Sterowanie rozmyte

What is fuzzy?

- A dictionary definition
  1. Of or resembling fuzz.
  2. Not clear; indistinct: *a fuzzy recollection of past events.*
  3. Not coherent; confused: *a fuzzy plan of action.*
  4. Covered with fuzz.
- And so what is a Fuzzy Set?
  - a not clear Set?

Fuzzy Sets

- Proposed by Ladeh Zadeh in 1965
  - , *"Fuzzy sets," Information and Control, vol. 8, pp. 338--353, 1965.*
- A generalization of set theory that allows partial membership in a set.
  - Membership is a real number with a range [0, 1]
  - Membership functions are commonly triangular or Gaussian because ease of computation.
  - Utility comes from overlapping membership functions – a value can belong to more than one set

Precise versus fuzzy statements

- Sally is tall
  - Sally if 5’10”.
  - If Sally is on the basket ball team:
    Sally is 6’4”.
- It is cold outside.
  - In the winter
    It is 12° F outside.
  - In the summer:
    It is 60° F outside.
  - In the summer in northern Canada
    It is 30° F outside.

Fuzzy Set Definition

The definition of a fuzzy set is given by the membership function

$$\mu_{\tilde{F}} : U \to [0,1]$$

elements of the universe of discourse *U*, can belong to the fuzzy set with any value between 0 and 1.

The degree of membership of an element u

$$0 \le \mu_{\tilde{F}}(u) \le 1$$

when the universe of discourse *U*, is discrete and finite, it is given for a fuzzy set *A* by

$$\tilde{A} = \frac{\mu_{\tilde{A}}(x_1)}{x_1} + \frac{\mu_{\tilde{A}}(x_2)}{x_2} + \ldots = \sum_i \frac{\mu_{\tilde{A}}(x_i)}{x_i}$$

Fuzzy Set Operations

The union of two fuzzy sets $\underset{\sim}{C} = \underset{\sim}{A} \cup \underset{\sim}{B}$ is defined by

$$\mu_{\underset{\sim}{C}}(x) = \max\left[\mu_{\underset{\sim}{A}}(x), \mu_{\underset{\sim}{B}}(x)\right]$$

The intersection of two fuzzy sets $\underset{\sim}{C} = \underset{\sim}{A} \cap \underset{\sim}{B}$ is defined by

$$\mu_{\underset{\sim}{C}}(x) = \min\left[\mu_{\underset{\sim}{A}}(x), \mu_{\underset{\sim}{B}}(x)\right]$$

The complement of fuzzy set A, C is defined by

$$\mu_{\underset{\sim}{C}}(x) = 1 - \mu_{\underset{\sim}{A}}(x)$$

Properties of Set Operations

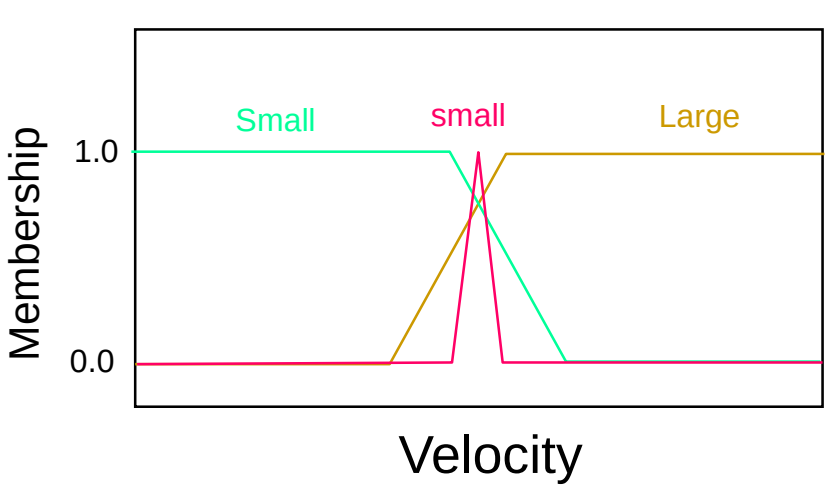
Most of the properties that hold for classical sets (e.g., commutativity, associativity and idempotence) hold also for fuzzy sets except for following two properties:

Law of contradiction $\underset{\sim}{A} \cap \overline{\underset{\sim}{A}} \neq \phi$

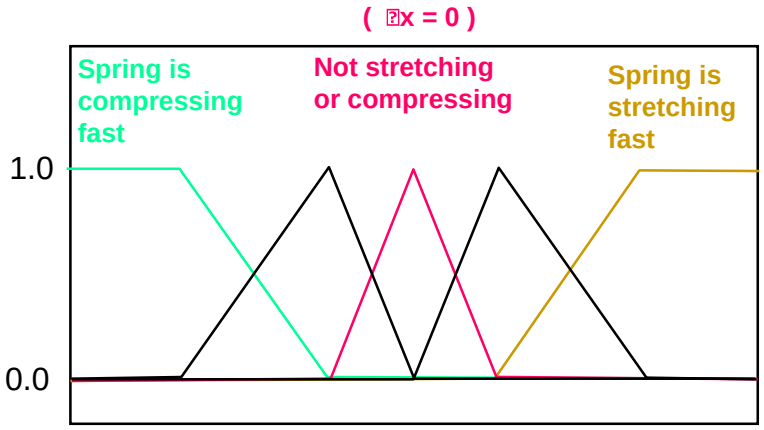
the intersection of a fuzzy set and its complement results in a fuzzy set with membership values of up to ½ and thus does not equal the empty set (as in the case of classical sets)

