Fuzzy Logic

“Soft Computing”

- Neural networks
- Fuzzy logic
- Neuro-Fuzzy control
- Genetic algorithms
- Swarm Intelligence
Example Reference

Neuro-Fuzzy and Soft Computing: A Computational Approach to Learning and Machine Intelligence


Fuzzy Logic History

- 1920, Jan Łukasiewicz, Multi-valued logic
- 1937, Max Black: Vagueness, an exercise in logical analysis, Phil. of Science, 4, 427-455
- 1967, Lotfi Zadeh, UCB: Fuzzy Sets, in Information and Control J.
- 1974, E.H. Mamdani, M. Sugeno: Control Systems
- 1980’s-90’s: Bart Kosko, USC
Fuzzy Founders/Followers

Jan Łukasiewicz (1878-1956)  Lotfi Zadeh (1921-)  Bart Kosko (1960-)

Prof. Zadeh:

As the complexity of a system increases,
our ability to make precise and yet significant statements about its behavior diminishes
until a threshold is reached beyond which precision and significance (or relevance)
become almost mutually exclusive characteristics.
“A Precise Logic of Imprecision”

http://www.youtube.com/watch?v=2ScTwFCeXGo

Fuzzy Journals

- IEEE Trans. on Fuzzy Systems
- International J. of Approximate Reasoning
- Intelligent and Fuzzy Systems
- Journal of Cybernetics
A Few Fuzzy Logic Applications

- Subway ride smoothness control
- Camcorder auto-focus and jiggle control
- Braking systems
- Saturn automobile transmission
- Copier quality control
- Rice-cooker temperature control

Neuro Fuzzy Rice Cooker
(Zojirushi Corporation)

The Neuro Fuzzy® Rice Cooker & Warmer features advanced Neuro Fuzzy® logic technology, which allows the rice cooker to 'think' for itself and make fine adjustments to temperature and heating time to cook perfect rice every time. The spherical inner cooking pan and heating system allows the heat to distribute evenly and cook rice perfectly. It also features different settings for cooking white rice, sushi rice, brown rice and porridge. Other features
Anti-Lock Brakes

- A typical ABS is composed of a central electronic unit, four speed sensors (one for each wheel), and two or more hydraulic valves on the brake circuit.

- The electronic unit constantly monitors the rotation speed of each wheel. When it senses that any number of wheels are rotating considerably slower than the others (a condition that will bring it to lock[1]) it moves the valves to decrease the pressure on the braking circuit, effectively reducing the braking force on that wheel.

- The wheel(s) then turn faster and when they turn too fast, the force is reapplied. This process is repeated continuously, and this causes the characteristic pulsing feel through the brake pedal.

- A typical anti-lock system can apply and release braking pressure up to 20 times a second.

Air-Conditioning System
(Mitsubishi)

Problem description:
Industrial air-conditioning system shall be able to react flexibly to changing ambient conditions

Realization:
50 rules
6 linguistic variables
Resolution: 8 bit
Input variables: room temperature, wall temperature and temporal evaluation of these signals.

Development:
4 days to create the prototype.
20 days for testing and integration.
80 days for optimization with real test objects.
Implementation as pure software solution on standard microcontroller.

Results:
Reduction of starting processes down to 40 percent of the standard solution.
Sustaining of the temperature even with interference factors (like open window, etc.) substantially improved.
Fewer sensors required, Established energy saving by testing: 24 percent.
More Commercial Applications of Fuzzy Logic

- Automatic control of dam gates for hydroelectric-powerplants (Tokyo Electric Power)
- Camera-aiming for the telecast of sporting events (Omron)
- Cruise-control for automobiles (Nissan, Subaru)
- Positioning of wafer-steppers in the production of semiconductors (Canon)
- Prediction system for early recognition of earthquakes (Inst. of Seismology Bureau of Metrology, Japan)
- Controlling of subway systems in order to improve driving comfort, precision of halting and power economy (Hitachi)

Fuzzy Silver Bullet?

- Fuzzy logic may not provide any new mechanisms that weren’t there before.
- It provides a viewpoint, or additional intellectual layer, that helps expedite problem solving.
- Analogy: Object-Oriented Programming didn’t create any new computable functions, it just made creating certain kinds of applications easier.
Fuzzy Set Basics

- Classical (“crisp”) sets:
  - Membership in a set is all or nothing
  - Characteristic function $c_S$: Universe $\rightarrow \{0, 1\}$
  - $c_S(x) = 1$ iff $x \in S$

- Fuzzy sets:
  - Membership in a set is a degree
  - Membership function $c_S$: Universe $\rightarrow [0, 1]$

Linguistic Characterizations of Degree of Membership

- Consider the set of “hot” days in Claremont in 2012.

