of persistence and resistance. I have also considered the phenomenological approach to science.

The paper has argued that the account of reality as resistance can be complemented by a positive, potentiality-based ontology. Furthermore, the Higgs and F-particle cases helped to clarify the concepts of resistance (before the realization of the entity) and persistence (after its realization in the appropriate conditions). I have also developed an account of perceptual persistence and resistance. A real thing cannot resist manifesting its signs or effects during realization processes and it persists in appearing under appropriate conditions after its realization. Finally, at the epistemological level, resistance and persistence imply respectively resisting being falsified and persisting across replicable experiments/observations.

In conclusion, the paper has proposed a way to understand the meaning of reality. Three levels of discussion have been explored: ontological, perceptual, and epistemological. At each level, the real's meaning incorporates two interrelated dimensions: persistence and resistance. Table 1 summarizes the positive and negative sides at each level.

Table 1. Ontological, Perceptual, and Epistemological Meanings of Reality

Level of discussion	*Positive side*	*Negative side*
Ontological	Persistent potentialities or powers	Resisting being considered as non-existence or as other things
Perceptual	Persisting in appearing by providing experience or evidence under appropriate conditions	Resisting disappearance by presenting signs or effects
Epistemological	Persisting across replicable experiments or observations (prospective)	Resisting being falsified (retrospective)

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References

Aaboud, Morad, et al. 2016. "Search for resonances in diphoton events at $\sqrt{s}$=13 TeV with the ATLAS detector." *Journal of High Energy Physics* 9:1–50. https://doi.org/10.1007/JHEP09(2016)001.

Aad, Georges, et al. 2012. "Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC." *Physics Letters B* 716(1):1–29. https://doi.org/10.1016/j.physletb.2012.08.020.

Aaltonen, Timo Antero, et al. 2010. "Combination of tevatron searches for the standard model Higgs Boson in the W+ W- decay mode." *Physical Review Letters* 104. https://doi.org/10.1103/PhysRevLett.104.061802.

Abbiendi, Giovanni, et al. 2003. Search for the standard model higgs boson at LEP. *Physics Letters B 565*(1–4):61–75. https://doi.org/10.1007/JHEP03(2020)131

Bhaskar, Roy. 1978. *A realist theory of science*. Hassocks: Harvester Press.

Bird, Alexander. 2007. *Nature's metaphysics: laws and properties*. Oxford: Clarendon.

Buehler, Marc. 2008. "Higgs boson at 160 gev at the tevatron." *Proceedings of Science* 55. https://doi.org/10.22323/1.055.0026.

Cartwright, Nancy. 1989. *Nature's capacities and their measurement*. Oxfored: Oxford University Press.

Cartwright, Nancy. 1999. *The dappled world: a study of the boundaries of science*. Cambridge: Cambridge University Press.

Chakravartty, Anjan. 2007. *A Metaphysics for scientific realism: knowing the unobservable*. Cambridge: Cambridge University Press.

Chatrchyan, Serguei, et al. 2012. "Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC." *Physics Letters B 716*(1):30–61. https://doi.org/10.1016/j.physletb.2012.08.021

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

Eronen, Markus I. 2015. "Robustness and reality." *Synthese* 192(12): 3961–3977.

Fine, Kit. 2001. "The Question of Realism." *Philosophers' Imprint* 1(1):1–30.

Franklin, Allan, and Slobodan Perovic. 2019. "Experiment in physics. In *The Stanford encyclopedia of philosophy*. Edited by Edward. N. Zalta. https://plato.stanford.edu/archives/win2019/entries/physics-experiment/

Gallagher, Shaun and Dan Zahavi. 2012. *The phenomenological mind*. London and New York: Routledge.

Giere, Ronald N. 2006. *Scientific perspectivism*. Chicago: University of Chicago Press.

Hacking, Ian. 1999. *The social construction of what*. Cambridge: Harvard University Press.

