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On Retroductive Explanation

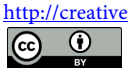
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Abstract

The aim of this paper is to elaborate on the concept of abduction, or retroduction, as a kind of rational thinking, though not logical, for conceiving and holding new physical hypotheses that could explain anomalous phenomena. Retroduction, as Norwood R. Hanson maintains, starts with data about the phenomenon to be explained and advances to a possible explanatory hypothesis, in reverse order to deductive explanation. The justification of explanations, whether retroductive or deductive, resides in the matching between the prediction of a hypothesis with the data about the *explanandum*, not in the form of the reasoning involved. However, neither of these kinds of explanatory reasoning, by themselves, allows us to find novel, fruitful hypotheses. There are, at least, two significant differences between retroductive and deductive explanations: firstly, in the former the data are *a priori* to the formulation of a possible explanatory hypothesis whereas in the latter the data are *a posterior* to a proposed hypothesis to provide an explanation; secondly, often retroductive explanations involves a conceptual change, even a conceptual improvement, while deduction in explanation allow performing the crucial labor of obtain the logical consequence of hypotheses without adding new conceptual content. Thus, successful retroductive explanations can sometimes innovate the conceptual framework of theories, in contrast to deductive explanations.

Keywords

Abduction, Deduction, Anomaly, Explanatory Hypothesis, Conceptual Innovation

1. Introduction

Is there a rational procedure to find new scientific hypotheses? How are the new hypotheses formed in the first place? Is there a logic of discovery? These questions concern our issue here, which is related to the concepts of abduction or retroduction as explanatory reasoning. Drawing mainly on Hanson's contribution to our

issue, this paper proposes a reformulation of the concept of retroduction that aims to justify the explicative hypothesis proposed.

First, we expose Peirce's concept of abduction as a rational procedure to find out explanatory hypotheses. Next, Hanson's thesis on retroduction, as a form of reasoning for discovering new hypotheses, is examined and elucidated. Also, we briefly review Kuhn's view of scientific discovery to underline that discoveries generally come with conceptual change within a theory or, even, with a change of theory. After, we elaborate, drawing on the former material, a concept of retroduction that aims to justify holding the explanatory hypotheses proposed on rational grounds. Very briefly, we criticize the thesis of the inference to the best explanation and the probabilistic inferences for explanatory hypotheses based on Bayes' theorem, which are relevant to our issue because they become alternative approaches to explanatory reasonings. We conclude with some general remarks about our issue here: the retroductive explanation.

2. Peirce on Abduction

Originally, Charles Sanders Peirce elaborated a novel concept of abduction, in contrast to both deduction and induction, as a kind of reasoning to conceive, generate new hypotheses: "Abduction is a process of forming explanatory hypotheses. It is the only logical operation which introduces any new ideas."[1] For Peirce, abduction is a reasoning which leads to a probable hypothesis about a surprising fact: "[…] abduction, although it is very little hampered by logical rules, nevertheless is logical inference, asserting its conclusion only problematically, or conjecturally, it is true; but nevertheless having a perfectly definitive form."[2]

This role of producing or inventing new hypotheses is not fulfilled either by deduction or induction. Deduction is the logical reasoning to obtain the testable predictions of hypotheses once formulated, whereas induction, for Peirce, is a process to assess tested hypotheses in function of their verified predictions. Thus, abduction is part of the methodology or logic of science together with deduction and induction.

Peirce claims that abduction is a logical reasoning whose form is the following:

The surprising fact, C, is observed.

But if A were true, C would be a matter of course.

Hence, there is reason to suspect that A is true.[3]

It is worth noting that the previous reasoning does not intend to prove hypothesis A or accept it as true, but rather just to adopt it as a possible explanation of fact C as a matter of course. Frankfurt objected that the anterior reasoning is not an inference to a new idea. He rightly argues that "After all, the new idea—the explanatory hypothesis A—must have occurred to one before one infers that there

[1]Cited by Douven (2025, p. 1) from Peirce (1935); 5:172.
[2]Cited by Hanson (1958b, p. 86) from Peirce (1935); 5:188.
[3]Cited by Douven (2025, p. 1) from Peirce (1935); 5:189.

is a reason to suspect that *A* is true, for *A* already figures in the second premise."[4]

Douven (2025, p. 1) reformulated Peirce's former version as follows:

Some phenomenon *P* is observed.

P would be explicable as a matter of course if *H* were true.

Hence, there is reason to think that *H* is true.

