An Introduction to Fuzzy Logic

Largely stolen from:

http://www.courses.psu.edu/Materials/infsy565_lmm121/FUZZY_ML.PPT

(Penn State University)

Fuzzy Logic

DEFINITION: Fuzzy Logic
A branch of logic that uses ***degrees*** of membership
in sets rather than a strict true/false membership

Founded by : Lotfi Zadeh, a professor at the University of California at Berkeley in 1965.

Introduction

- Which one of the following rules does not belong with the others?
  - If the room is too warm, reduce the thermostat.
  - If the television is not loud enough, turn the volume knob to increase the volume.
  - If the light is on when you are leaving the room, turn the light off.
  - If the carpet is dirty, clean the carpet.

Answer

- Were you right?
  - If the room is too warm, reduce the thermostat.
  - If the television is not loud enough, turn the volume knob to increase the volume.
  - ***If the light is on when you are leaving the room, turn the light off.***
  - If the carpet is dirty, clean the carpet.
- Now the tough question --- why?

The Reason

- The reason -- the concept of "on/off" is deterministic. *A light is either on or off.*
- The other three are subjective:
  - Too warm? In who's opinion?
  - Loud enough? Depends on the program and the other noise in the room....
  - Dirty carpet? Redundant by definition!

Classical Expert Systems

- Rely too heavily on facts labelled with binary (either/or) truth or falsehood.
  - Subjective judgments differing among users (concepts of "warm" versus "cold", "hot", etc.)
  - Situation-dependent judgments ("too loud"....)
  - "Spot judgments" (just what is it that suddenly converts a clean carpet to a dirty one?)

Fuzzy Logic

- A tool to represent imprecise, ambiguous, and vague information
- Its power is the ability to perform meaningful and reasonable operations
- Fuzzy logic is not logic that is fuzzy -- it is a logic of fuzziness.
- It extends conventional Boolean logic to recognize partial truths and uncertainties.

Linguistic Variables

- Fuzzy logic quantifies and reasons about vague or fuzzy terms that appear in our natural language
- Fuzzy Terms are referred to as **linguistic variables**

Definition: Linguistic Variable
Term used in our natural language to describe some concept that usually has vague or fuzzy values

Examples:

Linguistic Variable	Typical Values
Temperature	hot, cold
Height	short, medium, tall
Speed	slow, creeping, fast

Example

- Temperature. We can use "cool", "warm", and "hot" to describe a room.
  - What you view as "warm" depends.
    - Ever have a thermostat argument with your family?
  - Degree of warmth is not linear.
    - Most people would view 13 degrees and 16 degrees as equally cool or not hot.
    - But, opinions vary more between 19 and 22 degrees.

Fuzzy Sets

- Fuzzy sets are used to provide a more reasonable interpretation of linguistic variables

- A fuzzy set assigns membership values between 0 and 1 that reflects more naturally a member's association with the set

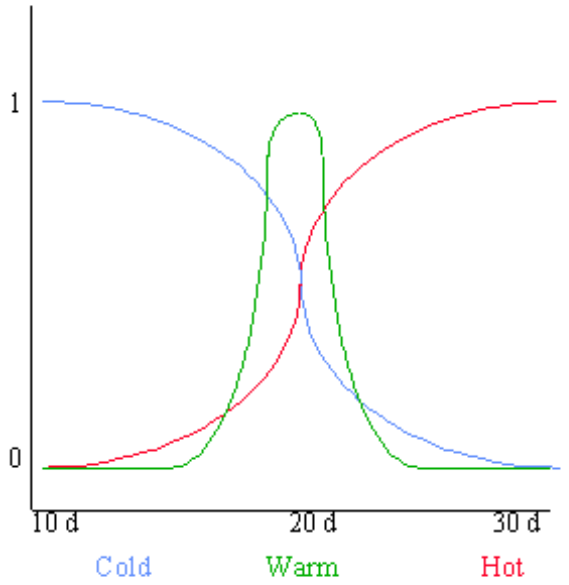
- A fuzzy set is an extension of the traditional set theory That generalizes the membership concept by using the Membership function that returns a value between 0 and 1 that represents the *degree of membership* an object x has to set A.

