

The Model of Uncertainty in Contemporary Philosophy of Science and the Beginnings of Fuzzy Logic

أنموذج اللاتيقين في فلسفة العلوم المعاصرة وبوادر منطق الضبابية

Le modèle de l'incertitude dans la philosophie contemporaine des sciences et les débuts de la logique du flou

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ملخص :

يهدف هذا المقال إلى رصد تأثير تطور المنطق والفيزياء المعاصرة على الإشكاليات والمناقشات التي هيمنت على فلسفة العلوم المعاصرة، وما صاحب هذا التطور من تحولات كبرى أفضت إلى سقوط أنموذج اليقين الذي كان سائدا فيها لعهود طويلة، على مختلف المستويات: العلمية والمنطقية والفلسفية، والذي حل محله أنموذج اللاتيقين. وقد تجسد هذا الأخير في التوجهات والتصورات المركزية لتيارات فلسفات العلوم المعاصرة، وأشهرها تيار الوضعية المنطقية، والنزعة التكوينية، بشكل يوحى - وعلى نحو لافت - إلى وجود تأثير لهذه التحولات في ميدان المنطق، والتي شكلت في نظرنا مناخا ملائما وممهدا لظهور منطق الضبابية. فعلى هذا الأساس حاولنا، من خلال هذا البحث، وباستعمال المنهج التحليلي المقارن، تسليط الضوء على هذا التأثير من خلال إقامة مقارنة بين مفهوم اللاتيقين في فلسفة العلوم المعاصرة - من خلال مفاهيم الاحتمال والتعزيز والاقتراب من الصدق - وبين المفاهيم التي يتركز عليها منطق الضبابية كالغموض والتعقيد وقيم الصدق الجزئية.

الكلمات المفتاحية :

اللاتيقين، الاحتمال، الاقتراب من الصدق، الغموض، التعقيد، منطق الضبابية.

Abstract :

This research paper aims to examine the impact of developments in contemporary logic and physics on the issues and debates that have dominated modern philosophy of science. These developments have led to major transformations, culminating in the collapse of the long-standing model of certainty across scientific, logical, and philosophical domains—replaced by a model of uncertainty. This shift has been embodied in the central orientations and conceptual frameworks of contemporary philosophies of science, most notably logical positivism and falsificationism. Strikingly, these transformations suggest an influence from changes within the field of logic itself, which, in our view, created a fertile and preparatory environment for the emergence of fuzzy logic. Based on this premise, and by using the comparative analytical method, this paper seeks to shed light on this influence by establishing a comparison between the concept of uncertainty in contemporary philosophy of science, through notions such as probability, corroboration, verisimilitude, and the foundational concepts of fuzzy logic, such as ambiguity, complexity, and partial truth values.

Keywords : Uncertainty, probability, verisimilitude, ambiguity, complexity, fuzzy logic.

Résumé : Ce travail explore l'impact des évolutions récentes en logique contemporaine et en physique sur les problématiques et débats qui ont marqué la philosophie moderne des sciences. Ces évolutions ont engendré des transformations majeures, aboutissant à l'effondrement du modèle traditionnel de certitude dans les domaines scientifiques, logiques et philosophiques remplacé par un modèle de l'incertitude. Ce changement s'est incarné dans les orientations centrales et les cadres conceptuels des philosophies contemporaines des sciences, notamment le positivisme logique et le falsificationnisme. Fait remarquable, ces transformations semblent refléter une influence des

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mutations internes au champ de la logique, qui, selon nous, ont créé un terrain fertile et préparatoire à l'émergence de la logique du flou. Partant de cette hypothèse, et en adoptant une méthode analytique comparative, l'article vise à mettre en évidence l'influence exercée par le concept d'incertitude dans la philosophie contemporaine des sciences- à travers les notions de probabilité, de corroboration et de vérisimilitude - en le confrontant aux concepts fondamentaux de la logique du flou tels que l'ambiguïté, la complexité et les valeurs de vérité partielles.

Mots-clés : Incertitude, probabilité, vérisimilitude, ambiguïté, complexité, logique du flou.

Introduction :

The feature of symbolism and pure formalism that characterizes contemporary logic, along with its use of new types of reasoning, has made it applicable in different fields of knowledge, to varying degrees, especially in experimental sciences, particularly physics. This logic quality has provided these sciences with methodological foundations and rigorous logical tools that have contributed to the development of scientific research by regulating and codifying relationships between phenomena. As a result, these sciences have become more accurate and certain. However, the rapid pace of scientific discoveries in the field of physics at the beginning of the 20th century—an era of major scientific revolutions and transformations—put an end to the concept of certainty that classical physics had long celebrated. It caused a rupture in the entire set of related concepts and ideas, such as determinism, consistency, and absolute truth. Instead, the concept of uncertainty, which was reinforced by pioneering theories in this field, took its place. These theories were pivotal in the history of science, specifically: the Theory of Relativity, Quantum Theory, and Chaos Theory. On this basis, we may ask how the emergence of the concept of uncertainty has influenced the scientific and logical domains, and what the most significant outcomes of this impact are.