- Was Oct. 29 “hot”? It might have been called one of:
  - “very hot”
  - “sort of hot”
  - “not hot”

- The answer depends on the observer, time, etc.
Sounds similar to probability, but isn’t

- Probability deals with *uncertainty* or *likelihood* of an event or condition.

- Fuzzy logic deals with *ambiguity*, *vagueness* of description, meaning.

Further explanations:


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**FUZZINESS VS. PROBABILITY**

BART KOSKO

*Electrical Engineering Department, Signal and Image Processing Institute, University of Southern California, Los Angeles, California 90089-0272, USA*

*(Received 14 November 1989; in final form 2 March 1990)*

So far as the laws of mathematics refer to reality, they are not certain. And so far as they are certain, they do not refer to reality.

Albert Einstein

Fuzziness is explored as an alternative to randomness for describing uncertainty. The new sets-as-points geometric view of fuzzy sets is developed. This view identifies a fuzzy set with a point in a unit hypercube and a nonfuzzy set with a vertex of the cube. Paradoxes of two-valued logic and set theory, such as Russell’s paradox, correspond to the midpoint of the fuzzy cube. The fundamental questions of fuzzy theory—How fuzzy is a fuzzy set? How much is one fuzzy set a subset of another?—are answered geometrically with the Fuzzy Entropy Theorem, the Fuzzy Subsethood Theorem, and the Entropy-Subsethood Theorem. A new geometric proof of the Subsethood Theorem is given, a corollary of which is that the apparently probabilistic relative frequency $n_x/N$ turns out to be the deterministic subsethood $S(X,A)$, the degree to which the sample space $X$ is contained in its subset $A$. So the frequency of successful trials is viewed as the degree to which all trials are successful. Recent Bayesian polemics against fuzzy theory are examined in light of the new sets-as-points theorems.

INDEX TERMS: Probability Theory, fuzzy set theory, fuzzy subsethood, geometry of fuzzy sets.
Fuzzy Membership

Are these disks, cylinders, or rods?

In other words, which object is a member of class disk, etc.?

Fuzzy Membership

Which of these is a pile of sand?

Where does the line get drawn about what is or is not a “pile”?
“Computing with Words”

http://www.youtube.com/watch?v=P8wY6mi1vV8

Membership function plots

is a pile

Player number 23 is tall to degree 0.65

grains of sand
Crisp vs. Fuzzy Membership Functions

is a pile

0 1

10 100 1000 10000 100000

fuzzy crisp

grains of sand

More Crisp vs. Fuzzy Membership Functions

Crisp

Fuzzy

universe of possibilities

“grade” of membership

Note: Universe can be continuous or discrete, ordered or unordered.
Some of Matlab’s Builtin Membership Functions

Fuzzification: Degree of Membership derivable quantitatively from attributes

- (Inspired by Prof. Zadeh)
- **Is X a goth?** (Degree of membership = gothicity)
  - Always wears black: add .2 to gothicity
  - Wears a cape: add .1
  - Black nail polish: add .1
  - Has a pet vampire bat: add .1
  - Wears chains: add .05*number of chains
  - Wears amulets: add .03*number of amulets
  - Wears spikes around neck: add .3
  - Piercings: add .05*number of piercings
  - Frequents death raves: add .1*frequency (in DRPM)
    ...
Defuzzification:
Those agree/disagree questionnaires

Degree of membership translates into numbers:

1. This course was effectively organized:
   ___ strongly disagree ___ disagree ___ neutral ___ agree ___ strongly agree

2. This course stimulated my interest in the subject matter:
   ___ strongly disagree ___ disagree ___ neutral ___ agree ___ strongly agree

   etc.

Ultimately a number is produced that will, e.g., be someone’s salary.

Possible Application:

Those agree/disagree questionnaires

Degree of membership translates into numbers:

1. This course was effectively organized:
   ___ strongly disagree ___ disagree ___ neutral ___ agree ___ strongly agree

2. This course stimulated my interest in the subject matter:
   ___ strongly disagree ___ disagree ___ neutral ___ agree ___ strongly agree

   etc.

