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Fuzzy Logic: Blurring the Line Between True and False

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Abstract. Since Aristotle's time, classical two-valued logic has been the foundation of Western rational thought. One of its most important principles, the law of excluded middle, states that every statement must be either true or false, with no in between. But when the situation is changed from the formal language to the everyday human language, there are a lot of unclear terms like "tall", "bald", and "pile". These terms cannot be clearly labeled as completely true or false, and their existence challenges the absolute authority of classical binary logic. This raises a key philosophical and logical question: how to deal with this common uncertainty in life? The idea of "fuzzy logic" was first suggested by L. Zadeh in the 1960s, who claims that traditional set theory does not work for describing the complex problems humans face in real-world systems because it focuses on absolutes. Therefore, solving such problems requires a theory of fuzziness. This paper aims to examine this claim. First, this paper talks about the classic problems that come up when things are vague and explains the basic ideas of fuzzy logic. Then, it looks at the big ideas behind it and how they can be used in the real world. Finally, after looking closely at these applications, the paper makes more conclusions. The value of fuzzy logic consists in its practicality, not its status as a philosophical theory of truth.

Keywords: Sorites paradox, vagueness, fuzzy logic

1. Introduction

The tricky problems that come from fuzziness are best shown by the ancient Sorites Paradox. This paradox is usually explained using the example of "baldness". Imagine there is a person with 100,000 hairs. It is assumed that this person is not bald, and everyone agrees that she is not bald. But if someone is not bald, then even if one hair is removed, she is still not bald. Based on these two simple assumptions, if people repeatedly apply the second assumption, they can conclude that a person's hair will always grow back if it starts to fall out. This conclusion is clearly wrong. The problem comes from how vague the term "bald" is. It does not have a clear boundary or cutoff point. Classic logic needs to clearly define what it means to be bald and what it means not to be bald. For example, having exactly 100 hairs could be the difference between boldness and nonboldness. But this does not make sense. A person with 100 hairs and a person with 101 hairs may look the same, so why can the first one be said to be bald, but not the second one? This shows a big problem with classical binary logic when it comes to boundary issues.

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To deal with this problem, philosophers have suggested different ways to do it. There are many ways to deal with ambiguity in philosophy, and epistemicism is a unique approach. This theory suggests that the vague words people use every day—like “bald” or “tall”—are not really without limits. Instead, each fuzzy predicate has an extremely precise boundary that is beyond human cognitive reach. This means that its exact location can never be determined [1]. For example, epistemicists believe that there is a clear limit to how much hair a person can have before people can call them “bald”. If someone has the amount of hair below this limit, they’re considered “bald”, but if she has one more strand of hair, she is not considered “bald”. This suggests that vague statements can be understood in the same way as other statements, for they can be either true or false. People cannot exactly say what the boundary value is because they can’t really understand the predicate itself. It is not that the predicate is vague, though. It is more that humans cannot really understand things beyond what they can actually perceive.

Supervaluationism is different from cognitivism. It tries to deal with the boundary problem by looking at fuzzy predicates. At the same time, it keeps the idea that true and false are always opposite each other, like in binary logic. This theory says that the main problem with fuzzy predicates is not the “existence of unknown exact boundaries”, but rather our ability to define different exact boundaries for the same fuzzy predicate in various reasonable ways. The establishment of these diverse boundaries constitutes what supervaluationism terms “precise definitions” [2]. So, the truth value of a fuzzy proposition is not determined by just one “precise definition”. Instead, it is determined by how it shows up across all reasonable precise boundary values. If a question is true according to all possible reasonable precise definitions, it is “super-true”. If it is false according to all reasonable and exact definitions, it is “super-false”. But if it is true for some of these definitions and false for others, the question does not have a definite answer. This is what people call the “truth gap”: the area where one cannot say for sure what the answer is. This approach keeps binary logic intact in deciding the truth-values of statements while also recognizing the unique status of borderline cases. For example, the question “Is a person with 1000 hairs bald?” has different answers. It depends on how precisely the term is defined, so there is no clear answer to the question that is unclear.

Contextualism is a framework that addresses the issue of fuzziness from a different perspective. The concept challenges the prevailing notion that “fuzzy predicates have fixed boundaries”, proposing an alternative perspective in which the meaning and boundaries of fuzzy predicates are not static but rather undergo dynamic shifts in accordance with the context of their utilization by individuals [3]. From the perspective of contextualism, the boundaries of fuzzy predicates are not due to multiple definitions or cognitively unknowable to the speakers. Instead, these elements are determined by the actual circumstances of the specific speakers, the purpose of the conversation, and the interests of the speakers. For example, the criteria used to ascertain whether an individual is deemed overweight in daily discourse diverge significantly from the criteria utilized in medical contexts to evaluate obesity. This example shows how the boundaries of fuzzy predicates vary according to conversational goals. This contextual dependency suggests that there is no absolute threshold; rather, the boundaries of fuzzy predicates are inherently linked to specific contexts and adapt accordingly. This phenomenon elucidates the observed variability in judgments concerning boundaries when employing a shared fuzzy predicate across varying situations.