However, this kind of reasoning does not justify the conclusion that hypothesis *H* is true; it does not follow from the second premise, even if *H* explains the phenomenon *P*.

A nonrealistic simple alternative version is as follows:

Given theory *T*, phenomena *P*, and data *D* about *P*, a hypothesis *H* is proposed.

Predictions about *P* are mathematically derived from *T* and *H*.

If such predictions match well with *a priori* data *D*,

Then, it becomes reasonable to hold hypothesis *H.*

This formulation, which avoids claiming that the hypothesis would be true and the intuitive idea of explanation as a matter of course, introduces a role for derivation in obtaining the predictions of *T* and *H*. However, it is quite different from Hempel's model of deductive explanation (see Hempel, 1966, chap. 5)[5]. The major difference between these two forms of explanatory reasoning, for the present purpose, resides in the relevant data, which in the retroductive scheme are *a priori* to the formulation of hypotheses, whereas in the deductive model are *a posteriori* to the formulation of hypotheses and the performance of experiments. Both intellectual procedures are rational; nevertheless, neither procedure of reasoning by itself gives an account of how the hypotheses involved are obtained. In Hempel's model of deductive explanation, the reasoning is from the *explanans* to the *explananda,* whereas abduction is a reverse procedure, as Hanson sustains (Hanson, 1958b, p. 85), it is a reasoning from the *explicanda* to *explicans*, from the prior data about the phenomenon to be explained to the explanatory hypothesis. Of course, a major difference is that the deductive model is logically valid, whereas the retroduction is not a logical reasoning, contrary to Peirce's and Hanson's intentions: The abductive inference is a "logical" process only in the sense whereby the term "logical" is understood as synonymous with "rational". (see Schickore, 2025, p. 2). That is right, there is no way to express abductive reasoning in logical terms. However, a formal version of retroduction in terms of probability theory could be Bayes' theorem as formulated below in section 7.

Hanson's thesis that "The reasoning is from data to hypothesis and theories not the reverse." (Hanson, 1958b, p. 88) could be understood in reference to the data of anomalies, where an anomaly in a theory is a discrepancy between the observed data for a phenomenon and the theoretical expectations about it, a lack of concordance between the data and the predictions. The anomaly involves, of course, a failure of explanation for a scientific theory of the phenomena concerned.

Perhaps, the following version of retroduction is suitable for the former remark:

[4]Cited by Douven (2025, p. 1), from Frankfurt (1958).

[5]We will disregard the criticism of Hempel's model. See, for example, Salmon (1998).

The phenomenon A is an anomaly requiring explanation within theory T.

Hypothesis H could explain A if the predictions of T plus H match well with the prior data about A.

Hence, it becomes reasonable to hold hypothesis H; H would resolve anomaly A.

3. Hanson on Retroduction

"Natural scientists do no 'start from' hypothesis. They start from data. And even then not from commonplace data—but from surprising anomalies." (Hanson, 1958b, p. 100) We may say that, for Hanson, in order to explain an anomalous phenomenon, the route is proposing a hypothesis from the available data about it, by a retroductive reasoning, —so that the *explicandum* is the anomaly whereas the *explanans* is the hypothesis—so far, a general hypothetical statement, a plausible conjecture, and after appraise if the predictions of the such hypothesis match well with those *a priori* data. If the matching is good enough—if the predictions fit the data as an admissible approximation—the hypothesis provides an explanation of the phenomena resolving the anomaly concerned.

Against the thesis of philosophers as Popper, Reichenbach and Brathwaite that insist on the philosophical irrelevancy of the called context of discovery, in contrast to the context of justification, Hanson defends the thesis that retroduction as a means for discoveries hypotheses have a proper place in scientific investigation: "At least it appears that the way in which scientists sometimes reason their way towards hypotheses may be a legitime an area of conceptual inquiry as are the ways in which they sometimes reason their way from hypotheses." (Hanson, 1958a, p. 1088).

Let us emphasize now that the general ideas of Hanson of scientific theories are quite different from the so-called "received view". For him:

Physical theories provide patterns within which data appear intelligible. They constitute a "conceptual Gestalt". A theory is not pieced together from observational phenomena; it is what makes it possible to observe phenomena as being of a certain sort and as related to other phenomena. Theories put phenomena into systems. They are built up "in reverse"—retroductively.

A theory is a cluster of conclusions in search of premises. From the observed properties of phenomena, the physicist reasons his way towards a keystone idea from which the properties are explicable as a matter of course. The physicist seeks not a set of possible objects, but a set of possible explanations (Hanson, 1958b, p. 90).