Ultimately a number is produced that will, e.g., be someone’s salary.
Linguistic Modifiers

Example: Composites of Young and Old
**Discrete Universe Examples**

**Ideal** number of courses to take
(ordered universe)

**Desirable** place to live
(unordered universe)

**Fuzzy-Set Operations**
expressed using membership functions

\[ c_{A \cup B}(x) = \max(c_A(x), c_B(x)) \]
\[ c_{A \cap B}(x) = \min(c_A(x), c_B(x)) \]
Fuzzy intersection (for the continuous case) is a “t-norm”

A t-norm is a function $T: [0, 1] \times [0, 1] \rightarrow [0, 1]$ satisfying:

- Commutativity: $T(a, b) = T(b, a)$
- Monotonicity: $T(a, b) \leq T(c, d)$ if $a \leq c$ and $b \leq d$
- Associativity: $T(a, T(b, c)) = T(T(a, b), c)$
- The number 1 acts as identity element: $T(a, 1) = a$

cf. Wikipedia article for more examples and results

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Fuzzy Operator Example

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M. Berthold, Uni Konstanz: Tutorial
Operator Example: Membership contours

M. Berthold, Uni Konstanz: Tutorial

Fuzzy Complement

$c_{A'}(x) = 1 - c_A(x)$.
Which Set-Theoretic Rules Hold?

\[
\begin{align*}
A \cup B &= B \cup A \\
A \cap B &= B \cap A \\
(A \cup B) \cup C &= A \cup (B \cup C) \\
(A \cap B) \cap C &= A \cap (B \cap C) \\
(A \cup B) \cap C &= (A \cap C) \cup (B \cap C) \\
(A \cap B) \cup C &= (A \cup C) \cap (B \cup C) \\
(A \cap B)' &= A' \cup B' \\
(A \cup B)' &= A' \cap B'
\end{align*}
\]

etc.

Fuzzy Anomaly?

The intersection of a set with its complement is not necessarily empty.

\[
c_A(x) = 1 - c_A(x).
\]
Fuzzy Implication

There is no single standard. A variety of versions exists:

- **Larsen:** \( x \rightarrow y = xy \)
- **Lukasiewicz:** \( x \rightarrow y = \min(1, 1-x+y) \)
- **Mamdani:** \( x \rightarrow y = \min(x, y) \)
- **Standard strict:** \( x \rightarrow y = x \leq y ? 1 : 0 \)
- **Goedel:** \( x \rightarrow y = x \leq y ? 1 : y \)
- **Gaines:** \( x \rightarrow y = x \leq y ? 1 : y/x \)
- **Kleene-Dienes:** \( x \rightarrow y = \max(1-x, y) \)
- **Kleene-Dienes-Luk:** \( x \rightarrow y = 1-x+xy \)

If we use an equation from classical logic:

\[ x \rightarrow y = (\neg x) \lor y \]

we would be led to:

\[ x \rightarrow y = \max(1-x, y) \]

the Kleene-Dienes version.
Fuzzy Query Languages

- FSQL (Fuzzy SQL)
  - [Link](http://www.lcc.uma.es/~ppqq/FSQL/)
  - Example: Give all persons with fair hair (in minimum degree 0.5) who are possibly taller than label $Tall$ (in minimum degree 0.8):
    ```sql
    SELECT * FROM Person
    WHERE Hair FEQ $Fair$ Threshold 0.5 AND Height FGT $Tall$ Threshold 0.8
    ```

- SQLf
- FQuery

Linguistic Rules

- In Fuzzy Logic, rules are expressed **qualitatively and linguistically**, rather than quantitatively.

- The result is qualitatively understandable, yet can be **interpreted quantitatively** when desired.

- The interpretive framework can be **adjusted to suit**.
Example: Egg-Boiling Robot

http://www.youtube.com/watch?v=J_Q5X0nTmrA

Example: Car Parking

http://www.youtube.com/watch?v=WUJLqKkZTw
Example: Game AI

http://www.youtube.com/watch?v=_YMgaVT3E44

Mamdani and Sugeno

Ebrahim MAMDANI
Electrical and Electronic Engineering Professor,
Imperial College of Science, Technology and Medicine, University of London

Michio Sugeno
Head of the Laboratory for Language-Based Intelligent Systems
Brain Science Institute, RIKEN
Japan
Fuzzy If-Then Rules