1-The scientific and philosophical context

Einstein's Theory of Relativity is one of the most popular scientific theories in the history of science. Its importance lies not only in presenting a new conception of the universe in terms of the movements of objects and then gravitational attraction, but also in overthrowing the mechanical view of the universe established by Newtonian physics, which had prevailed for long epochs. The theory proved its limitations and, as a result, replaced the concepts of certainty, consistency, and absoluteness with the notions of uncertainty and relativity in space, time, and motion. Quantum theory reveals the ambiguity and uncertainty that surrounds the micro world (the subatomic world) and the complex structure of the quantum molecule, which makes simultaneous measurement and definitive determination of its position and speed impossible—this is known as the principle of indeterminacy or uncertainty in quantum physics. The Theory of Chaos is a scientific theory concerning complex and intricate systems and some unpredictable dynamic physical phenomena due to their complexity and sensitivity to initial conditions, emergent variables, and multiple factors involved, which complicates the process of controlling, regulating, and predicting the outcomes of these phenomena.

Given what these theories have revealed about the uncertainty of both the macro and micro worlds—and the difficulty of accurately determining and predicting their changes due to their inherent ambiguity and complexity—the notion of the absolute truth of the scientific laws governing these worlds and the logic of definitive certainty in their truth has become unsuitable. As binary-value logic (truth-falsehood) has proved inadequate in dealing with this new situation in science, it has become necessary to develop new types of logic to accommodate these transformations and provide appropriate solutions to uncertainty-related problems.

Indeed, these transformations in the field of sciences, particularly physics, have been accompanied by crucial shifts in the realm of logic. Logic has abandoned some of its classical rules and the universality of its principles, especially the universality of the principle of the Excluded Third, which is founded on the determinism imposed by binary value (strict truth and strict falsehood). It

has embraced a broader range of partial values that lie between them, including ternary and quaternary systems, and multi-valued systems within the framework of what is called non-classical logic*. Undoubtedly, multi-valued logical systems have greatly contributed to resolving the difficulties that binary logic faced in understanding and addressing uncertain subjects and phenomena at the theoretical and logical levels. Probabilistic logic has achieved significant results in this regard by shifting away from seeking certainty and absolute truth in our scientific knowledge and establishing infinite truth values that lie between absolute truth and absolute falsehood to estimate their results and predictions. Nevertheless, the problem of uncertainty, ambiguity, and complexity prevalent in natural phenomena persisted, as it is a real problem and not merely a matter of logical system. Hence, addressing it requires a more efficient and suitable logic, which has been achieved with fuzzy logic. Fuzzy logic has made remarkable successes in addressing ambiguous and vague topics and phenomena and taking necessary measures in dealing with them, whether at the linguistic, logical, or real levels, including the physical reality and everyday life in all its aspects. This success has been particularly reflected in the practical field of technology, machinery, and artificial intelligence programs.

On the philosophical level, these major transformations in the field of logic and sciences at the beginning of the 20th century gave rise to new ideas and conceptions about the world, paving the way for the emergence of new philosophical currents in the contemporary philosophy of science. These currents draw inspiration from these transformations for their principles and overall concepts, and they build their theses upon them. By these currents, we mean the most significant and influential ones, namely logical positivism and Karl Popper's falsificationism.

The purpose of this research is to observe the most important philosophical implications of the development of logic and physics on the issues and discussions that were the focus of the contemporary philosophy of science. This development led to changes in the model of certainty that had prevailed for many centuries on the scientific, logical, and philosophical levels, replacing it with a model of uncertainty. This change was translated by contemporary currents in the philosophy of science—mentioned earlier—into a set of concepts and theses on which they based their perceptions, such as the concept of the probability of truth, the degree of confirmation, the concept of corroboration, verisimilitude, the holistic tendency in science, and the indicidability of the truth of scientific theories, among others. These concepts are central to the interests of fuzzy logic, and they might be among the factors or motivations that paved the way for its emergence in 1965 by the scientist Lotfi Zadeh.

To enable us to undertake the necessary comparison between these theses and the concepts on which fuzzy logic is based, we have decided to establish a work plan that includes the various elements of the subject. We will begin by defining the concept of fuzzy logic and highlighting its foundations, then addressing the issue of uncertainty in contemporary physics and how it is handled by logical positivism, which has shifted from a causal interpretation of phenomena to a probabilistic interpretation. We will focus on the aspects that highlight the weaknesses of probabilistic logic and explain, at the same time, the reasons that led to the emergence of fuzzy logic. Following this, we will present Popper's critiques of the certainty of predictive knowledge and the truth of scientific knowledge, and his introduction of the concepts of corroboration and verisimilitude as means to escape the state of inadequacy associated with the problem of uncertainty in experimental sciences. We will also raise some questions regarding the logical framework of these concepts.

2-The Concept of Fuzzy Logic

The emergence of fuzzy logic—a new field of research in contemporary logic—dates back to 1965, thanks to the creative and original works of the Iranian-born logician, Lotfi Askar Zadeh (1921-), who is a scientist in mechanics and a specialist in computer science. Lotfi Zadeh is considered the first to introduce what is known as "fuzzy set theory" in the field of contemporary logical studies; this theory has had numerous applications in industry and computer science (A. Moussaoui, 2021, p. 315).