The former thesis about theories in physics provides the background of Hanson's concept of retroduction, which, he said, is a free development of remarks in Aristotle and Peirce on abduction:

Schematically, it can be set out thus:

Some surprising, astonishing phenomenon p_1, p_2, p_3 … is encountered.

But p_1, p_2, p_3 … would not be surprising or astonishing if H were true—they

would follow as a matter of course from H; H would explain p_1, p_2, p_3 …

Therefore there is good reason for elaborating H—for proposing it as a possible hypothesis from whose assumptions p_1, p_2, p_3 … might be explained (Hanson, 1958a, pp. 1086-1087).

Nevertheless, the former kind of reasoning does not provide a clue about how the physicist could search for explanatory hypotheses of phenomena; a keystone idea for explaining them as a matter of course.

The question of how physicists could find out and propose a hypothesis as a candidate for explaining the surprising phenomenon in the first place arises. For Hanson, they do not formulate first any hypothesis but rather a kind or type of hypothesis: "The issue is, whether (*before* having hit on a hypothesis which succeeds in its predictions) one can have good reasons for anticipating that the hypothesis will be one of some particular *kind*." (Hanson, 1960, p. 94) As illustration, Hanson points out that Kepler *first* supposed a non-circular orbit for Mars, given the observed inadequacy of a circular orbit, and a*fter* proposes the hypothesis of an elliptical orbit which matched better with the available observational data. Moreover, he further extrapolated such a hypothesis for the rest of the planets of our solar system: "Kepler's was a great retroduction. Kepler needed no new observations to realize that ellipse covered all observed positions." (Hanson, 1958b, p. 89)

In that order of ideas, Hanson claims that "A logic of discovery, then, might consider the structure of the argument in favor of one *type* of possible explanation in a given context as opposed to other *types*." (Hanson, 1960, p. 101). For example, Galileo's discovery that gravitational acceleration is constant, governed by an inversely varying law, contrary to other types of law, was attained by retroductive reasoning (Hanson, 1958b).

There is an exemplary case of Hanson's pattern of discovery by retroduction in astronomy. As is well known, in the nineteenth century, Adams and Leverrier independently and almost simultaneously discovered the planet Neptune. At that time, astronomers observed a deviation of Uranus' orbit, which presented an anomaly. Both made the same supposition: the existence of an eighth planet that causes Uranus's deviating orbit. One might think that they attempt several explanatory hypotheses to account for such a deviation. By observations, they *discovered* Neptune. Because the predictions made by Leverrier and Adams concerning that eighth planet matched the relevant prior observational data, they resolved the anomaly involved.

The retroductive reasoning involved could be reconstructed as follows:

The prior observational data about Uranus's orbit present an anomaly.

The supposition that the deviation of Uranus' orbit is caused by an unknown planet.

The formulation of a hypothesis about the mass, orbit, and trajectory of such a supposed new planet.

The predictive calculus about the position of such a planet at a given time.

The observations that confirmed the existence of the eighth planet: The discovery of Neptune.

The appraisal of the matching of the relevant prior data with the predictions from the new confirmed hypothesis.

The resolution of the anomaly.

The key premise of the former retroductive reasoning is the supposition of the existence of an eighth unknown planet, which allowed Adams and Leverrier to discover Neptune, explaining the observed deviation of Uranus' orbit and, thus, resolving the anomaly.

As we will see in the next section, the discovery of Uranus by William Herschel, its identification as a planet rather than a comet or a star, does not seem to follow the same form of reasoning. As one could expect, the retroductive reasoning is fallible. Leverrier hypothesized an additional planet, Vulcan, to explain Mercury's perihelion anomaly using retroductive reasoning, but that was unsuccessful. Classical physics failed to account for this anomaly for two centuries. It was resolved by relative theory at the beginning of the 20th century.

The resolution of Mercury's perihelion anomaly was achieved by the theory of relativity in terms of a curvature of space-time in the region near the Sun. That means that a change of theory was required to explain the deviation of Mercury's trajectory: Indeed, a paradigm change, in terms of Kuhn, was needed. Thus, not all resolution of anomalies for a given theory comes from retroductive reasoning: For relativity, Mercury's orbit was not an anomalous phenomenon; the observed orbit of Mercury was the one expected for such a theory. Retroduction represents a significant methodological pattern of discovery, but even there are fortuitous discoveries such as Fleming's discovery of penicillin.