• Mamdani style (purely linguistic)
  If pressure is high then volume is small
  ![Graph showing Mamdani style with inputs high and small]

• Sugeno style (uses equations on rhs)
  If speed is medium then resistance = 5*speed
  ![Graph showing Sugeno style with inputs medium and resistance = 5*speed]

Fuzzification/Defuzzification in Function Implementation

Over-Simplified Picture

- Fuzzify
  - Crisp value: 98°
  - Linguistic value: Kind of Hot
- Transformation on Linguistic Values
  - Linguistic value: Lower (setting)
- Defuzzify
  - Crisp value: -.3 volt
Fuzzification/Defuzzification in Function Implementation

More-Realistic Picture (multiple applicable rules)

Mamdani Control Model
(next several slides)
Pole-on-Cart (Inverted Pendulum) Example

Problem

- Determine a fuzzy transformation adequate to specify the pole-cart controller.
Pole-on-Cart Example

- Speed of cart

The speed can have non-zero membership in more than 1 category.

Pole-on-Cart Balancing Example

- Angle of pole
Pole-on-Cart Balancing Example

- Angular velocity of pole

![Graph showing angular velocity and angle]

Transformation Rep. by “Fuzzy Rule Base” (Kosko: FAM = Fuzzy Associative Memory)

Example of a fuzzy-logic rule represented in this table:
“If the angular velocity is pos. low and the angle is zero, then set the speed at low.”

<table>
<thead>
<tr>
<th>angular velocity</th>
<th>angle</th>
<th>neg. high</th>
<th>neg. low</th>
<th>zero</th>
<th>pos. low</th>
<th>pos. high</th>
</tr>
</thead>
<tbody>
<tr>
<td>neg. high</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>neg. low</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>zero</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pos. low</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pos. hi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Control speed as a function of angle and angular velocity
Inference in a Mamdani-style Fuzzy System

- Start with quantitative input data
- **Fuzzify** the data
- Derive conclusion based on fuzzy data
- **De-fuzzify** the conclusion to get quantitative output

Fuzzification

In this case, the actual angle is a mixture of zero and pos. low.
Fuzzification

Here the actual angular velocity is a mixture of zero and neg. low.

Multiple Applicable Rules:

- angle is a mixture of zero and pos. low.
- angular velocity is a mixture of zero and neg. low

Three entries in the rule base are applicable.
We must determine how to combine them.
Determine the **degree** to which each rule is applicable.

- Consider the rule
  
  "If angle is zero and angular velocity is zero, the **speed** is zero".

  Suppose the actual value belongs to the fuzzy set zero to a **degree** of 0.75 for "angle" and to a **degree** of 0.4 for "angular velocity".

- Since this is an **AND** operation, the **minimum** criterion is used. (For **OR**, the maximum would be used.)

- The fuzzy set **zero** of the variable "**speed**" is **cut** at the **min** 0.4 and the output patches are shaded up to that value.

**Using min combination for AND**
((This is for one of three speed rules: zero.)

![Diagram showing the combination of fuzzy sets for angle, angular velocity, and speed.](image)
Similarly, for each of the (3) applicable rules we get a cut for inferred speed.

We then combine the results of the three rules to get an output fuzzy set.
Defuzzification

To actually set the speed, we need a number, not a fuzzy set. Various rules can be used to get the number. The most common one is to use the centroid of the fuzzy set.

![Diagram showing speed and centroid](image)

quantitative value of speed found at centroid

Centroid Review

Centroid (wrt x)

The point at which the areas on either side are equally balanced.

\[
\text{Centroid (wrt x)} = \frac{\int_a^b x f(x) \, dx}{\int_a^b f(x) \, dx} = \frac{\int_a^b f(x) \, dx}{\int_a^b f(x) \, dx}
\]
Control Surface for a **Pole Balancer**:  
Force = f(Angle, AngularVelocity)

An example worked in detail:

- Chapter 3 of “Fuzzy Logic for Just Plain Folks”: Let's Build a Fuzzy Logic Control System


![Figure 3. Motor Speed Control System](Image)
Rules for the Do-it-yourself Controller

Examples: Matlab’s Defuzzification Rules

mom = mean of max
lom = largest of max
som = smallest of max
Fuzzy Truck-Backer Applet
/cs/cs152/fuzzy/truck

An example simulation
A different example simulation

Control Surface for a Truck-Backer
Another Truck Backer using only 9 Rules

Kong & Kosko compared Fuzzy vs. Neural Controllers
Kong & Kosko
Derived Controller Functions