Law of excluded middle $\underset{\sim}{A} \cup \overline{\underset{\sim}{A}} \neq U$

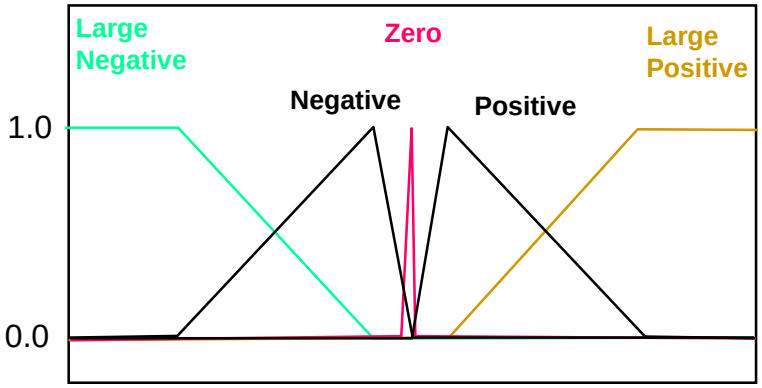
Example Membership functions



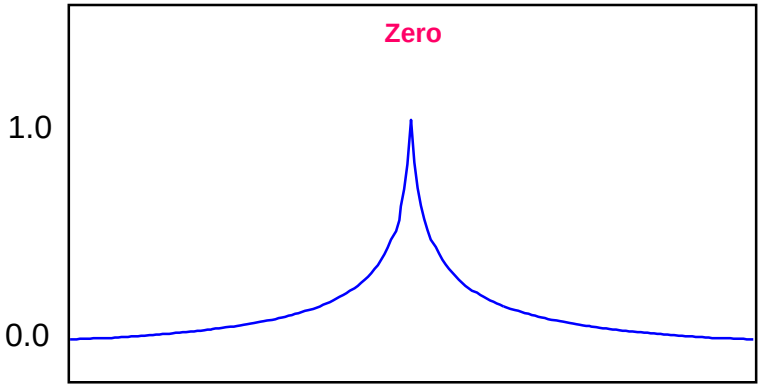
Velocity



Spring Stretching



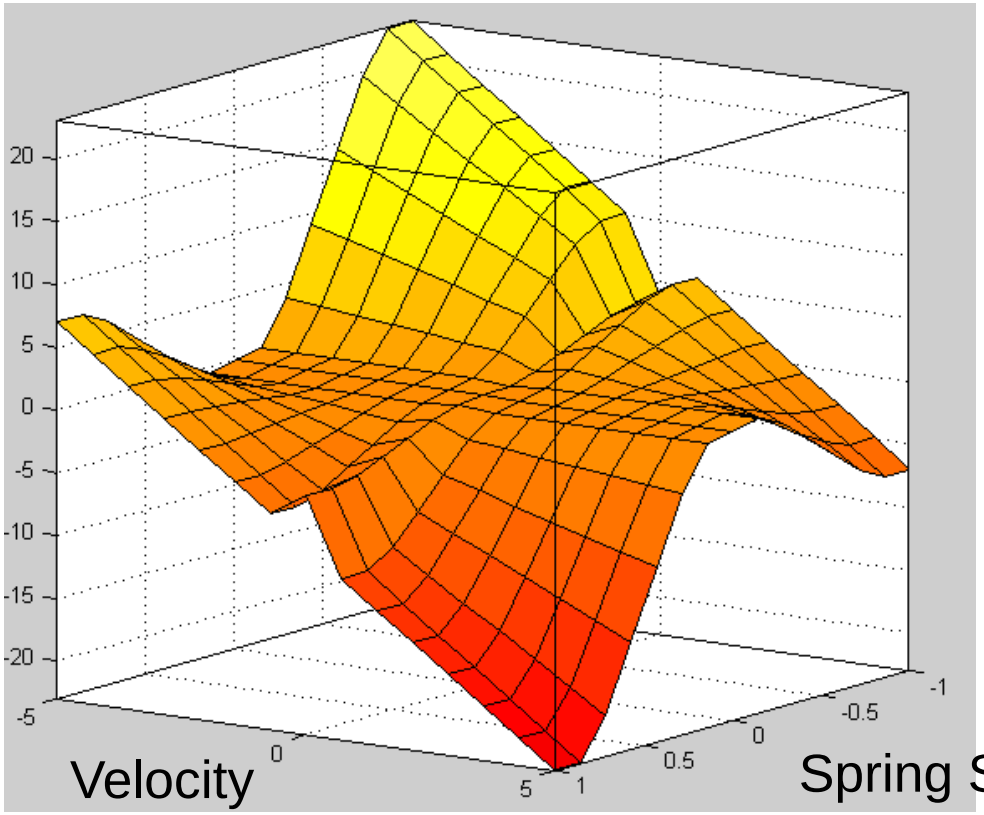
Position Error



Spring Length

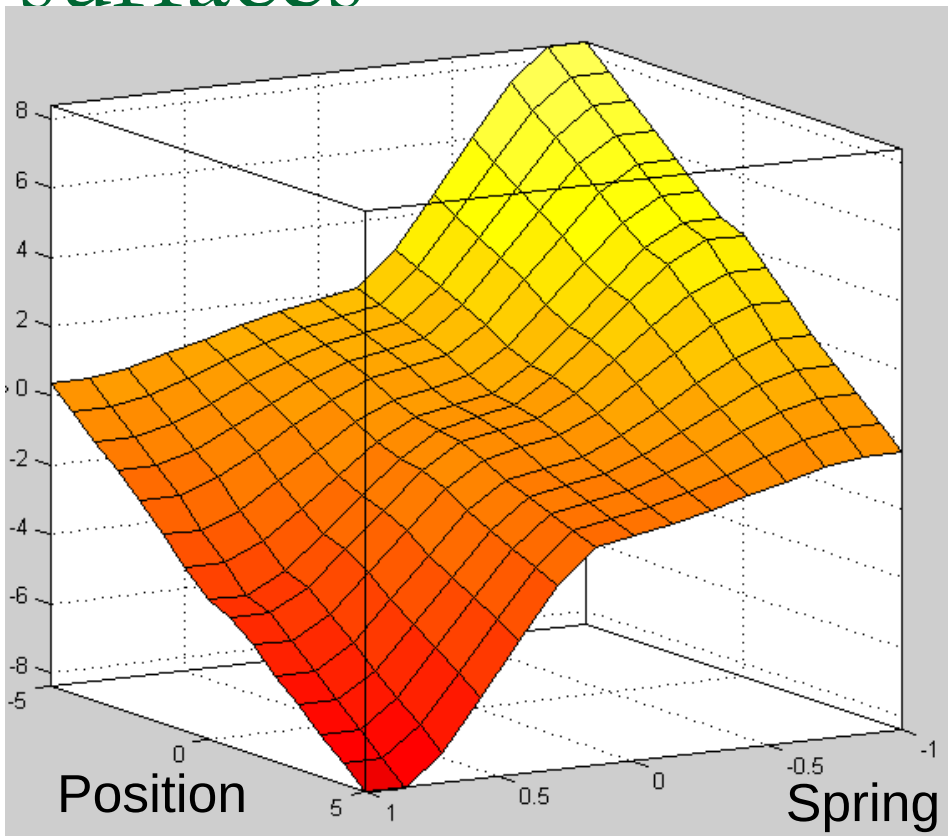
A few rules can make complex decision surfaces

Control Output



Constructed from 10 rules

A few rules can make complex decision surfaces



Constructed from 10 rules

Fuzzy vs. Probabilistic Reasoning

- Probabilistic Reasoning
  - "There is an 80% chance that Jane is old"
  - Jane is either old or not old (the law of the excluded middle).
- Fuzzy Reasoning
  - "Jane's degree of membership within the set of old people is 0.80."
  - Jane is like an old person, but could also have some characteristics of a young person.

Why fuzzy?

- Precision is not truth.
  — Henri Matisse
- 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
- As complexity rises, precise statements lose meaning and meaningful statements lose precision.
  — Lotfi Zadeh

Why the reluctance use of fuzzy logic?

- Engineers are trained using precise mathematics – differential equations
- Most of us are more comfortable with the *Law of the Excluded Middle*
  - every proposition must either be True or False
- The use of the word fuzzy.
  - What if AI were call Epistemological Engineering as suggested in 1968 at the Machine Intelligence workshop in Edinburgh?
- Not enough software people are in charge of engineering projects

Intelligent Control

- An intelligent control system is one in which a physical system or a mathematical model of it is being controlled by a combination of a knowledge-base, approximate (humanlike) reasoning, and/or a learning process structured in a hierarchical fashion.

- Under this simple definition, any control system which involves fuzzy logic, neural networks, expert learning schemes, genetic algorithms, genetic programming or any combination of these would be designated as intelligent control.

Fuzzy Control

- A fuzzy controller consists of three operations:

  (1) fuzzification,
  (2) inference engine, and
  (3) defuzzification.