Let us close this section with a remark by Hanson:

My task has been to illuminate an aspect of scientific inquiry neglected by philosophers, namely, the scientists' reasons for considering hypotheses seriously in the first place. Some philosophers, […] have given a wrong answer to this, suggesting, e. g., that all scientists reason initially from phenomena to hypotheses by variations on "inductuio per enumenationem simplicem". They make it sound as if insight and genius have nothing to do with discovery. (Hanson, 1958a, p. 1908).

4. Kuhn on Scientific Discovery

Kuhn shares with Hanson the central thesis about the role of anomaly in scientific discovery: discoveries begin with anomalies. However, their approaches are quite different: Hanson aims for a logical pattern, whereas Kuhn proposes a sociohistorical one. Hanson's thesis about retroductive reasoning, which provides an explanation of anomalous phenomena, involves the idea of a single, individual act of discovery. Like many other philosophers, he thinks that scientific discovery is a particular act, so it is feasible to identify when a discovery happened. They look for a form of reasoning when an act of discovery takes place. In contrast, for Kuhn, discoveries happen in long historical periods: "Examining select discoveries […]

we shall quickly find that they are not isolated events but extended episodes with a regularly structure." (Kuhn, 1962b, p. 52).

According to Kuhn, scientific discoveries generally occur in pre-paradigmatic periods as well as previously scientific revolutions involving changes in the conceptual frameworks of theories, and sometimes even a change in the worldview.

Let us expose Kuhn's idea about the historical structure of scientific discovery:

Discovery commences with the awareness of anomaly, i. e., with the recognition that nature has somehow violated the paradigm-induced expectations that govern normal science. It then continues with a more or less extended exploration of the area of anomaly. And it closes only when a paradigm theory has been adjusted so that the anomalous has been the expected. (Kuhn, 1962b, pp. 52-53).

To support his view, Kuhn chose the discovery of oxygen, which initiated a scientific revolution. Kuhn describes briefly a period that starts in the early 1770's and finishes around 1777, where several scientists, among others, Schelle, Priestley, and Lavoisier performed experiments that "enriched air in a laboratory vessel without knowing it". (Kuhn, 1962b, p. 53). For Kuhn, as discovery involves realizing *that* something is and *what* it is. This do not happen until 1777: "Presumably we wait for the work of 1776 and 1777 which led Lavoisier to see not merely the gas but what the gas was." (Kuhn, 1962b, p. 55). Lavoisier's discovery, Kuhn points out: "[…] was not so much the discovery of oxygen as the oxygen theory of combustion. That theory was the keystone for a reformulation of chemistry so vast that it is usually called the chemical revolution." (Kuhn, 1962b, p. 56). It is worth noticing that sometimes fact and theory are inseparably linked in a process of discovery, as this case suggests.

Nevertheless, Kuhn does not consider that there is any kind of reasoning that leads, or even justifies, a discovery; this issue does not arise from his sociohistorical view. Still, the question of priority, at least in this case, has no place: "Discovery is not the sort of process about which the question is appropriately asked." (Kuhn, 1962b: 54) Moreover:

Clearly we need new vocabulary and concepts for analyzing events like the discovery of oxygen. Though undoubtedly correct, the sentence, "Oxygen was discovered", misleads by suggesting that discovering something is a simple act assimilable to our usual […] concept of seeing. That is why we readily assume that discovery […] should be unequivocally attributable to an individual and to a moment in time (Kuhn, 1962b, p. 55).

Kuhn (1962a) presents an illustrative case of discovery: the discovery of planet Uranus, attributed to Willian Herschel. For nearly a century (1690-1780), several astronomers observed a celestial object, believing it to be a star. Using a more powerful telescope, Herschel first suggested that it was indeed a comet. However, the calculus obtained under such a hypothesis failed to match the observations. Then, Lexell hints that the object observed by Herschel could be a planet. The data derived from a planetary orbit fit well with the observations. The anomaly arises from Herschel's mistaken supposition that the object he observed was a comet.

The ulterior failure gives place to the successful Lexell's hint. Before that, there was no anomaly for the astronomers; rather, it was a mistaken identification of the observed object for almost a century. Perhaps this example shows both that discovery is a sociohistorical process, as Kuhn maintains, and that a retroduction occurs under the hypothesis adopted by Herschel, namely that the object is a new planet, which provides an explanation of the anomaly, as Hanson maintains. In a sense, this case is like the discovery of Neptune, except that Uranus was long observed before its identification as a planet.