Example of a Fuzzy Set

- The graph shows how one might assign fuzzy values to various temperatures based on 20 degrees = room temp.
- Climate for a given temperature is defined as:

- 10 degrees = {1 c, 0 w, 0 h}
- 20 degrees = {0.5 c, 1 w, 0.5 h}
- 30 degrees = {0.15 c, 0.15 w, 0.85 h}

- Sum of fuzzy values not always 1 -- often it more than 1

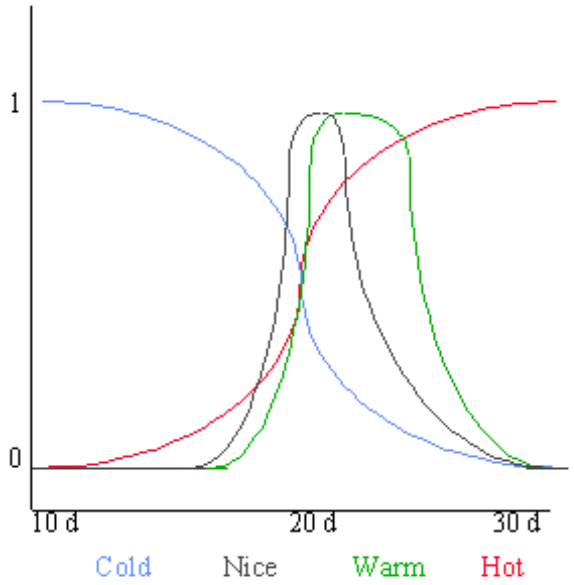


Example of a Fuzzy Set: Asymmetric Version

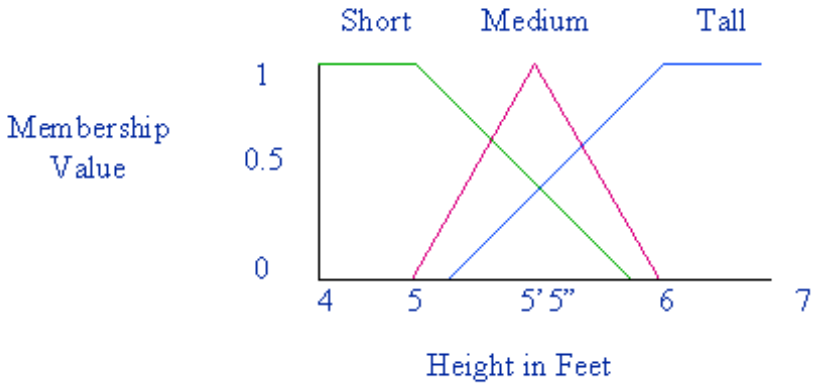
- Fuzzy sets are rarely symmetric.
- This might be considered by some to be a more accurate description of a room climate:
  - 10d = {1 c, 0 n, 0 w, 0 h}
  - 20d = {0.5 c, 1 n, 0.8 w, 0.5 h}
  - 30d = { 0.15 c, 0.7n, 0.95 w, 0.85 h}

Could also represent as:

WARM = (0/10, .8/20, .95/30)



Fuzzy Sets on Height



An individual at 5'5 feet would be said to be a member of "medium" persons with a membership value of 1, and at the same time, a member of "short" and "tall" persons with a value of 0.25.

Meanings of AND, OR, NOT in Fuzzy v. Boolean Logic

- Boolean Logic
- p AND q
  - ***TRUE*** if p and q are TRUE
  - otherwise ***FALSE***
- p OR q
  - ***FALSE*** if p and q are FALSE
  - otherwise ***TRUE***
- NOT p
  - ***FALSE*** if p is TRUE
  - ***TRUE*** if p is FALSE

- Fuzzy Logic
- p AND q
  - is ***TRUE***, and has the smaller fuzzy value of p and q
  - Ex., if p has a fuzzy value of 0.4 and q has a fuzzy value of 0.7, then (p AND q) has a fuzzy value of 0.4.
- p OR q
  - is ***TRUE***, and has the larger fuzzy value of p and q (0.7)
- NOT p
  - is ***TRUE***, and has the fuzzy value of 1 minus the value of p which would be 0.6

Employing Fuzzy Rules

- Conventional Boolean expert system - when a condition becomes true, the rule fires.
- Fuzzy expert system - if the condition is true to ***any*** degree, the rule fires.
  - Example rules:
    - If the room is hot, circulate the air a lot
    - If the room is cool, leave the air alone
    - If the room is cool and moist, circulate the air slightly

Fuzzy Expert System Process

1. Fuzzification -- convert data to fuzzy sets
2. Inference -- fire the fuzzy rules
3. Composition -- combine all the fuzzy conclusions to a single conclusion
   - Different fuzzy rules might conclude that the air needs different circulation levels
4. Defuzzification -- convert the final fuzzy conclusion back to raw data.