Fuzzy logic is classified within the types of non-classical logic based on multiple values and not limited to binary values related to strict truth and strict falsehood. Thus, it deals with varying degrees of logical truth, ie, partial truth values that lie in the range $[0, 1]$. The term "fuzziness" is not a characteristic of this logic itself or a distinctive feature of the results it reaches; rather, it is related to the subjects and concepts it addresses, which are ambiguous and not entirely clear, especially regarding their extension, which cannot be precisely determined. In other words, there are subjects for which it is impossible to definitively decide whether this type of concept applies to them or not, making the question undecidable (A. Moussaoui, 2019, p. 172), even if all relevant information is available. Since such concepts are part of our various inferences and impose themselves in our reality and daily interactions, excluding them as classical logicians did is far from solving the problem. Therefore, contemporary logicians had to build logical systems suitable for accommodating such concepts and dealing with them in a manner consistent with their nature.

Among these common fuzzy concepts, for example, are the concepts of "youth" and "adulthood." These are fuzzy concepts because they are very broad, and the age range for the category of individuals referred to by these concepts is not precisely defined by the upper and lower age limits (Ibid.). We can highlight the aspects of fuzziness in these two concepts as follows:

-For a person who is 35 years old, it is difficult to determine whether the concept of "youth" or "adulthood" applies to them. We face significant difficulty in classifying them into these two fuzzy groups, or the fuzzy subgroups derived from them, which all express age gradations, such as "adolescent," "adult," "young," "middle-aged," "fully grown," etc. Thus, we find that this person can belong to all these groups, but to varying degrees.

-Such fuzzy concepts, like the concept of "youth" for example, are not determined solely by the factor of age. Rather, they are determined by various factors and variables that may be physiological, such as mental and physical maturity, or they may be related to the social system, including customs, traditions, and the ability to bear responsibility.

-The issue of precisely determining the beginning and end of the age of "youth" is not without paradox. If it is agreed to designate the age of 18 as the threshold for the beginning of youth, this determination is surrounded by much ambiguity, due to the lack of a clear explanation or reasonable justification for the transition of a person from the category of "adolescence" to the category of "youth" upon reaching the age of 18, by a difference of a day, an hour, or even a second. An increase or decrease of a second in a person's age does not change their condition in any way, whether physically, psychologically, or socially. This slight difference in time does not justify assigning or denying them the attribute of "youth."

In truth, this example leads us to one of the famous paradoxes in the field of logic, namely the "heap paradox" (le paradoxe du Tas) or the "Sorites paradox" (paradoxe de Sorite). Some logicians have viewed it as a type of informal fallacy or a kind of embarrassment. However, the concept of a heap, in reality, is a vague one (See A. Moussaoui, *ibid.*, p. 173). The essence of this paradox lies in the difficulty of determining how many items are needed to form a heap. Since there is no specific number that separates a group of items that constitutes a heap from one that does not, adding a single grain at a time does not create a heap. Similarly, removing a grain in the same manner does not strip the group of its heap status. So, what is the exact number of grains upon which we can base the concept of a heap? That is the question that cannot be answered without falling into a paradox.

Lotfi Zadeh's seminal 1965 paper « *Fuzzy Sets* » introduced a logical framework for addressing problems whose ambiguity stems from the absence of clearly defined membership criteria within fuzzy sets. He described a fuzzy set as a class of objects characterized by varying degrees of membership. This type of set is determined through a membership function that assigns each object a degree of membership ranging between 0 and 1. Inclusion, intersection, and integration relations are used similarly to classical sets, but in an extended form (L. Zadeh, 1965, pp. 338-339).

The membership function formulated by Zadeh allows us to determine the degree of membership for each element within a given fuzzy set :

Membership Function: $f_A(x)$ (Ibid., p. 339)

Where:

- A represents the fuzzy set
- x is the element whose membership degree is being evaluated
- The value of this degree lies within the interval $[0, 1]$
Thus, the partial membership degree in a fuzzy set is expressed as :
- $f_A(x) \in [0,1]$

Since fuzzy logic is a logical system that deals with vague and indeterminate values rather than binary logic, it allows for partial degrees of truth. This makes it suitable for handling fuzzy cases such as those raised by the *Sorites paradox*. Accordingly, fuzzy logic can be employed to offer solutions by allowing gradations in the definition of a heap, rather than relying on strict boundaries. This is achieved using the aforementioned membership function, which enables us to determine the degree to which a collection of wheat grains constitutes a heap, or the degree to which it does not.

- A large heap of wheat would yield a high membership degree close to 1.
- A single grain of wheat would yield a very low membership degree, approaching 0.

In this way, we can resolve the ambiguity of many fuzzy concepts by using gradations in their membership values within the fuzzy sets to which they belong. This helps to alleviate the contradictions and indeterminacies often provoked within the framework of binary logic and its inferential rules. The practical inference rules of fuzzy logic, the property of partial membership in fuzzy sets, the branching and overlapping fuzzy subsets, the extended and infinite truth values, as well as its use of linguistic variables and their degrees of possibility—all these features tightly link the theoretical components of fuzzy logic to its practical applications, granting it several advantages and strengths that distinguish it from binary logic (Shahira Sharaf, 2016, p. 35-36).

