Practical and Philosophical Applications of Fuzzy Logic: A Brief Introduction

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Human beings are sometimes said to be different from mere computers and their associated algorithms (software) in that humans can reason and make decisions in settings where information is incomplete, conflicting, uncertain, imprecise or even partly wrong [1,2]. In recent decades workers in varied fields like computer science, psychology and cognitive engineering have attempted to "formalize" this capability. One particularly successful approach has been the field of "Fuzzy Logic" [3],

The field of Fuzzy Logic was launched by Lotfi Zadeh, an Electrical Engineering professor at the University of California, Berkeley, starting with the publication of his seminal article in 1965 [4]. Zadeh's breakthrough was to introduce the notion of a set or class with unsharp boundaries that permitted partial class membership. This conceptual breakthrough encouraged the development of qualitative approaches to the analysis of systems where linguistic rather than numerical variables are ordinarily used to describe behavior and performance. Because this innovative approach to problem solving and knowledge representation turns out to model many aspects of human reasoning and decision-making better than previous methods, it eventually gained wide acceptance. As a result, Fuzzy Logic has become a well-established topic in academia and even in industry, with practical applications in a number of areas from vacuum cleaner control to the operation of subway vehicles. While originally dismissed by many uninformed skeptics as unscientific and imprecise (in large part because of the word “Fuzzy”), the field is now well-established and rigorous, with its own journals and symposia.

To understand the place of Fuzzy Logic in the world of philosophy and logic, it is helpful to begin with Aristotle. Aristotle is well-known for his “laws of thought”, which consisted of three fundamental laws: the **law of identity** (an entity is the same as itself), the **law of non-contradiction** (in the words of Aristotle: "one cannot say of something that it is and that it is not in the same respect and at the same time"), and the **law of the excluded middle.** It is in connection with this last Aristotelian law that Fuzzy Logic becomes important.

Aristotle’s law of the excluded middle holds that for all propositions **p**, either **p** or **~p** (not **p**) must be true. Thus, “either John is a man, or John is not a man”, or “either Sally is pregnant, or she is not pregnant”; in either case there is no middle ground.

But the Law of the Excluded Middle does not apply in all situations. Consider the following examples. Either Joe is tall or he is not tall. Either the oven is hot or it is not hot. Either the wine is cold or it is not cold. Such examples make less sense to us, since, for instance, the oven might be warming up, so that it is neither hot nor cold at a particular time. The Law of the Excluded Middle is clearly not the right notion to express these situations. Instead, the Fuzzy Logic description may be more appropriate.

One key idea central to Fuzzy Logic is that an entity can have partial membership in a set or class. For instance, Joe, mentioned above, at 5' 8" in height, while considered to be either tall or not tall in the Aristotelian way of thinking, might instead be considered to be neither tall nor short, but assigned a 50% membership in the class of short people as well as 50% membership in the class of tall people. Similarly, Joe's friend Tom, at 5' 9" in height, is also neither short nor tall, but instead might be given a 40% membership in the class of short people and a 60% membership in the class of tall people.

In this sense Fuzzy Logic can be viewed as a superset of classical logic that has been extended to handle the notion of partial truth, where "truth values" may exist somewhere between "entirely true" and "entirely false". Of course, an important process in using Fuzzy Logic is establishing membership functions that indicate the degree of membership in a class. How this is done will depend on the specific context or application, and may involve a consensus process among experts or even a degree of reasonable arbitrariness.

Figure 1 provides a useful schematic illustration of the Fuzzy Logic concept using air temperature as an example. On the top left is shown a diagram for the rule that states that the air temperature is considered to be cool if and only if it is between 50 and 70 degrees Fahrenheit.