Fuzzy

- Regular path followed
- “Trained” by common-sense hand-coded rules
- Light-weight controller (comparisons and additions only)

Neural

- Sometimes followed irregular path
- Training time-consuming
- Controller computationally intensive

Kong & Kosko
Konclusions
Matlab Fuzzy Ball-Juggler Demo

Ball-Juggler Rule View
A typical rule based on crisp logic:

```c
DetermineAction()
    if(health < 10)
        if(ammo < 5) return ESCAPE
        if(ammo >= 5 && ammo < 20) return CAUTIOUS
        else return NORMAL
    else if(health >= 10 && health < 20)
        if(ammo < 5) return CAUTIOUS
        if(ammo >= 5 && ammo < 20) return NORMAL
        else return ATTACK
    else
        if(ammo < 5) return NORMAL
        if(ammo >= 5 && ammo < 20) return ATTACK
        else return FULL_ATTACK
```

Fuzzy rule-base table (example):

```
<table>
<thead>
<tr>
<th>Ammo</th>
<th>1.0</th>
<th>Low</th>
<th>Then Escape</th>
<th>Medium</th>
<th>Then Defence</th>
<th>High</th>
<th>Then Attack</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health</td>
<td>1.2</td>
<td>Low</td>
<td>Then Escape</td>
<td>Medium</td>
<td>Then Defence</td>
<td>High</td>
<td>Then Attack</td>
</tr>
<tr>
<td>Enemies in sight (I)</td>
<td>1.0</td>
<td>Many</td>
<td>Then Escape</td>
<td>Some</td>
<td>Then Defence</td>
<td>Few</td>
<td>Then Attack</td>
</tr>
</tbody>
</table>
```
Possible Fuzzy-NN Connections

- Fuzzy logic based tuning of neural network training parameters.
- Fuzzy logic criteria for increasing a network size.
- Representing fuzzification, fuzzy inference and defuzzification through multi-layers feed-forward connectionist networks.
- Realizing fuzzy membership through clustering algorithms in unsupervised learning in SOMs and neural networks.
- Deriving fuzzy rules from trained RBF networks.

Applications of Fuzzy Logic to Training MLP Neural Networks

- Control of variable learning rate in backpropagation (Choi, et al.):
  - Let CE denote Change of Error.
  - Let CCE denote Change of CE.
- Fuzzy Rules:
  - If CE is small with no recent sign changes, then increase LR.
  - If CE has recent sign changes, then decrease LR.
  - If CE is small, and CCE is small with no recent sign changes, then increase LR and momentum.
Application of Neural Networks to Fuzzy Logic

- Learned fuzzy rules for forecasting gas demand.
- Used backpropagation network with five layers.
- The input layer contains two nodes - temperature and the month and the output layer is the gas demand figure.
- Fuzzy rules were then extracted from the net.

Sugeno Control Model

- Extends Mamdani model
- Fuzzy part is still in antecedent of rules, which are used for selection
- Consequent of rules is more complex: some function (e.g. polynomial) of input variables
Fuzzy Inference System Using Sugeno-Style Rules

If speed is low then resistance = 2
If speed is medium then resistance = 4*speed
If speed is high then resistance = 8*speed

Rule 1: w1 = .3; r1 = 2
Rule 2: w2 = .8; r2 = 4*2
Rule 3: w3 = .1; r3 = 8*2

Resistance = \( \frac{\sum (w_i r_i)}{\sum w_i} \)
= 7.12

Example: 1-input Sugeno

- Rules:
  - If X is small, then Y = 0.1X + 6.4.
  - If X is medium, then Y = -0.5X + 4.
  - If X is large, then Y = X-2.

- The following 2 slides indicate the results of combining these rules using crisp vs. fuzzy logic.
demo sug1 (crisp)
(in /cs/cs152/matlab/soft)

(a) Antecedent MFs for Crisp Rules
(b) Overall IO Curve for Crisp Rules

---

demo sug1 (fuzzy)

(c) Antecedent MFs for Fuzzy Rules
(d) Overall IO Curve for Fuzzy Rules

---
Example: 2-input Sugeno

- Rules:
  - If X is small and Y is small, then \( Z = -X + Y + 1 \).
  - If X is small and Y is large, then \( Z = -Y + 3 \).
  - If X is large and Y is small, then \( Z = -X + 3 \).
  - If X is large and Y is large, then \( Z = X + Y + 2 \).