Harré, Rom. 1986. *Varieties of realism*. Oxford: Blackwell.

Heidegger, Martin. (1927) 1962. *Being and time*. Translation by John Macquarrie and Edward Robinson. Oxford: Basil Blackwell.

Hohwy, Jakob. 2013. *The predictive mind*. Oxford: Oxford University Press.

Khachatryan, Vardan, et al. 2016. "Search for resonant production of high-mass photon pairs in proton-proton collisions at $\sqrt{s}$=8 and 13 TeV." *Physical Review Letters* 117. https://doi.org/10.1103/PhysRevLett.117.051802

Khalili, Mahdi. 2021. "Perspectivism and special relativity." *Theory of Science* 43(2):191-217.

Khalili, Mahdi. 2022a. "*Reality in perspectives*." PhD dissertation. Vrije Universiteit Amsterdam.

Khalili, Mahdi. 2022b. “From phenomenological-hermeneutical approaches to realist perspectivism.” *European Journal for Philosophy of Science* 12:67. https://doi.org/10.1007/s13194-022-00495-5

Khalili, Mahdi. 2023a. “A dialogue among recent views of entity realism.” *Philosophy of Science*. https://doi.org/10.1017/psa.2023.18

Khalili, Mahdi. 2023b. “Entity Realism Meets Perspectivism.” *Acta Analytica*. https://doi.org/10.1007/s12136-023-00554-3

Latour, Bruno. 1987. Science in action: how to follow scientists and engineers through society. Cambridge: Harvard University Press.

Latour, Bruno. 1999. *Pandora’s hope: essays on the reality of science studies*. Cambridge: Harvard University Press.

Latour, Bruno. 2000. “When things strike back: a possible contribution of ‘science studies’ to the social sciences.” *The British Journal of Sociology 51*(1):107–123.

Latour, Bruno. 2018. *Down to Earth: Politics in the New Climatic Regime*. Translated by Catherine Porter. Cambridge: Polity Press.

Merleau-Ponty, Maurice. 1962. *Phenomenology of perception*. Translation by Colin Smith. London: Routledge and Kegan Paul.

Mumford, Stephen. 2003. *Dispositions*. Oxford: Clarendon.

Pickering, Andrew. 1995. *The mangle of practice*. Chicago: University of Chicago Press.

Radder, Hans. 1996. In and about the world: philosophical studies of science and technology. Albany: State University of New York Press.

Radder, Hans. 2006. *The world observed / the world conceived*. Pittsburgh: University of Pittsburgh Press.

Radder, Hans. (1988) 2012. The material realization of science: from Habermas to experimentation and referential realism. Dordrecht: Springer.

Radder, Hans. 2021. "Empiricism must, but cannot, presuppose real causation." *Journal for General Philosophy of Science*. https://doi.org/10.1007/s10838-021-09551-9

Salinas, Francisco. J. 2014. "Bruno Latour's pragmatic realism: an ontological inquiry." *Global Discourse* 6(1–2): 8–21.

Sider, Theodore. 2001. *Four-dimensionalism: An ontology of persistence and time*. Oxford: Oxford University Press.

Sirunyan, Albert, et al. 2020. "A measurement of the Higgs boson mass in the diphoton decay channel." *Physics Letters B* 805. https://doi.org/10.1016/j.physletb.2020.135425.

Tao, Junquan. 2018. "Measurements of the 125 GeV higgs boson at CMS." *Nuclear and Particle Physics Proceedings* 300–302:53–60. Https://doi.org/10.1016/j.nuclphysbps.2018.12.011.

Vallor, Shannon. 2009. "The pregnancy of the real: a phenomenological defense of experimental realism." *Inquiry: An Interdisciplinary Journal of Philosophy* 52(1):1-25.

Watson, Matthew. 2015. "Latour's more realistic realism: a reply to Salinas." *Global Discoursee 6*(1–2):22–25.