Another feature of fuzzy logic that we focus on in this research is the evaluation of fuzzy subjects or phenomena. In addition to quantitative evaluation, fuzzy logic incorporates qualitative evaluation in determining the belonging of a subject to fuzzy sets. It does so by utilizing some linguistic variables from natural language that we use in our daily lives. These include linguistic degrees of possibility (Ibid., p. 32) that distinguish between more and less, such as "slightly large," "somewhat small," "moderate", and so on. This type of ambiguous and fuzzy language cannot be precisely quantified and does not provide us with certain or definitive knowledge.

Based on this brief definition, we can derive some of the fundamental concepts upon which fuzzy logic is based, the most important of which are: uncertainty, ambiguity, complexity, confusion, undecidability, partial truth values, and quantitative and qualitative evaluation. Highlighting these concepts in this manner will allow us to compare them with the concepts and theses of the contemporary philosophy of science and its major currents.

3-Logical Positivism: From Causal Interpretation to Probabilistic Interpretation

The introduction of the concept of uncertainty into the contemporary philosophical and scientific scene is not an easy or straightforward matter. This is due to intellectual and historical considerations, the most important of which is that the model of certainty is a deeply rooted demand

in the history of scientific and human thought in general. This demand has theoretical foundations and metaphysical backgrounds on which it relies. This is because the belief in the idea of certainty and its persistence in people's minds is the result of a stable metaphysical belief in the existence of a general, stable, and orderly system by which nature operates without fail, allowing us to understand it and control its processes using the laws of causality that express the necessary relationship between (cause, effect).

If classical physics primarily relies on the causal interpretation of natural phenomena, asserting the existence of a sequential relationship between cause and effect, contemporary physics, which has analyzed atomic events based on quantum theory, shows that the laws of causality do not apply to the micro world. According to the principle of indeterminacy, the electron's speed, position, and trajectory cannot be simultaneously determined. Scientists cannot achieve this regardless of the tools they use, as it represents the nature of the electron itself (M.-F. Zidan, 1982, p. 28). The famous Schrödinger's cat experiment is the most striking embodiment of the indeterministic and uncertain nature of quantum mechanics. It demonstrates how a physical entity can exist in two completely contradictory states simultaneously—a condition that is fundamentally undefined and cannot be represented within the framework of binary logic, where statements are either true or false. This is precisely what occurs in the cat experiment, where the cat is placed inside an isolated box containing a radioactive atom (infernal device) and is considered to be both alive and dead at the same time, in equal proportions. This condition is known as superposition, or a mixed state (L. Maccone, 2024, p. 3).

. Therefore, Hans Reichenbach, one of the pillars of logical positivism, believes that the solution to the problem of uncertainty and indeterminacy posed by quantum theory requires a shift from the causal interpretation of the micro world to a probabilistic statistical interpretation. According to him, individual atomic events do not admit a causal explanation but are governed solely by probabilistic laws (H. Reichenbach, 1951, p. 164).

The sole motivation behind the logical positivist movement's incorporation of probabilistic logic to explain physical phenomena was not merely the problematic situation created by the issue of uncertainty, in parallel with the successive scientific developments in the field of contemporary physics—especially after the emergence of the theories of relativity and quantum mechanics—and the consequent need to reconsider the logical and theoretical frameworks that govern it, as well as the necessity to change the existing concepts and models. This is because the problem of uncertainty also affected the field of scientific methodologies when David Hume first raised the issue of predictive knowledge, also known in epistemological circles as the problem of induction. This is fundamentally a logical problem that subsequently took on a scientific and philosophical dimension.

Hume's analysis of the problem of induction led to the realization of the uncertainty of the scientific knowledge that we acquire through inductive reasoning. His criticisms of the inductive procedure, expressed in terms of causal relations, resulted in an attempt to justify it by arguing that the course of nature and its events follow a specific order, and that the inferred result is knowledge based on the association of ideas, which, when supported by repetition based on the concepts of similarity and resemblance between the past and the future, leads to accurate predictions and solid beliefs about what will happen in the future (D. Hume, 2007, p. 113).

Therefore, the assertion that the course of nature is orderly and follows a specific system, known in epistemological circles as the principle of the uniformity of nature, is the reference point for all inductive tendencies and the fundamental principle of every induction (R. Nadeau, 1999, p. 171). The belief in the existence of harmony and consistency in nature is the motivation for formulating universal laws of nature, and it is the guarantee of their certainty at the same time. It also justifies the predictive quality of science. Thus, according to proponents of inductive tendencies, the existence of such uniformities is the sole premise of all induction. Based on it, we can make experimental generalizations that we consider fixed laws, rather than mere incidental generalizations subject to chance (Ibid.).

This situation, which characterizes induction due to its connection with the principle of the uniformity of nature and the laws of causality that ensure the certainty of its results, is, in our view,