2. What is fuzzy logic

All these theories attempt to resolve issues either within the framework of binary logic or by modifying it. Fuzzy logic, however, takes a more extreme approach: it fundamentally redefines the

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foundations of logic, allowing truth values themselves to be graded [4].

To inquire deeper into this research, one must first understand what fuzzy logic entails. Consider the proposition "Xiao Ming is tall". In classical logic, people must establish an absolute threshold (e.g., 185 cm), where values above it yield true (1) and below yield false (0). In fuzzy logic, however, truth values can be any number between 0 and 1 [5]. A person measuring 185 cm might have a membership degree of 1 for "tall", one measuring 180 cm might be 0.8, one at 170 cm could be 0.5, and one at 160 cm might be 0.1. Here, 0.7 truth does not imply "a 70% probability of being tall", but rather "a 70% degree of tallness". This distinction highlights the difference between fuzzy logic and probability theory: probability deals with the uncertainty of an event occurring, while fuzzy logic addresses the degree of membership [6].

Fuzzy logic handles ambiguity directly and intuitively and deals perfectly with the gray areas of real life. In fuzzy logic, the change in the actual proximity of a "pile" to the boundary caused by adding a single grain of sand is infinitely small. More specifically, it reduces the membership degree from 0.50000 to 0.49999, thereby avoiding the abrupt, sharp cutoff point found in classical logic. Its core advantage is the high intuitiveness it offers for measurable predicates, while simultaneously avoiding the arbitrary boundaries encountered in other theories.

3. The philosophical implications of fuzzy logic

However, fuzzy logic can raise profound philosophical questions: what exactly does "0.7 true" mean? The answers to this question leads to debates on the meaning of words and the nature of reality.

One way to understand fuzzy logic is through the Semantic Interpretation. This interpretation is that truth values don not directly describe what is happening in the world. Instead, they describe how people use language in different situations. For example, the value 0.7 is a way to measure how well the word "tall" applies to a specific height in a certain situation. It shows that people recognize the same things when people use language. This way of understanding fuzzy logic takes it to be a model of how things are understood and how they are applied, rather than a direct metaphysical claim about the world itself [7].

Another way to understand fuzzy logic is through the Metaphysical Interpretation. This view, which is more controversial, states that truth values are directly related to the properties of things in the world. In other words, a person's height is more than just a number; it also has a certain quality that makes them tall. That is to say, fuzziness is just part of how the world is, not a problem stemming from how people talk or think [8].

Using this idea as a starting point, people can better understand fuzzy logic by comparing it with other philosophical theories. Fuzzy logic is different from supervaluationism as well. Supervaluationism keeps classical logic's truth values the same by making a lot of improvements, and it believes that cases that are not clear have no truth value. However, fuzzy logic claims that cases that are not clear-cut have some degree of truth to them. The former view embodies "global precision, local fuzziness", while the latter one represents "global fuzziness". Fuzzy logic is also different from epistemicism. Epistemicism recognizes that there is a hidden, unknown, exact boundary. However, fuzzy logicians believe that precise boundaries don not exist. For fuzzy logic, fuzziness is real, not just a result of humans.

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4. The applications of fuzzy logic

Although some debates surrounding its philosophical foundations remain, the most compelling merit of fuzzy logic lies in its technical applications. It transforms a philosophical problem into a powerful tool for solving real-world engineering problems in our daily concrete lives, such as air conditioners and washing machines. This transformation exemplifies the interconnection and integration of logic and philosophy in real-world technology.

The primary application of fuzzy logic is in the control systems. Traditional control systems rely heavily on precise mathematical models, but it is exceedingly difficult, if not impossible, to construct such models for complex or ill-defined systems. Within control systems, fuzzy logic mimics decision-making processes by using "if-then" rules expressed in natural language. A classic example of this process is fuzzy logic's application in washing machines. Rather than precisely calculating the quantity, weight, and dirty level of laundry, it makes judgments by rules such as these: for example, if the dirty level is "high" and the load is "large", the washing time should be "long", and if the water hardness is "soft" and the fabric type is "delicate", the washing intensity should be "gentle." Inputs (e.g., water hardness) from the sensors are converted into fuzzy values by these rules. They will be first processed to generate a fuzzy value and then defuzzied to make a precise command (e.g., washing intensity). This approach is far more stable and efficient than traditional methods.