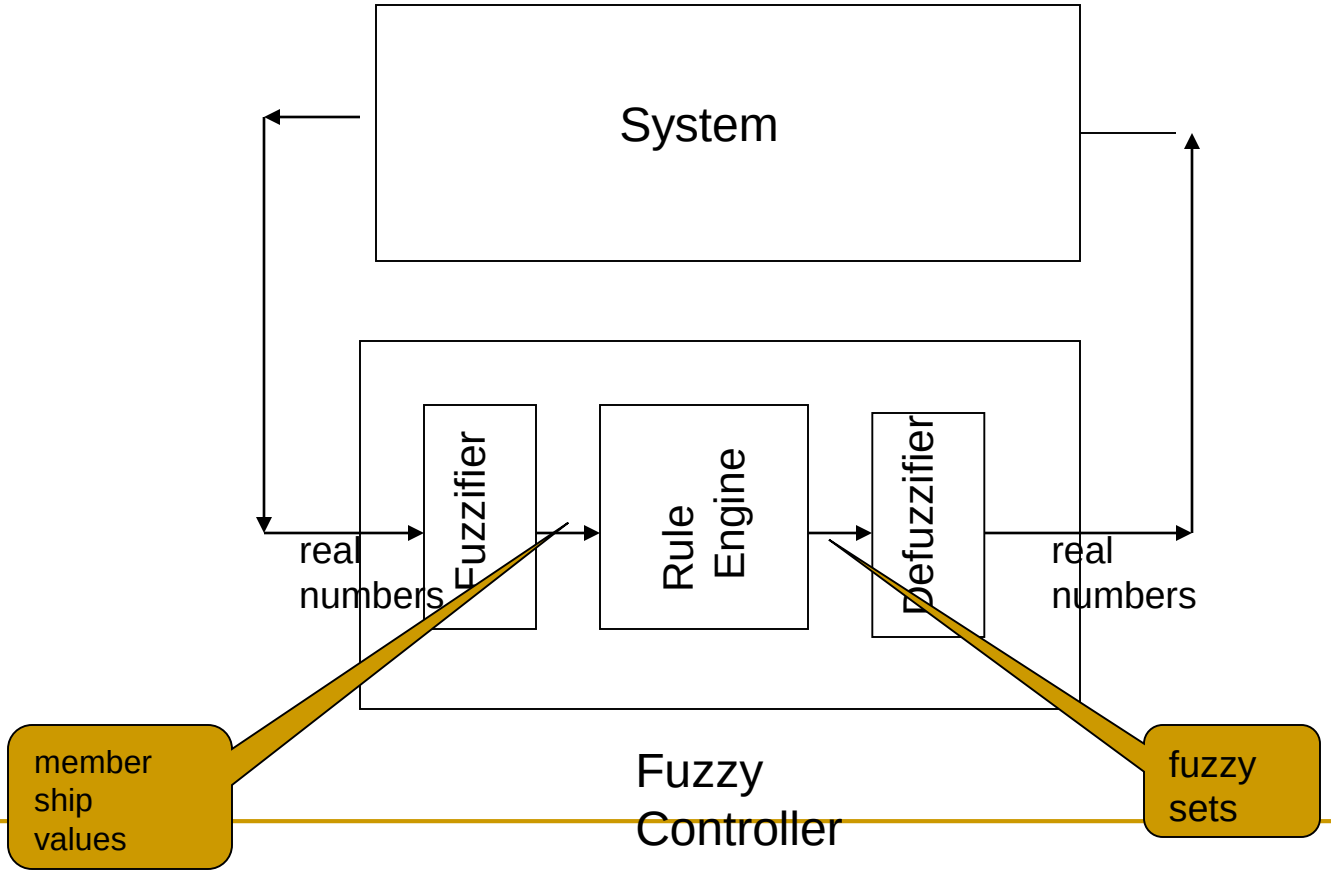
- A common definition of a fuzzy control system is that it is a system which emulates a human expert. In this situation, the knowledge of the human operator would be put in the form of a set of fuzzy linguistic rules.

- The human operator observes quantities by observing the inputs, i.e., reading a meter or measuring a chart, and performs a definite action (e.g., pushes a knob, turns on a switch, closes a gate, or replaces a fuse) thus leading to a crisp action

- The human operator can be replaced by a combination of a fuzzy rule-based system (FRBS) and a block called *defuzzifier*. The input sensory (crisp or numerical) data are fed into FRBS where physical quantities are represented or compressed into linguistic variables with appropriate membership functions.

- These linguistic variables are then used in the *antecedents* (IF-Part) of a set of fuzzy rules within an inference engine to result in a new set of fuzzy linguistic variables or *consequent* (THEN-Part). Variables are combined and changed to a crisp (numerical) output.