the strongest motivation that directed the attention of the members of logical positivism to strive to solve the problem of induction by reconsidering the foundations of knowledge itself and providing a new interpretation for it instead of a causal explanation. Hans Reichenbach found this explanation in probabilities. If the law of causality, according to Reichenbach, is a law of regularity that knows no exception—expressed in the form: "If X happens... Y always happens"—then probabilistic laws include exceptions that occur in a percentage of cases in the form: "If X happens... Y happens in a certain percentage of cases." Modern logic provides us with a way to handle such a relationship, which is called probabilistic implication (H. Reichenbach, *ibid.*). Therefore, to explain our physical world, we must employ the theory of probabilities instead of the law of causality, which is considered the most comprehensive explanation in classical physics. However, natural phenomena are, in reality, ambiguous and complex, involving multiple factors and considerations that causal explanation cannot fully encompass. In this context, Reichenbach presents the example of a physicist calculating the trajectory of a bullet fired from a rifle. The physicist considers some of the main factors that contributed to this event, such as the gunpowder charge and the direction of the barrel, but he fails to account for secondary factors affecting the event, such as wind direction and air humidity. Therefore, his calculations regarding the point the bullet will hit will only be accurate within a certain degree of probability. Therefore, according to him, the necessity of the idea of probability existed even before the results of quantum mechanics appeared; it only reinforced this necessity. The law of causality, even if it is correct, remains limited because it only applies to ideal subjects and situations, while the actual cases we deal with in reality can only be controlled to a certain degree of probability (*Ibid.*).

This example provided by Reichenbach accurately represents phenomena and events that involve a significant amount of uncertainty, ambiguity, and complexity, which are the types of phenomena that fuzzy logic addresses. In this respect, Reichenbach succeeded in drawing attention to and describing these fuzzy phenomena, but he was mistaken in thinking that they could be understood and addressed solely through probabilistic interpretation. This is because uncertainty, in the example above, precedes the occurrence of the event of firing the bullet from the rifle and is not concurrent with it. However, it turns into complete certainty after the bullet reaches its target and its trajectory becomes clearly outlined. Thus, predicting this trajectory is probable before it occurs and becomes certain after it occurs, either by confirming or refuting the prediction, which means that probabilistic theory, in this case, refers to two values: true or false.

Reichenbach used the concept of frequentist probability to express his new approach to solving the problem of uncertainty in the physical sciences and the scientific laws governing them. The first step he took in his effort to solve the problem of predictive knowledge, ie, the problem of induction, was to abandon the pursuit of certainty in the inductive result and completely give up the idea of the truth of empirical propositions and the truth of our judgments about the future. He then engaged in the path of justifying inductive reasoning by basing it on "probability theory" (*Ibid.*, p. 231), which is known as "inductive probability logic." This approach reflects the new relationship that connects empirical truth with probability theory, meaning that the truth or falsehood of empirical propositions, which was previously decisive and final, is now measured according to this approach by an ascending and descending scale of probabilities, with the highest and lowest limits being 0 and 1.

Therefore, probabilistic logic relies on the frequentist interpretation of events. Probabilistic judgments express relative frequencies of repeated events observed in the past, assuming that the same frequency will approximately apply in the future. These frequencies are presented as a percentage of a total that is always formed through inductive reasoning (*Ibid.*, p. 233). This leads us to the conclusion that inductive reasoning is a special case of more generalized reasoning related to the stability of frequency, where the frequency ratio is complete, ie, one hundred percent. Thus, according to this interpretation, we cannot talk about certain judgments but only about more likely judgments. Undoubtedly, this interpretation, in which the predictive result is a likelihood, relieves us from the obligation to prove its truth. The best we can demand is proof that it is a good likelihood or, at the very least, the best likelihood we have. The function of probability here is to provide us with its degree of probability and its percentage of approaching the truth (*Ibid.*, p. 236).

However, we must point out here that discussing the frequentist interpretation as an alternative to the causal interpretation of events does not fundamentally change much. This is because the frequentist interpretation also relies on the idea of order and the existence of true frequencies and similar repetitions from which we can formulate general laws through the inductive procedure. The only difference is that the frequentist interpretation does not seek certainty in the inductive result, as is the case with the causal interpretation.

The second fundamental concept in logical positivism is the concept of confirmation and degree of confirmation, which Rudolf Carnap introduced to express his view of logical probability. Carnap believes that the theory of logical probability, which he equates with inductive probability, provides us with the rational basis for the controversial inductive reasoning, in that it does not involve the necessity of deductive inferences (R. Carnap, 2015, p. 269) in terms of their accuracy and certainty of results. So, what does Carnap mean by confirmation and degree of confirmation?

The concepts of confirmation and degree of confirmation in Carnap's epistemology fall within the context of abandoning the verification criterion—the first central thesis of logical positivism—after criticisms revealed its impracticality. In practice, it is not possible to definitively and conclusively verify the truth of empirical propositions, no matter how universal they are. For instance, saying "all crows are black" is a universal statement formulated as a law that is unverifiable. Yet, it is confirmable insofar as every new observation confirming the existence of a black crow contributes to its degree of confirmation. Therefore, confirmation is a kind of adequacy between the logical results of a certain hypothesis and the results of observation. It serves as the justification for choosing and favoring this hypothesis over other hypotheses, even though it does not carry any kind of certainty or finality regarding it (R. Nadeau, *ibid.*, p. 83).

The degree of confirmation is the technical limit chosen by Carnap to interpret logical probability. It is, in his view, the logical relationship between a certain sensory datum and the hypothesis, similar to the relationship of "logical implication" but with a numerical value (R. Carnap, *ibid.*). We express the degree of confirmation after obtaining the total results of the test that a certain hypothesis undergoes, through its observable results, in confronting reality, taking into account the rigor of the tests to which the hypothesis is subjected. We express this degree either qualitatively, for example, by saying: a high degree of confirmation, or statistically with a numerical value ranging between 0 and 1. For example, we might say that a degree of confirmation equals 0.995 (R. Nadeau, *ibid.*, p. 84-85).