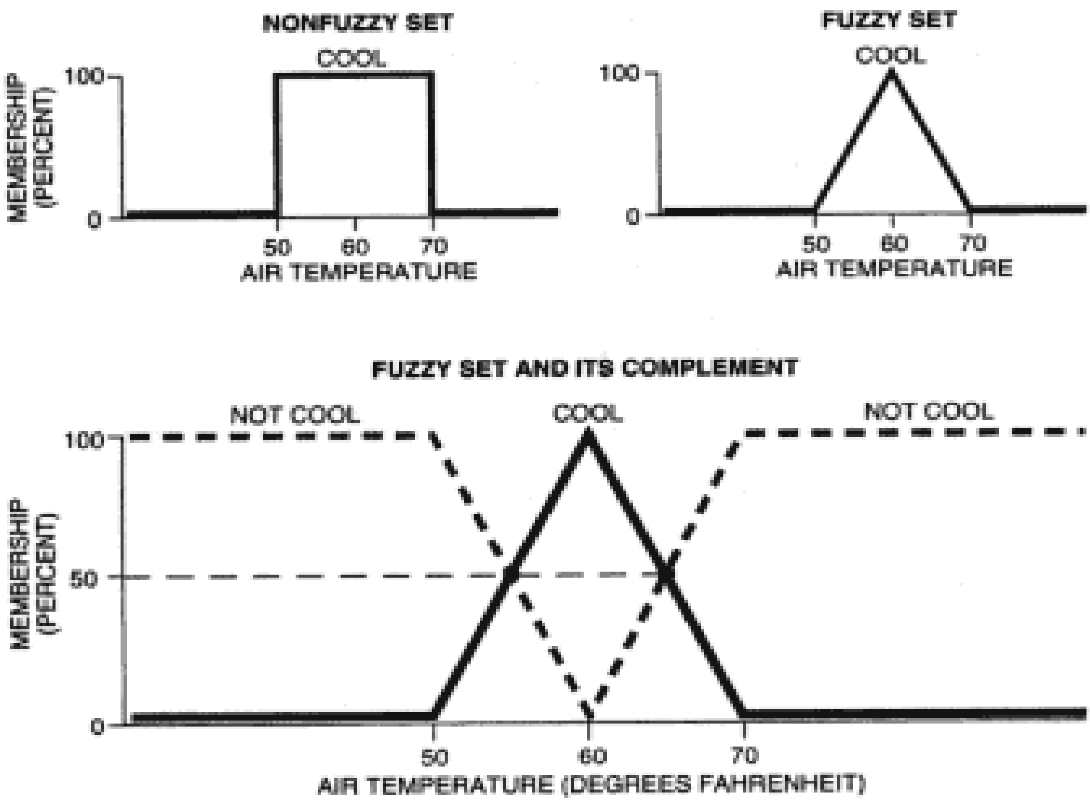

Figure 1. A comparison between classical and Fuzzy Logic representations for the concept of "cool air". See text for details. **Image Credit:** http://www.fortunecity.com/emachines/e11/86/graphics/fuzzylog/FUZZY1.gif

On the top right is a Fuzzy Logic model where the air can possess various degrees of coolness. In this case, if the air temperature is 55 degrees it is assigned 50% membership in the class ***cool*** and 50% membership in the class ***not cool***. A similar situation exists if the air temperature is 65 degrees. Note that only if the air temperature is exactly 60 degrees is the air given full membership in the class ***cool***. The applications of Fuzzy Logic to practical problems in engineering, science and medicine have been numerous [e.g., 5-8]. In some cases problems that were impractical or impossible to solve using classical engineering techniques were solved fairly readily using FL methods. This is at least in part because of the ability of Fuzzy Logic to provide nonquantitative solutions to some problems. An example of this is shown in Figure 2 below, which illustrates the use of Fuzzy Logic to control the rate of insulin administration to a diabetic patient.