Fuzzy Control Architecture



Fuzzy Control: Inverted Pendulum Problem

State variables

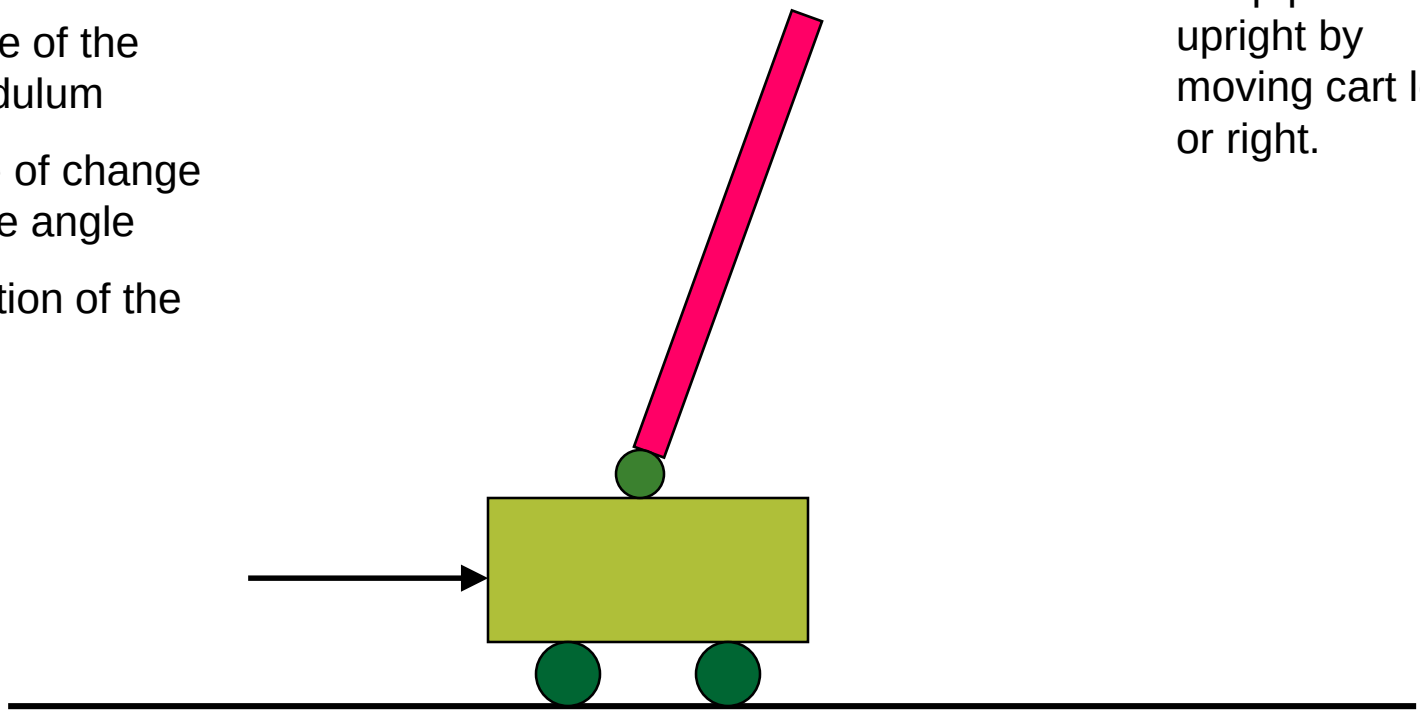
Angle of the Pendulum

Rate of change of the angle

Position of the cart

Problem

Keep pendulum upright by moving cart left or right.

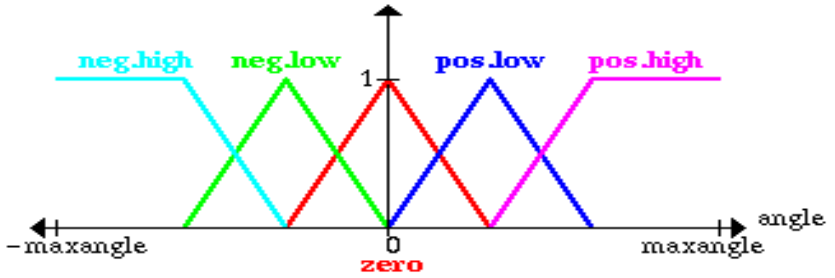


http://www.flll.uni-linz.ac.at/aboutus/whatisfuzzy/introduction.html

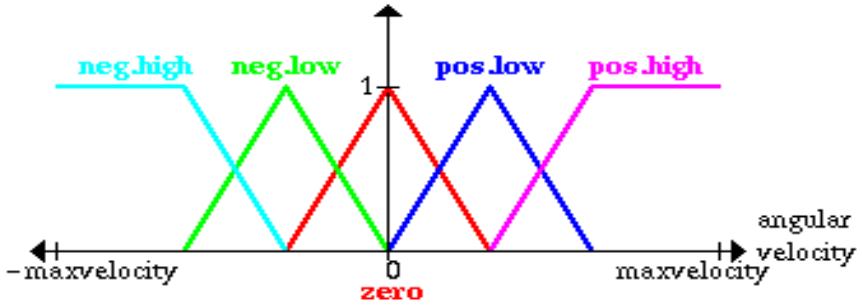
Partition variables

Inputs

Pendulum Angle

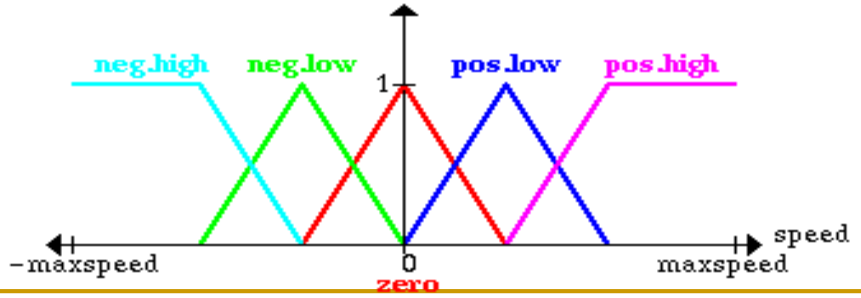


Pendulum Angular Velocity



Output

Cart Speed



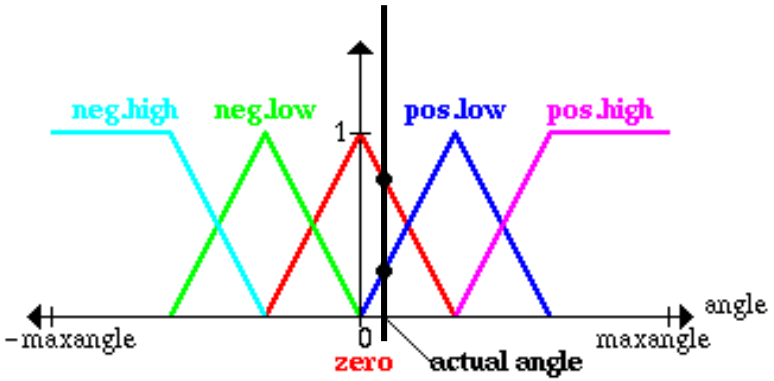
Controller Rules

If angle is zero and angular velocity is zero
then speed shall be zero.