From here, we observe that the degree of confirmation expresses the degree of uncertainty present in our knowledge of natural phenomena and the laws that govern them. The truth of these laws is neither complete nor definitive, but we express it statistically with a numerical percentage between 0 and 1, or qualitatively using linguistic degrees of possibility such as "higher... lower." This directly refers to fuzzy logic, which similarly relies on quantitative, statistical, and qualitative evaluation of ambiguous and complex phenomena that do not follow a precise system. Carnap himself noticed the relationship between the degree of confirmation, as he conceives it, and the degree of order present in phenomena, associated with the general and broad concept of the uniformity of nature. He found that this relationship is proportional; the higher the degree of order in a world, the more acceptable its universal laws are, and the higher their degree of confirmation. On the other hand, randomness is a high degree of disorder (R. Carnap, *ibid.*, p. 173). Undoubtedly, by the degree of disorder, Carnap refers to what we call today the "degree of complexity", which is a central term in fuzzy logic.

Despite the achievements of probability theory in many fields of knowledge, it has failed to address the problem of uncertainty in certain subjects and ambiguous phenomena. This shortcoming was a catalyst for the emergence of fuzzy logic. Here, we can mention the most significant aspects of its inadequacy regarding these subjects :

1-Probability theory fails to express non-repetitive individual events. Reichenbach himself acknowledges this, stating that expressing the probability of a single event based on frequentist ratios is meaningless (H. Reichenbach, *ibid.*, p. 233). We assign a probability degree to a category, but a single individual event cannot be measured by degrees. If a relative is diagnosed with a serious illness

and I ask the doctor about the probability of their survival, the doctor might respond that 70% of similar cases result in the patient staying alive. While this probabilistic judgment may help the doctor who generally determines what percentage of his patients will not die from this illness, it doesn't help me personally. What matters to me is this particular person's chance of surviving. Therefore, another theory needs to be developed to address individual and exceptional cases separately and be able to calculate and predict them. This characteristic is only found in fuzzy logic.

2-In probability theory, as knowledge increases, uncertainty decreases, and probability diminishes, and vice versa. However, in fuzzy logic, increasing knowledge does not lead to a reduction in fuzziness; instead, the opposite occurs. As knowledge increases, fuzziness and uncertainty, as one of its manifestations, also increase (S. Sharaf, *ibid.*, p. 134).

3-Probability theory becomes technically less effective as the number of probabilities or the number of computational variables increases. The effort and time required to complete it and predict certain events multiply. For instance, the direction of hurricanes can be predicted based on precise and complex calculations performed by a high-precision computer, but the hurricane might pass before the computer completes its calculations (*Ibid.*, p. 131). This makes this theory insufficient in many cases, necessitating a more efficient tool. This is where fuzzy logic comes in to handle ambiguous and complex phenomena (*Ibid.*, p. 135).

4-Karl Popper and the Problem of Scientific Theories' Truth

Karl Popper's treatment of the problem of uncertainty in scientific knowledge is closely linked to his treatment of the problem of induction, which can be considered the core of his entire scientific philosophy. Popper's stance on this issue was extremely clear, as he rejected all forms of justifying the inductive procedure, whether based on habit and repetition founded on the idea of order and the concept of similarity or resemblance between events, as Hume did, or based on building a probabilistic inductive logic similar to that of logical positivism. He deemed Reichenbach's attempt to extend the mathematical probability theory to account for the relative frequency of scientific hypotheses as a doomed endeavor (K. Popper, 2004, p. 318).

What appears to us through Popperian treatment of formulating scientific theories and universal laws is that we cannot establish their final and definitive truth because they are falsifiable; as Popper says, « They are not certain or fixed, but are essentially hypothetical and conjectural, and their truth cannot be definitively determined » (K. Popper, 1999, p. 15); accordingly, the claim of being able to determine their truth essentially stems from a preconceived assumption, without any real justification, that cases can only accept the values of truth or falsehood exclusively. Thus, abandoning this assumption is seen as the solution in his view. However, this does not mean abandoning truth altogether, for the idea of truth cannot be overlooked or wholly rejected, despite being unattainable or elusive, as it remains the fundamental goal of all scientific activity. When it comes to testing our theories and selecting the best among them, the very principle of competition between these theories aims at reaching the truth or at least approximating it (K. Popper, 1998, p. 77).

On this basis, it seemed to us that the concept of approaching truth, the hypothetical speculative nature of our theories, as well as the concept of corroboration and degrees of corroboration, which Popper proposed as an alternative to the truth and verification of scientific theories, are the essential concepts that reflect the uncertain nature of our scientific theories. For this reason, they have attracted our attention.

Popper found that the hypothetical nature of scientific theory is a very natural result of Einstein's revolution, which showed that theory should only be considered a hypothesis or an approximation to truth, even if it is well-proven, like Newton's theory (K. Popper, 2002, p. 91). The revolution caused by the theory of relativity was the most important factor in shaping the 'initial horizon' of Popper's philosophy and his model of the process and growth of science. This is true in several aspects, the most important of which are :

-This theory did not begin, as we are accustomed to in the inductive method, with observation and experimentation followed by generalization and the formulation of the law. Instead, it presented

a set of bold assumptions that were subjected to rigorous testing. What is noteworthy here is that Einstein's theory was more falsifiable than Newton's theory, which was widely accepted, until its success in the Eddington experiment in South Africa. The impact of this event was profound on Karl Popper, who drew much inspiration from this theory and this experiment (M.-F. Zidan, *ibid.*, p. 57).

