Fuzzy Logic and Applications

Chapter 1. Introduction

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Outline

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Administrative

- lectures FLA & LFA (Wednesday 16-20): Doru Todinca, e-mail: doru.todinca@cs.upt.ro;
- lab (D. Todinca): see the web-page of the course, or the timetable.
- web page FLA: `www.cs.upt.ro/~todinca` in Teaching, Fuzzy Logic and Aplications
- web page LFA: `www.cs.upt.ro/~todinca` in Teaching, Logica fuzzy si aplicatii
- or: `www.cs.upt.ro/~todinca/fl/curs_fl.html`
- Username: *fl* ; Passwd: *fl_2007*
- Written exam, counting 50% of the final grade
- Additionally to official presentations, it will be one more exam, during the last LFA/FLA lecture (in the 7^{th} week).
- Bonus points can be obtained at both the lab, and the exam
- Lab counts 50% in the final grade.

Lab assignments

1. For grade 10 with bonus points: an OMNeT++ program, as an example of application of the fuzzy inference, **and the presentation of the simulation results obtained.**
    - There can be two students at one project, but, in this case, each student has to do her/his own presentation **and** a very short document (containing the simulation results and their interpretation) in order to obtain the bonus points for exam
    - The assignments (projects) are on the course's web page
    - It is also given the OMNeT++ code of a FLC (Fuzzy Logic Controller)
    - OMNeT++ is an open source network simulator, based on C++

Lab assignments

2. For 9 or 10 grade (without bonus points): the presentation of a scientific paper from the web page of the LFA course
   - A paper can be chosen and presented by only one student
   - For a 10 grade, the presentation must be very good and the student should be able to answer the questions related to fuzzy logic aspects of the paper
   - If the student is not able to answer the questions, then the maximum possible grade will be 7 (seven).
   - It is allowed to include in the presentation figures from the paper, but not text !
3. For a 5 or maximum 6 grade: ...

- The presentation realized by IA programs **will not be accepted !**
- In all cases it is absolutely forbidden to copy code, text, presentations, from colleagues or from other sources.
- The students who will copy **WILL NOT PROMOTE THE FLA / LFA LAB !!!**

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Fuzzy logic: historical perspective (after [Wan99])

- Created in 1965, by Lotfi A. Zadeh
- Among the precursors: Grigore Moisil, with multivalued logic
- Zadeh had also essential contributions: fuzzy algorithms (1968), fuzzy decision making (1970), and especially:
- 1973: the concept of linguistic variable, utilization of IF-THEN rules in order to express the (*human knowledge*), these rules being the foundation of *fuzzy control*.
- The extension principle (also Zadeh, 1973): allows the "fuzzification" of other mathematical or non-mathematical domains (i.e., their extension through the framework of fuzzy theory): fuzzy functions, fuzzy numbers, fuzzy arithmetic, fuzzy flip-flops, etc
- 1975: Mamdani and Assilian: the first practical application of fuzzy logic, in control engineering: the control of a steam engine ("the birth of fuzzy controllers for real systems" [Wan99])
- 1978: the first industrial application of a fuzzy controller (Holmblad and Østergaard): *fuzzy cement kiln controller*

Fuzzy logic: historical perspective

- In early 1980's the domain of fuzzy logic become unpopular, especially in US, but also in Western Europe: many researchers had to change the domain due to lack of funding.
- The Japanese engineers and scientists saved the field, by successfully applying fuzzy controllers on many practical problems:
  - 1980: Sugeno: the control of a water purification plant (at Fuji Electric)
  - 1983: also Sugeno: a fuzzy robot and a self-parking car
  - 1989: Yamakawa: inverted pendulum
  - In the early '80: Yasunobu and Miyamoto from Hitachi began to work at an automated (i.e., without driver) subway.
  - In 1987 the Sendai subway began operation
  - This was a very spectacular application, which gave a strong impulse to pro-fuzzy sentiment
  - Fuzzy logic was incorporated into many consumer products: fuzzy washing machine, fuzzy camcorder, fuzzy systems in cars, etc

Outline

Examples of fuzzy sets

- The word *fuzzy* means imprecisely defined, blurred, confuse, vague, fluffy
- The term opposite to *fuzzy* is *crisp*.
- As an example of fuzzy sets, we can mention the age of a person
- We can consider that a person can belong to one of those age categories: *young*, *middle age* and *old*
- How can we define these age categories ?
- We can consider that definitely somebody is young at 20 years, middle age at 40, and old at 60 years.
- But how is the transition from one age category to another ?