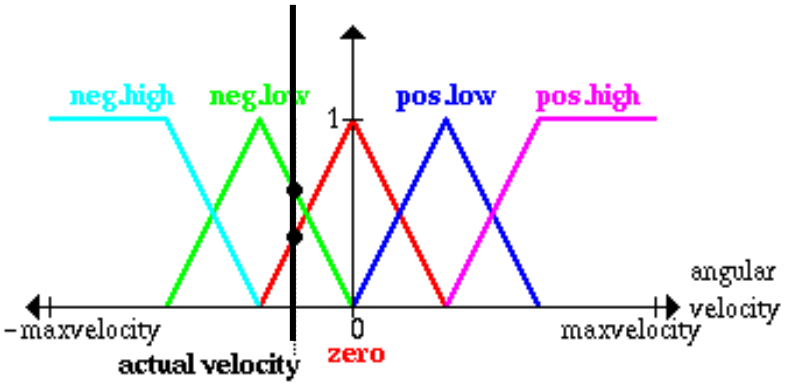
Angle Velocity	Angle: Negative High	Angle: Negative Low	Angle: Zero	Angle: Positive Low	Angle: Positive High
Negative High			Negative High		
Negative Low		Zero	Negative Low	Zero	
Zero	Negative High	Negative Low	Zero	Positive Low	Positive High
Positive Low		Zero	Positive Low	Zero	
Positive High			Positive High		

This is an example of a Fuzzy PD Controller!

Example input



Input is both **zero** and **positive low**.

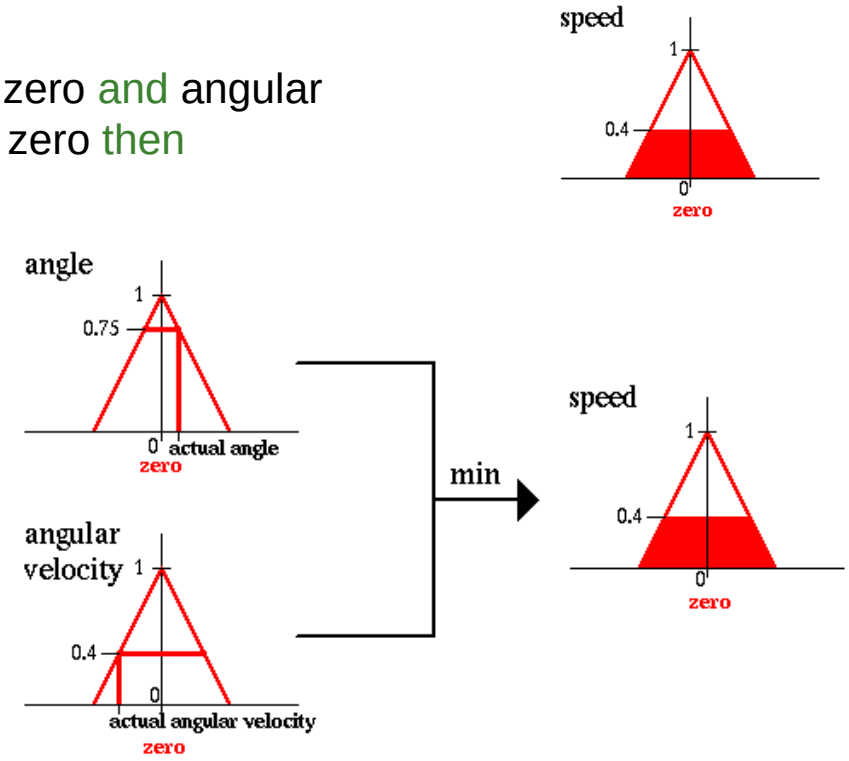


Input is both **zero** and **negative low**.

How many rules will be fired?