-This theory undermined the certainty of Newton's theory, which dazzled scientists with its success to the extent that it became an unquestionable model of certainty and a fixed reference. After Einstein's revolution, Newton's theory became approximate, limited in accuracy, and even subject to being surpassed. Consequently, the uncertain and provisional nature of our scientific theories became acceptable after Einstein's revolution (R. Bouveresse, 1986, p. 11).

-Einstein's theory of relativity highlighted some of the irregularity, inconsistency, and instability present in the universe or the macro world. According to this theory, space is neither uniform nor homogeneous as Newton claimed, based on the idea of uniformity; rather, it curves around the masses floating within it in its three dimensions and the fourth dimension, time. This curvature property contributed to solving many problems that classical physics failed to address (Y.-T. Al-Khouli, 2000, p. 206).

What distinguishes a scientific theory, in Popper's view, is not its final truth but its ability to be wrong and fall under rigorous critical tests in the light of new experimental data. In fact, the belief in its certainty is rather a sign of its ambiguity and an obstacle to its improvement, which can only happen through continuous criticism (R. Bouveresse, *ibid.*, p. 11). This, despite our inability to verify the truth of our theories, does not at all prevent us from striving to attain the truth or trying to approach it.

Karl Popper considers the concept of verisimilitude a logical concept, belonging to the field of metalogic. Popper used this concept to escape the state of helplessness accompanying all attempts to establish the truth and certainty of our theories. He argues that saying a theory is 'closer to the truth' represents an idea that is clearer than the idea of truth and more applicable in reality. This refers to some characteristics of fuzzy logic, which is distinguished by its practical application in reality. By this concept, Popper means that every theory, even if false, contains a certain amount of truth and a certain amount of falsehood. The more the truth content of a theory exceeds its false content, the closer it is to the truth, and vice versa. This leads us to question the logic that underpins this concept of 'closeness to the truth,' as it does not exclusively express the value of truth or falsehood but expresses a partial truth value and a partial falsehood value, based on the concepts introduced by Popper: 'truth content' and 'false content' of scientific theories. If this logic is not a type of multi-valued logic known in the era when Karl Popper worked, it, as he states in his book 'Conjectures and Refutations,' 'achieved some of the goals set by proponents of multi-valued logic' (K. Popper, 2006, pp. 344-345).

The concept of 'corroboration' and 'degree of corroboration' is one of the most important epistemological concepts after falsifiability. It is the strongest response to those who advocate verifiability and the existence of crucial experiments that definitively determine the truth of theories by excluding their competitors. Theories that withstand rigorous tests and have not been falsified remain merely corroborated theories, temporarily, and not true. Karl Popper states: 'Theories are not verifiable, but they can be corroborated' (K. Popper, 2004, p. 248). Thus, discussing the corroboration of a theory is about the ability of this theory to endure and withstand the rigorous tests it has undergone, and the extent of its success in demonstrating its value and explanatory efficiency. Instead of debating the truth or probability of theories, we should evaluate the tests they have undergone and the degree of corroboration they have received.

The concept of corroboration differs from the concept of truth; for Popper, corroboration is not a value of truth because truth is a logical concept, like falsehood, and not empirical. From this perspective, they resemble the concepts of tautology and contradiction in that they evaluate a statement independently of time, that is, regardless of the changes that may occur in the empirical world, while physical phenomena are characterized by transformation and change over time. Corroboration, however, takes into account the temporal factor and emerging changes. Thus, we say that a statement is corroborated until a certain moment in time. For this reason, corroboration can take

on a logical value provided that the value is not absolute. Unlike the absolute and timeless logical concept of truth, the concept of corroboration is relative and temporary (K. Nizar, 2002-2003, pp. 125-126).

Therefore, we mean by corroboration a specific logical relationship that connects a theory or theoretical system to a set of foundational statements accepted at a certain time. A single theory can thus acquire different values of corroboration, all of which are considered valid because they are logically derived from the relationship of that theory to foundational statements accepted at different times.

As for the degree of corroboration, it cannot simply be based on the count of corroborating and supporting cases for the theory. Instead, it is founded on fundamental logical relations that connect the theoretical systems to a set of accepted foundational statements, whether they are in agreement or conflict. Karl Popper states: 'By the degree of corroboration, I mean the summary balance of the critical discussion of the theory at time t, which relates to how the theory addresses the problems it tackles, its testability, the rigor of the tests it has undergone, and its way of enduring them' (K. Popper, 1998, p. 61).