What we wish to emphasize about Kuhn's view on scientific discovery is that in the proper discoveries, when both a new fact and a hypothesis are found, a conceptual change could occur in the related theory. Sometimes happens that, besides finding something in nature, new concepts are incorporated, some concepts are modified, or both, improving the conceptual framework of the theory concerned, often involving a change of worldview.

5. Retroductive Explanation

Hanson's main theses concern the context of discovery, understood as the conceptual, rational context for suggesting and formulating new hypotheses to explain phenomena observed and, thus, resolve anomalous phenomena.

The background of such context consists of the available theory for which phenomenon A is an anomaly—the conceptual framework and laws of that theory. A physical theory delimits what could be possible from its perspective and so narrows down the possible kinds or types of hypotheses that can be proposed, which must be consistent with the theory's laws. It may be that some presuppositions or even hypotheses about phenomena A, which make it an anomaly within the available theory, could provide hints for formulating promising new hypotheses. About that, a key question might be: What is wrong in the failed explanation of A that makes it an anomaly? Thinking on that kind of question could be a guide for looking at a possible new hypothesis, to realize what must be removed, changed, or replaced in the wrong explanation, in the direction of proposing a plausible explanatory hypothesis, which would explain phenomena A. However, retroductive reasoning does not generate any hypotheses but at most suggest them.

Of course, the previous is not enough to achieve a hypothesis whose conceptual content allows us to think about the phenomena concerned in a different way, to conceptualize them so that the anomaly involved disappears; it seems that the talent and genius of the scientists are needed.

If T is a physical theory, D stands for the available data about an anomalous phenomenon A *before* the formulation of a plausible hypothesis H, and P stands for the predictions about such a phenomenon derived from T and H together. Then, the sort of retroductive explanation that Hanson elaborates could be reformulated thus:

1) Given T and D, a hypothesis H is proposed.

2) Predictions P are mathematically derived from T and H.

3) The predictions P match well with the prior data D.

Then,

4) H is held as an explanation of the anomalous phenomena A.

If the former schema is satisfied, it is reasonable to accept H as an explanatory hypothesis for the phenomenon in question. The key premise that justifies the conclusion is (3), the match of the predictions of H with the *a priori* data D. Such match indirectly provides support for hypothesis H, not as a true statement but rather as a plausible explanation of the anomaly involved.

Nevertheless, in the last instance, the provisional acceptance of the explanation resides in the resolution of the anomaly. Of course, if such a matching fails, H does not explain A. The abductive inference is expressed by the premise (1), which is the first step to obtaining a retroductive explanation of the anomaly A, provided by the whole reasoning expressed by statements (1)-(4). The retroduction involved is not an inference logically valid, however the whole reasoning (1)-(4) does not lack rationality. We think that the anterior schema expresses a semi-formal version of retroductive explanation. A complete formal version of retroductive reasoning, in terms of probability theory, could be Bayes' theorem as formulated below in section 7 "The probabilistic approach".

In contrast, the deductive-nomological model of explanation can be formulated as follows: Let L be the laws of a theory, and C statements about concrete facts concerning the phenomenon E to be explained. If E is logically deduced from L and C then L and C explain E. In semi-formal terms: If (L & $C \rightarrow E$) then L & C explain E.

This sort of explanation assumes the truth of the premises; especially, of the laws L, otherwise the deductive argument does not explain the phenomenon E. Moreover, the intended justification of the explanation of phenomenon E does not reside on the logical form of the argument but rather on the assumed truth of L and C. Thus, the justification of the inferred explanadum E requires posterior confirmation by testing it via experience. Maybe, it would be fair to say that if E is deduced from L and C then E could be accepted as a plausible hypothesis to be tested to explain the phenomenon E. In case that *a posteriori* data obtained by empirical procedures match well with statement E, the claim that L and C explain E would be justified.

Both intellectual procedures are rational; nevertheless, neither procedure of reasoning by itself gives an account of how the hypotheses involved are obtained.

In the case of retroduction, we point out the mathematical derivation, which is the usual procedure in mathematical physics and astronomy, whereas in the case of the deductive model, we point out logical inference. Both modes for obtaining conclusions from premises are *rational*; although generally logical deduction is considered by philosophers as the model of rationality, it is not the main means for acquiring predictions in physics; it is a simplification or an idealization to think and claim that logic is the main intellectual device for obtaining predictions from hypotheses or nomic statements.