Example output from one rule

if angle is zero and angular velocity is zero then



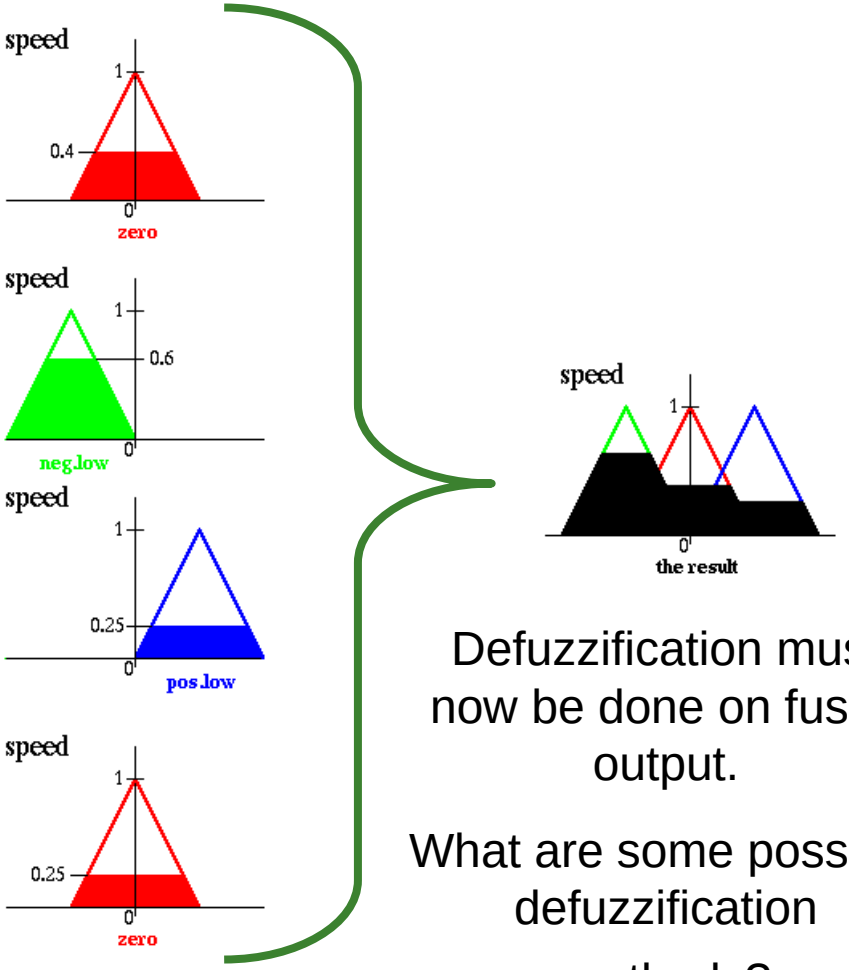
Fused output from four rules

if angle is zero and angular velocity is zero then

if angle is zero and angular velocity is negative low then

if angle is positive low and angular velocity is zero then

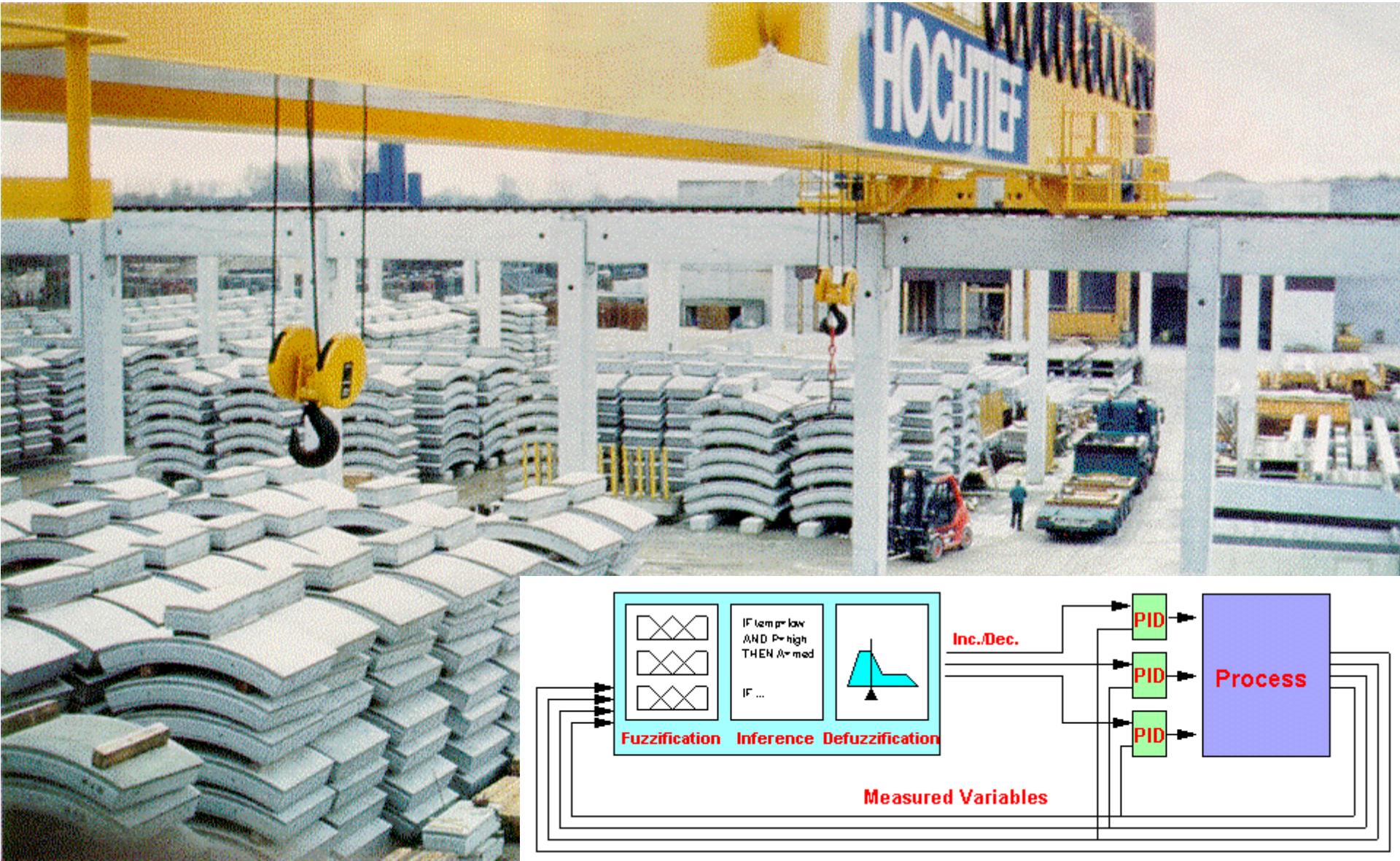
if angle is positive low and angular velocity is negative low then



Defuzzification must now be done on fused output.