Example: age categories

1. The threshold method:
   - We can assume that there are clear separators between these age categories
   - For example, somebody is young until 30 years, middle age between 30 and 50, and old after 50 years.
   - This would mean that before the 30 years birthday somebody is young, and that the very next day, the same person is not young any more, but middle age !
   - Similar, one day before being 50 years, somebody is not old, but he or she becomes old immediately after the 50 years birthday !
   - This sudden change of category is not according to human way of thinking !

Example: age categories

2. The method of partially overlapping regions
   - There is a region, for example between 25 and 35 years, where the degree in which somebody is young decreases from 100% to 0%
   - Between 25 and 35 years the degree in which somebody is middle aged increases from 0% to 100%, while between 45 and 55 years, this degree decreases from 100% to 0%
   - Between 45 and 55 years, the degree in which somebody is old increases from 0% to 100%
   - Of course, the limits of the regions are subjectives :-) !
   - This method is much more suited for human way of thinking

Examples of fuzzy sets

- The notions: *young*, *middle age* and *old* are fuzzy sets
- If we represent graphically these fuzzy sets using the method of overlapping regions, we will obtain a diagram that has on the abscissa the age (in years), and on the ordinate the degree in which a person of a certain age belongs to each of the fuzzy sets.
- This degree is called grade of membership or membership function, and it has values in the $[0, 1]$ interval.
- At the threshold method, the grade of membership has only two values: either 0, when an element does not belong to the fuzzy set, or 1, when it belongs.
- For fuzzy sets, an element belongs to a set *in a certain degree*.
- In this example the fuzzy sets *young*, *middle age* and *old* are continues, but the fuzzy sets can also be discrete (see in the next chapter).

Figure !

Fuzzy versus probabilistic uncertainty

- Both fuzzy logic and probability theory study imprecision, or uncertainty
- Since both work with real values between 0 and 1, many people confounds them
- We will try to clarify the difference between fuzzy logic and probabilities
- Probabilistic, random, or stochastic uncertainty, deals with the situation when the future state of a system is unknown, because it would be too complicated to determine it
  - For example, when we roll a die, it would be too complicated to determine what number (what face of the die) will be obtained
  - Similarly, if we shoot at a target, extract a ball from a bag (containing balls of different colors), etc

Fuzzy versus probabilistic uncertainty

- Fuzzy uncertainty is related to the subjective appreciation of the degree in which an element belongs to a certain category (cet).
  - It is nothing random in the age of a person, the imprecision is given by how we include a person of a certain age into an age category (e.g., young, old, etc)
  - Also, it is nothing fuzzy when we roll a die: we don't know what number we'll get, but that number is *crisp*, not fuzzy.
- The two types of imprecision can be combined - will be discussed later.

Fuzzy vs probabilities: an example

- For clarifying the distinction between fuzzy and probabilities, we give an example after Jerry Mendel [Men95]:
- If we say that a bottle contains a liquid (water) that is 90% potable (potable in an grade of 0.9), what interpretation do we give to this thing, from fuzzy logic point of view, and from probabilities point of view ?
- Probabilities:
  - The probability that the bottle contains potable water is 0.9
  - Which means that, if we have a very large number of such bottles, e.g. one million, in 900 thousands bottles will be absolutely potable (pure) water
  - But in the rest of 100 thousands bottles is another liquid, possible not potable, maybe poison, hydrochloric acid, etc !
- Fuzzy:
  - In that bottle it is not exactly what we would like to drink, (pure water or bottled spring water), but, if necessary, we can drink from the bottle without any danger
  - For example it is swamp water (water from a pond)

Types of fuzziness (fuzzy imprecision) [Zim91]

1. Intrinsic fuzziness
   - The meaning of a term (or of an expression) depends on the context and on the subjectivity of the person who makes the appreciation (the characterization)
   - Examples: tall men, good student, fast car, etc
   - If we refer to the term *tall man*, the meaning depends on the person who makes the appreciation (e.g. on the height of that person), but also on the context: if we refer to a basketball player the term *tall* has a different meaning than for an usual man.
2. Informational fuzziness
   - It could be possible to make a complete crisp description of the term, but it is too much information that has to be processed.
   - Example (Zimmermann): *creditworthy customer*: the appreciation depends on both the financial basis of the customer (assets, but also the difference between properties and debts), and his/her personality (mental and physical health, individual motivation, customer's disposition to obey business laws and and mutual agreements, etc)

Outline

Motivations of using fuzzy logic [Wan99]

After [Wan99]:

1. Real world is too complex for a precise description, so we have to use approximations (imprecison, or *fuzziness*) in order to obtain a tractable model
   - This is true, but it is not a unique characteristic of fuzzy approaches
   - In fact any model (mathematical or other type) of a real system uses approximations and imprecision !
2. Fuzzy logic offers a method to formulate *human knowledge* in a systematic (and mathematical) manner and to include it, together with other information (like mathematical models and information from measurements obtained from sensors), into engineering systems
   - This is indeed a unique characteristic of fuzzy logic, which distinguishes it from other approaches

Where/when to apply fuzzy logic ?