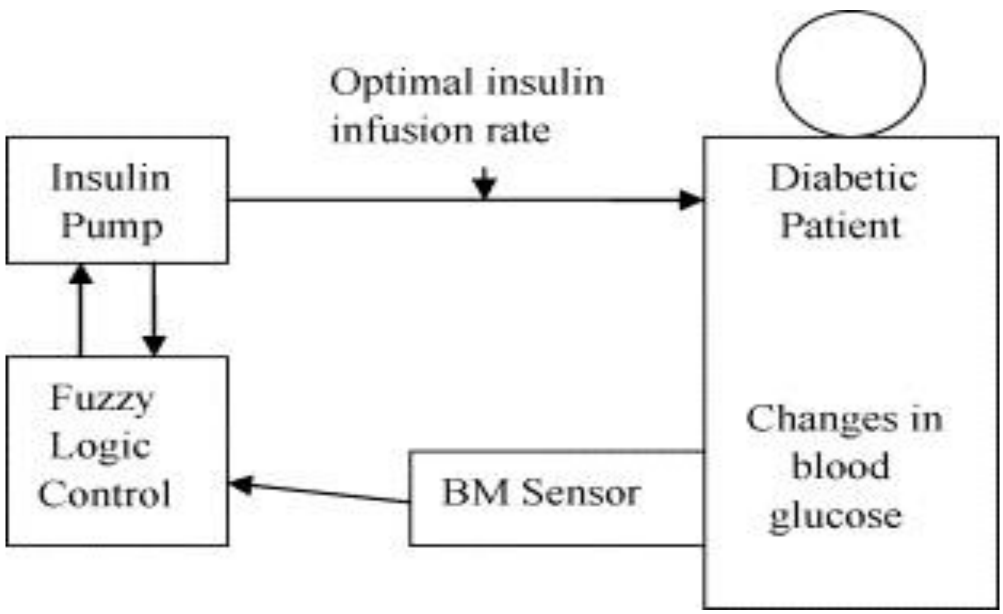

Figure 2. A practical application of Fuzzy Logic to control glucose levels in diabetics. Here a closed loop feedback system based on Fuzzy Logic continuously monitors a patient's blood glucose level and adjusts an infusion of insulin to an optimal rate. From Grant, P. A new approach to diabetic control: Fuzzy logic and insulin pump technology. Medical Engineering and Physics. 2007; 29:824-827.

A special area of application for Fuzzy Logic has to do with how people use language in everyday life. For instance, when doctors talk about their patient's condition, they often use modifier terms like "mild", "severe", "very", "little", "sort of", and so on [9]. A doctor might, for example, state that for patients with mild postoperative pain he or she recommends the use of acetaminophen, while recommending the use of intravenous morphine in cases of severe pain. If a computer programmer wanted to write an "Artificial Intelligence" computer program to capture the doctor's approach to treating pain, Fuzzy Logic might be used. This process might begin by asking the patient to rate his or her pain between 0 (no pain at all) and 10 (worst pain imaginable). (This is standard clinical practice done millions of times daily around the world). The pain score obtained would then be mapped into a pain class in some manner. For example, membership in the class "moderate pain" might take on 0% membership at a pain score of 4, and take on a 100% membership value with a pain score of 8. The class "severe pain" might be designed to start at 6 and take on 100% membership value at 10, the maximum possible pain score in the system.

Fuzzy Logic also plays a potentially useful role in more philosophical fields like linguistics, ethics and law. For instance, while traditional ethical systems tend to operate in binary terms such as true vs. false, guilt vs. innocence, premeditated vs. unplanned, one can imagine how notions of degrees of truth, degrees of guilt and related concepts might be introduced into ethics and law. As an example, in a civil law suit, a man who was injured because someone ran into his car at a stop light might be required to bear, say, 25% of the responsibility for his injuries because he was not wearing a seatbelt.

Consider next a bioethical example. Almost everyone agrees that a person is either alive or dead. However, medically speaking, the situation is actually more complex in some special cases. For instance, the notion of “incomplete” brain death has arisen in the medical literature [10], as might occur in the case of “the patient with a massive brain injury who meets the criteria for brain death only imperfectly, perhaps because one small patch of neurons in a brain-stem nucleus is still operating intermittently”.

It is important to emphasize the distinction between Fuzzy Logic and probability theory, as the two are sometimes confused. Recall that the central notion of Fuzzy Logic is that allowable membership values take on values between 0 to 1, where 0 represents No Membership / Absolute Falseness and 1 represents Complete Membership / Absolute Truth. If we then consider the statement “John is old" and John is actually 60 years of age, we might assign the statement “John is old" a truth value (degree of membership) of 0.7. This is very different from saying that there is a 70% probability that John is old. This difference in semantics is significant: the probability view holds that John either is or is not old (as per the Law of the Excluded Middle) with a 70% chance of the former. By contrast, the Fuzzy Logic perspective holds that John is "mostly" old (or some such verbiage) with a 70% membership in the class of old people.

Individuals seeking to learn more about Fuzzy Logic have many sources available to them [e.g., 11-13]. While a great many of these sources are reports in the fields of engineering, mathematics, medicine and computer science, there are also many reports that are aimed at philosophers, especially those who are professional logicians. In the latter case, they are sometimes found in obscure academic journals such as *Journal of Symbolic Logic* or *Studia Logica.* Unfortunately, most material in these journals is completely unintelligible to individuals without advanced training in symbolic logic, a situation that even includes most professional philosophers.

In conclusion, Fuzzy Logic is a new way of knowledge representation that goes beyond classical Aristotelean logic and the Law of the Excluded Middle. A fundamental notion in Fuzzy Logic is that allowable membership in a class can take on values anywhere between 0 to 1; that is, partial class memberships (partial truth values) are permitted. Fuzzy Logic's strength is that it allows qualitative approaches to the analysis of systems where linguistic terms rather than numerical variables are ordinarily employed. Because this approach models many aspects of human thinking better than previous methods, it has turned out to be remarkably successful in many domains.

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