In contrast to Popper, who maintains that there is no method to conceive new scientific ideas, Hanson intends to outline a procedure for how a type of hypothesis could be acquired by retroductive reasoning. Nevertheless, it is worth noting that his pattern of such type of reasoning does not account for the very act of conceiving a hypothesis or hypothesis-type.

We think that a plausible thesis about retroduction could be that the novel hypothesis involves a reconceptualization of the anomalous phenomena, through a conceptual change or adjustments into the theory concerned, that allow the resolution of the anomaly involved, and under which one can obtain a match between the predictions of such a hypothesis and the prior data about the phenomena that ask for explanation, as well as testing the very hypothesis by means of further experiments and observations.

Generally, the clue to resolving an anomaly lies in reconceptualizing the phenomena involved through a novel hypothesis that fits well with prior data. The conception of such a novel hypothesis is a complex intellectual procedure, which, although not logical, is rational. Retroduction is a kind of reasoning, as Hanson maintains, from the explananda to the explanans; however, the issue is how that sort of reasoning takes place in the first instance. There is no algorithm for doing such reasoning. Similarly to deductive hypothetical reasoning, proposing a new hypothesis is an open question. The difference, nevertheless, is that in retroductive reasoning, besides a theory, there are prior data about the phenomena to be explained, while in deductive reasoning, there is only the theory concerned. The anomalous phenomena represent a challenge to the physicist, but at the same time, the data about them could give him hints for finding a promising explanatory hypothesis, because such a hypothesis would fit the data. Of course, those hints, if any, are not sufficient to conceive an explanatory hypothesis, but they can sometimes serve as a guide. Physicists require their intellectual capacities to explore various possible explanatory hypotheses, without a warranty that any of them will succeed. The main challenge is that resolving an anomaly often requires changing the theory's conceptual framework or even the whole theory, as was the case with the resolution of the anomaly about Mercury's perihelium by relativity theory. This is not needed in the model of deductive-nomological explanation, whose objective is mainly to resolve a scientific problem without requiring a change in theory beyond the new explanatory hypotheses that increase the theory, even though they do not improve its conceptual framework.

The exemplary Hanson's case of retroduction is Kepler's discovery of the elliptical orbits of the planets within our solar system. Hanson points out that once Kepler refused the hypothesis about the circular orbit of the planets, Kepler looked for a hypothesis of a non-circular orbit that matches the Mars observed trajectory with variant velocities at 90 and 270 degrees and explains the apparent anomaly. (Hanson, 1958a, pp. 1974-1975). In general, the questions might be these: "1) Does H look as if it might be that from which known phenomena p_1, p_2, … etc., could be shown to follow? 2) Does H look as if it might explain p_1, p_2, … etc.?"

(Hanson, 1958a, pp. 1974-1975.) This type of question might be a guide to search for a possible explanatory hypothesis, which in Kepler's discovery involved a great change in the conceptual view of the world.

In Kuhn's philosophy of science, retroductive reasoning becomes central as an intellectual tool for scientific discovery. Deductive hypothetical reasoning, or instead mathematical derivation, is the key intellectual procedure for testing hypotheses once we have one. Mainly, the place of such reasoning is in normal science, resolving puzzles, not anomalies. In contrast, the major place of retroductive reasoning is in the pre-paradigmatic period and preceding scientific revolutions, which involve the resolution of crucial anomalies in the prevailing paradigm; though with exceptions since for Kuhn there are cases of resolving anomalies just by adjustments of the conceptual framework in a period of normal science. Thus, retroductive reasoning comes often together with changes in the conceptual frameworks of theories. The difference between deduction and retroduction is major because the former only makes explicit in the conclusions what is implicit in the premises, whereas the latter sometimes, but not necessarily, brings conceptual changes that could be significant innovations for a theory.

6. Harman on Inference to the Best Explanation

The thesis about the inference to the best explanation, due to Gilbert Harman (1965) failed to justify that the conclusions of such a type of inference are true; the best or better available explanation does not entail that it is true. Generally, an explanation assumes the truth of the *explanans*; thus, one cannot claim that it is true based on the presumed fact that explains the available evidence.

Let us see that. In the first place, Harman intends to distinguish enumerative induction from inference to the best explanation, where the former consists in inferring from observed regularity to universal regularity, or at least to regularity to the next instance, while the latter is an inference from the fact that a certain hypothesis would explain the evidence to the truth of that hypothesis (see Harman, 1965, pp. 88-89). He asserts that:

I wish to argue that enumerative induction should not be considered as a warranted form of nondeductive inference in its own right. I claim that, in cases where it appears that a warranted inference is an instance of enumerative induction, the inference should be described as a special case of another sort of inference, which I shall call "the inference to the best explanation" (Harman, 1965, p. 88).[6]

Harman rightly claims that induction is not a valid inference, whereas that inference to the best explanatory hypothesis, though neither deductive, could justify its conclusion, that is, the truth of the hypothesis involved. Such a kind of inference is invalid, in the sense that it does not allow us to conclude that the explanatory hypothesis, if any, is true.