MFs for demo sug2 (2-input)
Control surface for sug2

Tsukamoto model

- Aggregate rule outputs by a \textit{weighted average}, rather than by defuzzification.
Example of Hybrids: ANFIS
(Adaptive Neuro-Fuzzy Inference System)

- Developed by J.-S. R. Jang
- Uses Sugeno or Tsukamoto models
- Similar to Radial Basis Function network

\[
\begin{align*}
  z_1 &= p_1 x + q_1 y + r_1 \\
  z_2 &= p_2 x + q_2 y + r_2 \\
  z &= \frac{w_1 z_1 + w_2 z_2}{w_1 + w_2}
\end{align*}
\]

• ANFIS (Adaptive Neuro-Fuzzy Inference System)
ANFIS: Parameter ID

- Hybrid training method

\[ x \xrightarrow{\text{forward pass}} \sum w_i^i z_i \xrightarrow{\text{backward pass}} z \]

<table>
<thead>
<tr>
<th></th>
<th>forward pass</th>
<th>backward pass</th>
</tr>
</thead>
<tbody>
<tr>
<td>MF param.</td>
<td>fixed</td>
<td>steepest descent</td>
</tr>
<tr>
<td>(nonlinear)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coef. param.</td>
<td>least-squares</td>
<td>fixed</td>
</tr>
<tr>
<td>(linear)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Pseudo-outer product based fuzzy neural network (POPFNN)

Applied to Fingerprint Classification by Zhou & Quek, 1966
**POPFNN Structure**

| Layer 1: Linguistic nodes: Inputs are non-fuzzy linguistic variables. |
| Layer 2: Conditional layer: Convert inputs to fuzzy values. |
| Layer 3: Rule nodes (fuzzy rule base) |
| Layer 4: Consequence layer: Combine rule outputs. |
| Layer 5: Output classification/confidence. |
3 Learning Phases in POPFNN

- Self-organization: Initialize membership functions by determining widths and centroids.
- POP learning: Identify relevant fuzzy rules, based on Hebbian principle.
- Supervised learning: Fine-tuning using backpropagation.

Examples of POPFNN Rules for Fingerprint Authentication

Rule 1: if $x_0$ is large and $x_1$ is large, then ‘fingerprint is authentic’ is 1.000000 true;
Rule 2: if $x_0$ is median and $x_1$ is median, then ‘fingerprint is authentic’ is 0.959801 true; and
Rule 3: if $x_0$ is small and $x_1$ is small, then ‘fingerprint is authentic’ is 0.618143 true.
Critiques of Fuzzy Logic

- Google on the title for several examples.
- One of the harder ones follows (next slide).
- You should read the full critique before going gung-ho Fuzzy Logic for control systems.
- Yet FL will no doubt have its uses in information processing.

Contrary Opinion

WHY I DESPISE FUZZY FEEDBACK CONTROL,
by Michael Athans (EECS Prof. at MIT)

also http://fuzzy.iau.dtu.dk/download/athans99/index.htm

Asserts, among other things, that fuzzy control only shown applicable to trivial (SISO) systems, not more complex (MIMO) systems.
Athans’ Asserted Shortcomings of Fuzzy Controllers

- Fuzzy rules just generate nonlinear static functions.
- Performance specifications “vague” or nonexistent.
- Cannot generate “differential equation” controller rules.
- Not easy to differentiate noisy sensor signals by finite differencing, as almost always done in fuzzy applications.
- No utilization of dynamic filtering (e.g. Kalman filtering).
- Athans “has never seen a multiple-input multiple-output (MIMO) fuzzy control application”.
- Combinatorial complexity for high-order and multivariable applications.

Prof. Zadeh responds
(http://www.lavoisier.fr/notice/gbEKO23RXA2OSSLO.html)

“Zadeh said that Athans had painted quite a picture, but one in which he could not recognize fuzzy control, and that the picture was not connected to reality. He immediately noted the large number of books on fuzzy control and stated that if the audience members took it upon themselves to read these books, they would see that many of the issues Athans had brought up were resolved by these texts. In the question-and-answer period that followed, the fuzzy control panel members asked questions of Athans and the conventional control panel members asked questions of Zadeh. As time remained, each participant fielded one additional question. Following the question-and-answer period, the participants made their 3-minute closing statements. The debate then ended with a handshake between the two old friends.”