What can be inferred from this brief definition is that the temporal and provisional nature of the concept of corroboration is evidence of the uncertainty of our scientific theories and the impossibility of establishing them definitively and conclusively, despite their success and corroboration. This should not be considered an indicator of their efficiency and validity in the future, nor can this success be used to predict subsequent successes (K. Nizar, *ibid.*, p. 125). Thus, it becomes clear to us that the relative nature of our scientific knowledge, this uncertainty and instability that characterize our theories in terms of the impossibility of final and conclusive decision-making regarding their truth, and the inability to make certain predictions—this is what Popper's concept of corroboration has led to—is one of the most important indicators of ambiguity and fuzziness at the level of our scientific theories and the level of our real world, full of changes, exceptions, and surprises. Therefore, when examining the concept of corroboration and the degree of corroboration, we cannot help but raise questions about the logical frameworks through which we can understand these concepts. Does the degree of corroboration refer to the degree of probability or support, especially knowing that both employ the concept of evaluation? Or is it another type of multi-valued logic that accepts partial truth values? Suppose Popper talks about the evaluation of the degree of corroboration. How can we express this evaluation when comparing the degrees of corroboration of competing theories and when ranking them on an ascending scale, if this evaluation is not subject to numerical calculation, which would facilitate the comparison and selection process? As he points out in his book *The Logic of Scientific Discovery*: « We cannot define a numerically calculable degree of corroboration, but can speak only roughly in terms of positive degree of corroboration, negative degree of corroboration and so forth » (K. Popper, 2004, p. 266).

In light of Popper's insistence that the discussion of corroboration and the degree of corroboration lies outside the framework of binary logic, and that it differs from the logic of probabilities, while incorporating qualitative considerations in their evaluation, such as 'positive degree of corroboration' and 'negative degree of corroboration', we can only see this as referring directly to certain aspects of fuzzy logic. Fuzzy logic could be the logical foundation for this type of epistemological concept.

Conclusion

Based on the foregoing, it becomes clear that consolidation of the concept of uncertainty in contemporary physics—following the scientific revolution brought about by the theories of relativity, quantum mechanics, and cosmic chaos—has created a fertile and conducive scientific and philosophical climate. This climate has led to the emergence of a set of concepts and theses that have formed the foundation of major currents in contemporary philosophy of science, which in turn have

had a significant impact on the development of logic. Accordingly, this research has shown that these concepts lie at the heart of fuzzy logic's concerns, due to the shared features between them, including:

- **Frequentist probability and degree of confirmation** in the logical positivist tradition are foundational concepts in what is known as probabilistic logic. They express the degree of uncertainty inherent in our knowledge of natural phenomena and the laws governing them. This type of logic belongs to the family of multi-valued logics, where truth is measured along a graded scale of probability ranging between 0 and 1. This is precisely the framework within which fuzzy logic operates—as a logical system that cannot be computed according to binary logic (absolute truth vs. absolute falsehood), but rather through partial degrees of truth that fall within the interval $[0, 1]$.

- The concept of **degree of confirmation** is employed in evaluating propositions either quantitatively—through a statistical ratio indicating a certain level of truth—or qualitatively, using linguistic modalities such as “higher,” “greater,” or “less.” This leads us directly to fuzzy logic, which similarly relies on both quantitative and qualitative assessments of ambiguous and complex phenomena that do not follow a precise and deterministic system. Carnap's notion of “degree of disorder” closely aligns with the “degree of complexity” in fuzzy logic.

- The conjectural and hypothetical nature of our scientific theories, as emphasized by Karl Popper, renders them uncertain and falsifiable. Therefore, we cannot establish their truth definitively and conclusively; all we can say is that they approximate truth.

- Popper's concept of “**verisimilitude**” does not express a strictly binary value of truth or falsehood, but rather a partial degree of truth and a partial degree of falsehood. This makes it more applicable to real-world contexts—a fundamental feature of fuzzy logic.

- Popper's notion of “**corroboration**” is one of the key manifestations of ambiguity and fuzziness in our theories and in the complex, uncertain reality they aim to describe. It reflects the relative nature of our scientific knowledge and the uncertainty and instability that permeate it, preventing us from making definitive truth claims.

- Popper's inclusion of notions such as “**positive degree**” and “**negative degree**” of **corroboration** introduces qualitative considerations into the evaluation of confirmation. As this research has shown, these notions point to essential aspects of fuzzy logic, which we regard as the logical framework most suited to understanding and assimilating such concepts.

Thus, we can say that the epistemological issues addressed by logical positivism and Popperian critical rationalism, as well as the concepts and notions resulting from them, are at the core of fuzzy logic's interests. Abandoning the idea of absolute truth and moving towards the concept of partial truth, probability, degree of support, and verisimilitude are all manifestations of fuzziness at the logical level. Uncertainty, indeterminacy, hypothetical conjectural approach, and the concept of corroboration are also manifestations of fuzziness at the epistemological level, while complexity and ambiguity represent their manifestations in the real and ontological realm due to their relation to the nature of things and subjects themselves. These concepts and notions, which we have diligently analyzed and highlighted over the previous pages to the extent allowed by the context, along with other scientific developments, have, as we believe, prepared the ground and theoretical foundation for the emergence of fuzzy logic. They have paved the way for it to address situations and scenarios that other logical systems failed to comprehend and manage.

* **Non-classical logic** extends to various types of logic that address qualitative or normative cases and topics, or subjects that are not precisely defined, allowing for multiple degrees of truth and probability. It also encompasses contingent propositions related to future events. Among the types of this logic are **normative logic**, **modal logic**, **probabilistic logic**, and **fuzzy logic**.

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