[6]"The inference to the best explanation" corresponds approximately to what others have called "abduction", "the method of hypothesis", "hypothetical inference", "the method of elimination", "eliminative induction", and "theoretical inference". (Harman, 1965, pp. 88-89).

As in Hempel's model of deductive explanation, generally philosophers of science agree that proper explanation assumes that the *explanans* statements are true to infer the truth of the *explanandum* statement. This is just a logical matter. In contrast, a reasoning to the best explanation does not involve or entail that from the fact that one considers that a hypothesis provides the best (available?) explanation of given evidence that such a hypothesis is true. This is a logical matter also. Here, the *explanandum* statement contains available evidence about, say, a physical event or process, whereas the presumed *explanans* statement is a proposed hypothesis. It is a reverse inference from the *explanandum* to the *explanans*, like abduction and retroduction. Nevertheless, neither Peirce nor Hanson claims that one can infer the truth of the conclusion. If inferences to the best explanation are not demonstrative, why can one claim that their conclusions are true? In the best case, as in induction, one could say that the conclusions are probable, as Peirce said about abduction and Hanson about retroduction.

Harman points out that, in general, there will be several hypotheses, and that "Thus one infers, from the premise that a given hypothesis would provide a 'better' explanation for the evidence than any other hypothesis, to the conclusion that the given hypothesis is true." (Harman, 1965, p. 89). The central step in the anterior reasoning is the "inference" that a hypothesis is true from the situation that it provides the better explanation of the evidence concerned: simply the former claim does not follow from the latter situation; the statement "Hypothesis *H* is true about evidence *E*" is not entailed by the statement "Hypothesis *H* gives the better explanation for evidence *E*".

In any case, it seems that one may conclude that a given hypothesis is the best hypothesis that one has been able to propose so far, without assuming that it is the best possible explanatory hypothesis at all. Moreover, as Bas van Fraassen (1989, p. 143) objected, the lot of the available hypotheses could be a bad lot, so one selected the better hypothesis from a poor lot.

Harman refers to a physical situation as an inference to the best explanation: "[…] When a scientist infers the existence of atoms and subatomic particles, he is inferring the truth of an explanation for various data that he wishes to account for. […] the inference from experimental data to the theory of subatomic particles certainly does not seem to be describable as an instance of enumerative induction." (Harman, 1965, pp. 89-90).

The hypothesis of the existence of the electron has a long history, from Thomson's experiment measuring its mass to Millikan's experiment determining its electric charge. There was not a single inference to the conclusion that electrons exist, let alone a theory or, at least, a model of electrons. Wolfgang Pauli, in 1930, inferred the existence of the neutrino as a conjecture, not as a true hypothesis, to save the principle of conservation of energy because of a loss of energy in beta disintegration. Something similar one may say about the Higgs' particles. In 1964, Peter Higgs inferred the existence of a missing particle in the standard model of elementary particles physics. Indeed, they hypothesize that such subparticles exist not based on available evidence about them but rather within the conceptual

framework of atomic physics at the time.

According to Ian Hacking, the way to conclude that there are entities such as subatomic particles is experimental. His experimental argument holds that it is not sufficient for scientists to successfully test their hypotheses about such entities to claim that they exist. He sustains that the successful experimental manipulation of subparticles, such as electrons and protons, in the laboratory to intervene with other particles and produce an expected effect supports our conclusion that there are subparticles such as these (see Hacking, 1983, chaps. 1 and 9). Whatever, the methodological procedure that allows scientists to affirm that some kind of unobservable entity exists is more complex than simply reasoning for the better explanation to some, if there is any, evidence about them.

We do not have any point to Harman's conclusion: "I conclude that inferences which appear to be applications of enumerative induction are better described as instances of IBE." (Harman, 1965, p. 91). Our objection is rather that the inference from a better explanatory hypothesis of some evidence to the claim that such hypothesis is true is not a right inference; it is not even a plausible inference. In any case, Harman's paper seems to move between the theses that inference to the best explanation is a warranted inference and that it provides support that the hypothesis is true—as one could verify on the above quotations.