- When fuzzy logic appeared, scientists estimated that it will be successfully applied in humanities (linguistic, sociology, etc), but this didn't happen, partly because these domains were not prepared for a mathematical approach, not even fuzzy.
- Eventually, the most successful domain of application of FL was in engineering, more exactly in *control engineering*
  - This is because the control engineering domain was more mature and mathematized, compared to humanities
  - The improvement of FL in control engineering was the possibility to incorporate human experience in the cases where the mathematical models are not successfully (either a mathematical model cannot be obtained, or it can be obtained, but it is too complex to be solved)

Where/when to apply fuzzy logic ?

- Fuzzy logic can be efficiently applied in cases where we cannot obtain a precise mathematical model, or where the resulted model is too complex and cannot be solved, but where we can use the experience of a human operator in order to solve the problem.
- This experience is given as IF – THEN rules, not as complex mathematical models (e.g., with differential equations)
- Fuzzy logic offers the mathematical tools that transpose the IF THEN rules into precise formulas, which can be applied for the control of a system

Examples of application of fuzzy logic

1. An industrial chemical process (e.g., a cement kiln)
    - It is possible that the chemical reaction of that process to be well understood if the process is in a lab, but in an industrial plant the process can be influenced by factors like the lack of purity of the input substances, etc, hence making the industrial process more difficult to understand and to control.
    - However, a human operator, who does not necessarily understand that chemical reactions, is able to control the industrial process based on his/her experience.
    - This human operator is using rules like: IF the temperature is *too high* AND the pressure *increases* THEN *decrease strongly* the volume of the combustion gas.

Examples of application of fuzzy logic

2. Inverted pendulum: it is a benchmark in control engineering
   - The idea is to keep in balance a stick on the palm !
   - More rigorously, the problem can be formulated as: a cart of mass M which can move horizontally under control of an electronic servo system, has a pivot pole mounted on the cart. The pole of length l has on top a (ball of) mass m. The servo system acts with a horizontal force F (vector) over the cart, in order to keep the pole stable (vertical)
   - The system of differential equations that describes the inverted pendulum has no analytical solution, only numerical.
   - Which means that every time when something is changed in the input data (the mass of the cart or of the ball, the length of the pole, etc), the numerical solution has to be re-computed.
   - However, even a child can hold a stick on the palm, with some practice, and the child does not solve differential equations !!
   - Yamakawa implemented the fuzzy control of the inverted pendulum by computing the force F as a function of the angle θ (between the pole and the vertical axis), and the angular speed of the pole ($d\theta/dt$)

Where/when NOT to apply fuzzy logic ? ?

1. Firstly, when it is not necessary !
   - This means, if the problem can be solved using classic, precise methods, then we use these methods
2. Fuzzy logic is an heuristic method, hence it cannot be formally proved that a fuzzy solution will work !
   - In consequence, fuzzy logic will not be applied in cases where we must formally prove that the system will work in the given condition
   - Such situations appear in *safety critical domains*: nuclear plants, civil avionics, etc
   - However, in miliary aviation FL is applied !! There exist a type of fight plain which, in order to be more maneuvrable, it is not stable and which is stabilized using FL
3. If a system must evolve, or learn, FL cannot be applied by itself, but FL can be combined with, e.g., neural networks (NN) or with genetic algorithms (GA).

Outline

The structure of the FLA course

1. Introduction
2. Fuzzy. Operations with fuzzy sets
3. Extensions. The extension principle
4. Measure of fuzziness
5. Fuzzy relations
6. Fuzzy logic. Linguistic variables. **Fuzzy inference**
7. Fuzzy Logic Controllers (FLCs). Architectures of digital FLCs
8. Introduction to fuzzy arithmetic
9. Applications of fuzzy logic in computers and telecommunications (also at lab)

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Fuzzy logic systems for engineering: a tutorial.
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Li-Xin Wang.
A course in fuzzy systems.
Prentice-Hall press, USA, 1999.

H.-J. Zimmermann.
Fuzzy Set Theory – and Its Applications, Second, Revised Edition.
Kluwer Academic Publishers, 1991.