Applying the Fuzzy Process

Example of Room Temperature

- Fuzzification
  - Currently 30 degrees and 40 percent humidity
  - Temp. = { 0.15 cool, 0.15 warm, 0.85 hot }
  - Humidity = { 0.90 dry, 0.20 moist, 0.01 wet }
- Inference
  - Truth of the condition if each rule is measured.
  - Conclusion is true based on the degree of the condition (many methods for determining this degree).
  - Ex. If room is hot and moist, then air requires much circ.
    - Hot=.85, Moist=0.20,
    - Therefore much (using straight method)=0.20

Applying the Fuzzy Process

- Composition
  - Combine all the findings into one fuzzy set for the thermostat.
  - Ex. There are 9 rules in our expert system
    - Three say that the air requires minimal circulation
    - Two say that the air requires slight circulation
    - Four say that the air requires much circulation
    - No rules were bypassed
  - Therefore, our rules produce 9 different conclusions.

Primary Uses of Fuzzy Logic

- Real-time Controllers. Fuzzy logic can efficiently control mechanical or environmental processes.
  - Cruise control in cars: determines ambient acceleration or deceleration and provides countering application of gas and brake.
  - Ship boilers: can monitor temperature, pressure, and chemical content to ensure stability.
  - Smoke detectors, motion detectors, food quality, environmental monitoring, AI, dishwashers

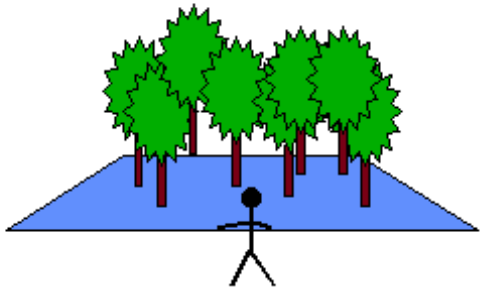
Primary Uses of Fuzzy Logic

- More Real-Time Control Examples:
  - Satellite tracking:
    - Satellite dish can use fuzzy logic to identify when and in which direction a geocentric satellite deviates.
  - Camcorder stabilizers:
    - Fuzzy logic can identify when the subject of a video shot is moving versus when motion is caused by the cameraman's vibrations.

  And hundreds of other inventions….

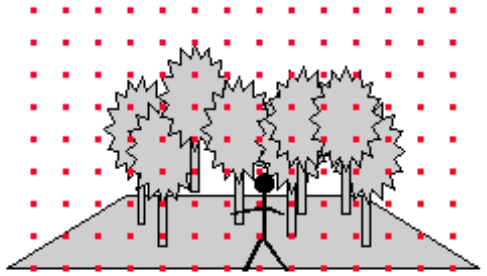
Camcorder Example

- Stabilizer operates by attempting to identify the subject versus the background. Using this, we can determine whether it is the subject and/or background that is moving, or if it is the holder of the camcorder that is moving.



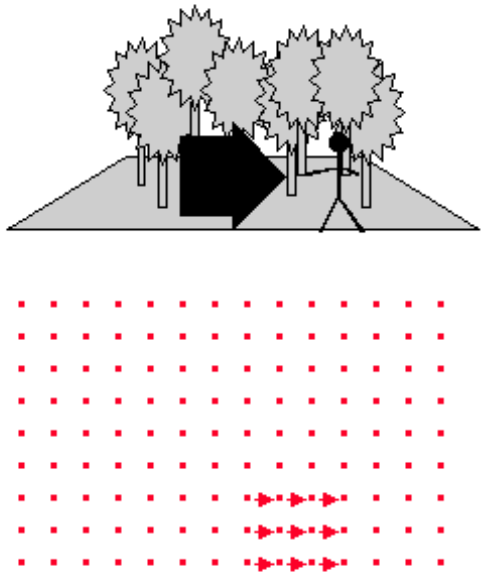
Camcorder Example

- One method is to use a set of input points in a grid and poll those points twice per second.
- Between pollings, the camcorder deduces which direction the objects have shifted....