Apart from this, fuzzy logic has several other applications that improve people's lives. For instance, in cooling and heating systems, fuzzy logic can optimize the control of temperature. Since traditional thermostats operate according to fixed temperature thresholds, they may cause equipment to be switched on and off frequently in response to minor temperature changes. It consequently generates great energy consumption. However, fuzzy logic can accurately apply descriptions such as "a bit cold" or "a bit warm" that go closer to everyday perception. It transforms these descriptions into continuous adjustment commands, making subtle temperature changes possible. This method makes sure that the room temperature can remain within an optimal range, which can effectively reduce energy waste and protects the environment. In the automotive industry, fuzzy logic is also a key element in the Active Protection System (APS). APS systems can use fuzzy logic to analyze data such as wheel speed and vehicle position so as to fine-tune engine power and braking in real time. This feature enables safer driving in adverse conditions like raining or snowing.

Fuzzy logic is also widely used in digital cameras. It significantly enhances imaging performance by improving autofocus and image stabilization. Traditional camera systems struggle with unclear outlines thanks to inaccurate focus, repeated focusing errors, and insufficient lighting. However, by optimizing image clarity and contrast, fuzzy logic enables the rapid identification by more accurate and faster focusing. The area of artificial intelligence also deploys the vital role fuzzy logic plays in complex problem-solving scenarios. Even in medicine, fuzzy logic plays an important role. Because symptoms are often described vaguely, such as "slight pain" or "like prickling", medical diagnosis can be difficult. Since, similar symptoms may appear the same in different conditions, this kind of vagueness poses challenges for doctors who rely solely on conventional data for judgments. Fuzzy logic plays a role when doctors integrate vague symptom descriptions with patients' histories and other factors in analysis, so more comprehensive evaluations can be conducted. It has helped escalated diagnostic accuracy and reliability.

The extensive and successful real-world applications demonstrate that fuzzy logic perfectly meets the needs of daily life. It has effectively overcome the limitations of traditional logic in processing diverse information. It plays an indispensable part in enhancing device performance and optimizing product effectiveness.

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5. Critical discussions

According to the above discussion, does fuzzy logic truly "solve" the problem of fuzziness represented by the Sorites Paradox? This paper argues that the answer depends on the meaning of the term "solve".

If "solve" means it provides a practical solution enabling people to construct robust systems using fuzzy predicates, then the answer is yes: it does resolve the ambiguity problem. It successfully avoids the so-called gray zone in boundary definitions and models minute changes in a way consistent with our intuition.

However, if "solve" implies offering an uncontroversial semantic answer to the nature of fuzziness itself, the answer may be negative. Some critics have pointed out that fuzzy logic itself faces questions about higher-order fuzziness: is the transition from completely fuzzy to comparatively truer truth degrees inherently fuzzy? If so, would it be necessary to establish yet another fuzzy logic for judging truth degrees themselves? This could lead to infinite regression in fuzzy logic [9]. Therefore, a more reasonable idea is that fuzzy logic should be regarded as an extremely useful modeling tool rather than a final solution. It does not resolve the philosophical debates surrounding fuzziness, but it provides a powerful linguistic and mathematical framework enabling people to manipulate, compute, and harness fuzziness to address a range of problems encountered in everyday human life. It transforms philosophical questions from paradoxes that obstruct practical reasoning into resources capable of generating tangible, positive benefits.

All in all, fuzzy logic is a radical departure from classical logic. It reshapes how people think about truth, vagueness, and reasoning. It has practical success in a lot of areas of engineering and AI, showing that philosophy-inspired ideas can reshape technology. However, as a philosophical approach to the Sorites Paradox, fuzzy logic dissolves rather than solves the paradox. It sidesteps the classical reasoning that generates the contradiction, but at the cost of introducing precise mathematical structure to effectively model vague concepts. In other words, fuzzy logic offers a compelling model of vagueness that blunts the force of the Sorites paradox by rejecting bivalence, but it replaces vagueness with artificial precision rather than explaining it.

6. Conclusion

This paper traces how fuzzy logic emerged from the classical logical problem of vagueness and demonstrates how it addresses and develops this issue. The Sorites Paradox reveals the limts of binary logic in describing real-world phenomena. Zadeh's fuzzy logic, by introducing truth degrees and fuzzy sets, provides a continuous framework tolerant of minor variations for handling boundary issues. Although its core concept of "fuzziness" has initiated a series of philosophical debates over semantic interpretations, this has not hindered its tremendous success in engineering and technology. From washing machines to artificial intelligence, fuzzy logic displays how abstract philosophical thinking can yield profound technological impacts on human daily life.

The answer to the core question addressed in this paper is that fuzzy logic does provide a better approach for handling fuzziness, but primarily at the practical and computational levels. It may not offer the most fundamental answer about the nature of "truth", but it undoubtedly serves as an indispensable bridge connecting human fuzzy cognition with machine precision. Its broader significance amounts to the reminder that accepting, confronting, and skillfully navigating ambiguity—rather than futilely pursuing illusory precision—is often the wiser and more effective approach in philosophy, law, technology, and even everyday decision-making.

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