What are some possible defuzzification methods?

Other examples:



A Java-based Simulation

- Fuzzy Pendulum Demo created using the FuzzyJ Toolkit by the Integrated Reasoning Group of the National Research Council of Canada
  - http://www.cs.dartmouth.edu/~spl/publications/fuzzy%20talk/FuzzyPendulum.html
  - http://people.clarkson.edu/~esazonov/neural_fuzzy/loadsway/LoadSway.htm
  - ftp://ftp.elet.polimi.it/users/Andrea.Bonarini/share/AppletJava/html/fuzzy/cartpole/FuzzyCartPole.html

History

- **Cantor:** *Set Theory* at the end of 19th century.
  - (CRISP SETS)
- **Sanders Peirce** (1839-1914):
  - Uncertainty theory
- **Bertrand Russel** (1872-1970):
  - *"All language is vague"*
- ***Jan Lukasiewicz*** *(1878-1955):*
  - *Many-valued logic*
- **Max Black** (1909-1988) *proto-fuzzy* sets
- **Lotfi Zadeh** Inventor of fuzzy logic

- **McNeill and Freiberger** Fuzzy Logic (book)

  Max Black: Leif Eriksson of Fuzzy Logic

  Lotfi Zadeh: Cristopher Columbus
- Zadeh's key idea:

  Graded membership functions.

  First paper by Zadeh on Fuzzy Logic in 1965
- **Rudi Kalman**: *"Fuzzification is a kind of scientific permissiveness: it tends to result in socially appealing slogans unaccompanied by the discpline of hard scientific work and patient observations. I must confess that I cannot concieve of 'fuzzification' as a viable alternative for the scientific method."* (*Quote from McNeill and Freiburger: Fuzzy Logic*).

History

- Lotfi Zadeh visiting scientist at IBM in 1969, IBM not interested
- 1973 Zadeh's paper on how to apply fuzzy logic to control theory.
- ***Mamdani*** *in England started applying fuzzy control to steam engine control.*
- *Researchers in Holland: Warm water plant and ship autopilot.*
- ***The first industrial application*** *of fuzzy logic is said to be* ***control of cement kiln****, which was implemented in Denmark by F.L. Schmidt&Co.*

Fuzzy control in Japan

- **Hirota:** "*History and current trends on Fuzzy Logic in Japan*“ (article).
- *1979* ***Hitachi*** *and* ***Fuji Electric*** *started applying fuzzy logic.*
- *Hitachi was developing a new,* ***automatic train*** *for the Sapporo subway.*
- *Fuji Electric applied fuzzy logic in* ***waste water treatment*** *plant.*

First wave

- Late 1980's many other industrial applications
- *Group control in elevators (Hitachi, and others)*
  - *In high rise buildings, waiting time during rush hours is reduced significantly.*
- *Ventilation systems in expressway tunnels (Toshiba)*
  - *Judging from the traffic density, it controls the on-off switching of the fans in a more economical way saving electricity and prolonging the life time of the fan.*
- *City garbage incinerators (Mitsubishi Heavy Industries)*
  - *The garbage layer thickness is kept even for incineration to reduce the damage done to the incinerators.*

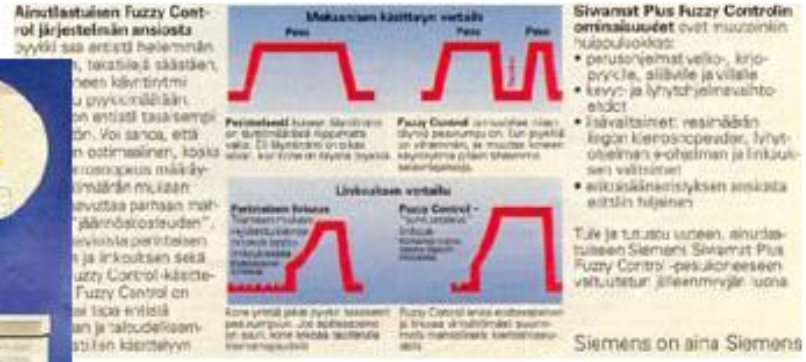
Second wave

- ***Consumer goods like***
  - *Water mixing valve (Matsushita)*
  - *Air conditioner (Mitsubishi)*
  - *8 mm VCR with auto iris (Sanyo)*
  - *Fuzzy autofocus still camera (Canon)*
  - *Neuro-fuzzy consumer products are advertised*
- ***Cars***
  - *ABS brakes*
  - *Automatic transmission*
  - *Control of idle speed*
- ***Automatic container crane operation***
- ***Automatic train operation***
- ***Fuzzy logic in consumer products***
- ***Products of General Electric with fuzzy logic***

Rice cooker


Makes soft, fluffy delicious rice every time
好一鍋香甜、鬆軟的米飯
ZDJ101A 181A
110v
220v
White
-WB
Wine
-VA
Neuro-Fuzzy Heat Adjuster
Fine-tuned heat adjustment
Three sensors help the Neuro-Fuzzy make the precise choice. Sensitive to the exact quantity and your tastes, you get tasty, fluffy rice every time, just the way you like it.
具備尖端科技的"繁知"系統(Fuzzy)
——細致入微的火候調節

Washing machine



Automatic gear shift

Recovery Boiler Fuzzy Logic Control