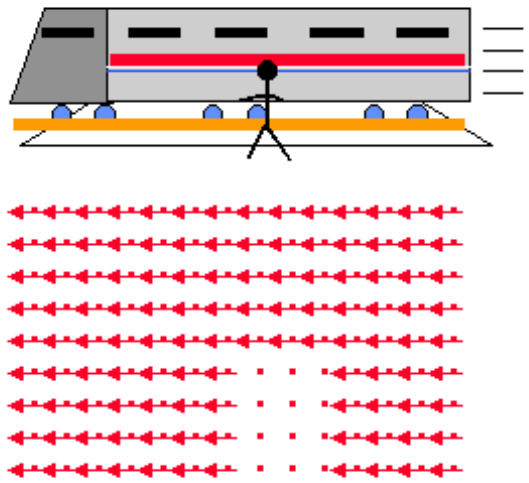
Camcorder Example

- If the subject moves, then the camcorder detects a shift among points in a localized region. If this region is somewhere in the lower center of the shot, then the chances that it is a subject-move is even greater.



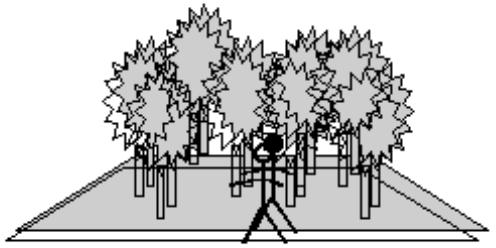
Camcorder Example

- However, if it appears that a significant amount of the screen is shifting yet a localized region is standing still, then the camcorder can deduce that the background is moving while the subject is not.



Camcorder Example

- If it appears that the entire picture has shifted and that there is no distinction of subject or background, the camcorder can identify this and deduce that the camera-holder's hand has shifted. The camcorder can then compensate for the shift.



Camcorder Example

- The fuzzy logic would work as follows:
  1. Fuzzification: The fuzzy set could be: red, orange, yellow, ..., purple, black, and white. Each pixel is identified as having a degree of each of these colors based on the levels of red, green, and blue detected.
  2. Inference: First layer of rules deduce where the shifts occur among single pixels. Second layer of rules clump together like shifts into shifted regions.
  3. Composition: Based on the collected evidence, deduce overall shift of camcorder (slight up-down, slight left-right, ...)
  4. Defuzzification: Translate the overall shift of camcorder into compensatory action (slight up-down: shift picture up 1 pixel...)

Example of "Belief System"

Used by military computers during war:

- Fuzzy Identify Friend or Foe (IFF) System:
  - Plane identifies = OK, we know the result
  - Plane fails to identify = Why?
    - Malfunction in the IFF
    - Malfunction in the aircraft transponder
    - No IFF present on the aircraft
    - Jamming of the IFF signal
    - Radio silence

"Belief Systems" and Fuzzy Logic

- Failure to Identify can mean = "we believe it is hostile, with a strength of belief 0.7"
- Evidence from other sources (tracking, visuals, etc.) contribute to the support or refutation of belief (using mathematical models).
- Final belief might translate to a stronger or weaker position that the aircraft is hostile.

Other fuzzy belief systems are being tested by artificial intelligence researchers.

Strengths

- Strengths of Fuzzy Logic systems:
  - Very efficient for simple applications
  - Easy to adjust
    - Can individualize the fuzzy sets to reflect differing tastes or needs.
  - Provides more robust capability for vague or uncertain information
    - Big help for engineers in real life situations

Weaknesses

- Limitations of Fuzzy Logic:
  - Increases complexity of the expert system
    - For large systems, fuzzy logic might be horribly inefficient -- combining with conventional logic is often difficult
  - Validation and verification can be complex
    - Fuzzy fan: simple -- does the user like the climate?
    - Ship's boiler: tough -- might there be conditions where fuzzy controller causes instability or chaos?