7. The Probabilistic Approach

Patrick Suppes, in the context of a set-theoretical axiomatization of probability theory, formulated Bayes' theorem as follows:

If $X = \bigcup H_i$, for $i = 1 \to n$ and if the events H_i are pairwise incompatible and $P(H_i) > 0$ for $1 \le i \le n$ and if B is an event such that $P(B) > 0$, then

$$P(H_i \mid B) = P(B \mid H_i) P(H_i) / \sum P(B \mid H_i) P(H_i), \text{for } i = 1 \to n$$

Further, he points out that one of the hypotheses H_i should offer a "best explanation" of the event B (Suppes, 1957, p. 283).

This theorem allows us to infer the *a posteriori* probability of hypotheses H_i given the event B or, in another version, given the evidence represented by B. To do that, it becomes necessary to assume or somehow establish the *a priori* probability values of hypotheses H_i, which "[…] are the center of most of the controversy concerning applications of the theorem." (Suppes, 1957, p. 284). In addition, it is necessary to calculate the conditional probability, called likelihood, of each $P(B|H_i)$.

Then, to find a better explanatory hypothesis, say H_k, of the event B, that is to say, the inverse probability $P(H_k|B)$ with a higher value among all $P(H_i|B)$, one must assign a probability value to each hypothesis H_i, which amounts to finding the *a priori* explanatory plausibility of the H_i in the first place.

If we consider the probabilistic inference based on Bayes' theorem as a reasoning to find explanations of physical events, not just to infer the hypothesis with higher value given evidence B, we must realize that it fails also because the *a pos-*

teriori probabilities $P(H_i|B)$ that such theorem allows infer, requires that before one supposes or establish the *a priori* probabilities $P(H_i)$ of the alternative hypotheses, which is tantamount to our problem in the first place.[7]

8. Conclusion

First, neither Peirce's abduction nor Hanson's retroduction nor Hempel's deductive model nor Kuhn's view on scientific discoveries nor, of course, my own version of retroductive explanation provides an account of how new explanatory hypotheses are conceived and proposed in the first place. The genius and talent of great scientists play a crucial role in conceptual innovations that occur during the formulation of novel hypotheses and the resolution of anomalies. In a sense, something similar happens in the art of music. We don't have to underestimate the role of the genius and talent of great musicians like Mozart, Bach, and Beethoven when they compose their inventive concertos.

Second, our main conclusion is that retroductive explanation, in contrast to deductive explanation, involves a change in the conceptual framework of the theory concerned, sometimes even leading to a change in the whole theory. As we said, to resolve an anomaly in a theory through a new hypothesis, it is necessary to reconceptualize the anomalous phenomena, which entails a conceptual change in that theory. The new hypothesis must be squared with the prior data about the phenomena, so that the very hypothesis obtained by retroductive reasoning must contain new concepts or, at least, a changed concept. Without changes to the conceptual framework of a given theory, that theory is unable to resolve its anomalies. Again, the challenge of resolving the anomalies of a theory is to find a novel hypothesis, formulated in terms of new concepts, whose predictions fit well with the prior data about the anomalies. When a conjectured hypothesis fits the prior data of an anomalous phenomenon, it provides a retroductive explanation of that phenomenon. As in deductive explanation, the *justification* of retroductive explanation resides in the match between the hypothesis proposed and the experimental or observational data, not in the reasoning used to obtain the explanation, whether deductive or retroductive.

Generally, philosophers of science have sidestepped retroduction and overestimated deduction; nevertheless, the former can sometimes contribute conceptual content, whereas the latter makes explicit the logical consequences of a set of premises without adding new conceptual content. From Kuhn's philosophy of sci-

[7]There is no room here to examinate the Bayesianism view on probability theory. However, we can remark that Bayesianism adopts the subjective interpretation of probability generally in terms of degrees of beliefs, with the consequence that all *a priori* probabilities are subjective, dependent on the beliefs of individual subjects. (see de Finetti, 1937). Lin (2024) points out that some bayesians face *the problem of the priors*—how assign coherent *a prior* probability values to a set of alternatives hypotheses?—with the aim to objectify such probabilities by the following norm, called "Explanationist Bayesianism": "One's prior ought to be such that, given each body of evidence under consideration, a hypothesis that explains the evidence better has a higher posterior.", which is just a reformulation of a reasoning to the better explanation.

ence, again, the place of deduction in scientific inquiry is in resolving puzzles, while retroduction has a place in resolving anomalies.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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