Fuzzy Logic

Theory and Applications

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Fuzzy Logic

- Introduction
  - What is Fuzzy Logic?
  - Applications of Fuzzy Logic
  - Classical Control System vs. Fuzzy Control
- Developing a Fuzzy Control System
- Examples
- Theory of Fuzzy Sets
- Fuzzy Inference Systems
- Assignment #2

Topics

- Introduction
- Basic Algorithm
- Control Systems
- Sample Computations
- Inverted Pendulum
- Fuzzy Inference Systems
  - Mamdani Type
  - Sugeno Type
- Fuzzy Sets & Operators
- Defuzzification
- Membership Functions

Basics

Control Systems

Computations

Inverted Pendulum

Mamdani

Sugeno

Fuzzy Sets

Defuzzification

Mem. Fcns

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Motivation

Previously

Systematic exploration of alternatives

find a path or a plan of action

e.g. sequence of moves to solve a puzzle

States finite and complete

e.g. arrangement of tiles in a puzzle

Moves deterministic and discrete

e.g. up, right, down, left

Next set of problems

- States with continuous-valued and ill-defined inputs
- Dynamically-changing world

e.g. target is moving to the left and its speed is increasing fast

Continuous-valued actions
uncertainty in inputs

e.g. exact steering angle, speed, exact Force

What is Fuzzy Logic?

‘Fuzzy’ – a misnomer

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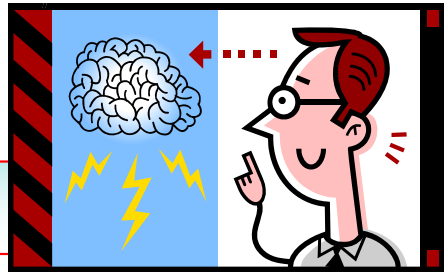
Fuzzy Logic

What is Fuzzy Logic?



A **computational paradigm that mimics how humans think**.

Fuzzy Logic looks at the world in **imprecise terms**, in much the same way that our brain takes in information (e.g. temperature is hot, speed is slow), then responds with **precise actions**.

The human brain can reason with uncertainties, vagueness, and judgments. Computers can only manipulate precise valuations. Fuzzy logic is an attempt to combine the two techniques.

Fuzzy Logic

What is Fuzzy Logic?

FL is in fact, **a precise problem-solving methodology**.

It is able to simultaneously handle numerical data and linguistic knowledge.

A technique that facilitates the control of a complicated system without knowledge of its mathematical description.

"Fuzzy" – a misnomer, has resulted in the mistaken suspicion that FL is somehow less exacting than traditional logic

e.g. *Why would you purchase a fuzzy-controlled auto-focusing camera?... Wouldn't it produce fuzzy images?*

What is Fuzzy Logic?

History

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Fuzzy Logic

History of Fuzzy Logic

an American, mathematically oriented, computer scientist, electrical engineer of Iranian descent, born in Russia.

Professor Lotfi A. Zadeh

http://www.cs.berkeley.edu/~zadeh/

In **1965**, **Lotfi A. Zadeh** of the University of California at Berkeley published "**Fuzzy Sets**," which laid out the mathematics of fuzzy set theory and, by extension, fuzzy logic. Zadeh had observed that conventional computer logic couldn't manipulate data that represented subjective or vague ideas, so he created fuzzy logic to allow computers to determine the distinctions among data with shades of gray, similar to the process of human reasoning.

This paper drew 90,000 Google Scholar citations (as of 2017).
It is the highest cited paper in the literature of Computer Science (Web of Science);

Source: August 30, 2004
(Computerworld)

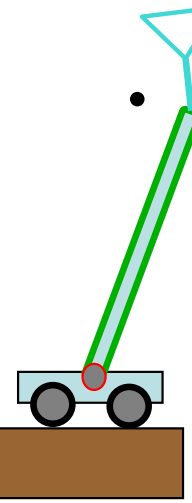
http://www.cs.berkeley.edu/~zadeh/suprco.html

http://www.computerworld.com/news/2004/story/0,11280,95282,00.html

Pioneering works

20 years later after its inception

- Interest in fuzzy systems was sparked by **Seiji Yasunobu** and **Soji Miyamoto** of **Hitachi**, who in **1985** provided simulations that demonstrated the superiority of fuzzy control systems for the **Sendai railway**. Their ideas were adopted, and fuzzy systems were used to control accelerating and braking when the line opened in **1987**.



- Also in **1987**, during an international meeting of fuzzy researchers in Tokyo, **Takeshi Yamakawa** demonstrated the use of fuzzy control, through a set of simple dedicated fuzzy logic chips, in an "**inverted pendulum**" experiment. This is a classic control problem, in which a vehicle tries to keep a pole mounted on its top by a hinge upright by moving back and forth.

- Observers were impressed with this demonstration, as well as later experiments by **Yamakawa** in which he mounted a wine glass containing water or even a live mouse to the top of the pendulum. The system maintained stability in both cases. Yamakawa eventually went on to organize his own fuzzy-systems research lab to help exploit his patents in the field.

What is Fuzzy Logic?

Applications

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Fuzzy Logic

Introduction of FL in the Engineering world (1990's),

(*News excerpt from the 1990s*) **Fuzzy Logic** is one of the most talked-about technologies to hit the embedded control field in recent years. It has already transformed many product markets in Japan and Korea, and has begun to attract a widespread following In the United States. Industry watchers predict that fuzzy technology is on its way to becoming a multibillion-dollar business.

Fuzzy Logic enables low cost microcontrollers to perform functions traditionally performed by more powerful expensive machines enabling lower cost products to execute advanced features.

Intel Corporation's Embedded Microcomputer Division Fuzzy Logic Operation

Motorola 68HC12 MCU

http://www.intel.com/design/mcs96/designex/2351.htm

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Sample Applications

In the city of Sendai in Japan, a 16-station subway system is controlled by a fuzzy computer (Seiji Yasunobu and Soji Miyamoto of Hitachi) – the ride is so smooth, riders do not need to hold straps

Nissan – fuzzy automatic transmission, fuzzy anti-skid braking system

CSK, Hitachi – Hand-writing Recognition

Sony - Hand-printed character recognition

Ricoh, Hitachi – Voice recognition

Tokyo's stock market has had at least one **stock-trading portfolio based on Fuzzy Logic** that outperformed the Nikkei exchange average

Sample Applications

NASA has studied fuzzy control for **automated space docking**: simulations show that a fuzzy control system can greatly reduce fuel consumption

Canon developed an **auto-focusing camera** that uses a charge-coupled device (CCD) to measure the clarity of the image in six regions of its field of view and use the information provided to determine if the image is in focus. It also tracks the rate of change of lens movement during focusing, and controls its speed to prevent overshoot.

The camera's fuzzy control system uses **12** inputs: 6 to obtain the current clarity data provided by the CCD and 6 to measure the rate of change of lens movement. The output is the position of the lens. The **fuzzy control system** uses **13 rules** and requires **1.1 kilobytes** of memory.

http://en.wikipedia.org/wiki/Fuzzy_system

Sample Applications

Segway Robotics Mobility Platform

- Algorithm: combination of Fuzzy Logic and Expert System
- Sensors: multiple gyroscopes and accelerometers
- Estimates the 3D position of the mobile robot
- The control system dynamically prevents the robot from falling over.

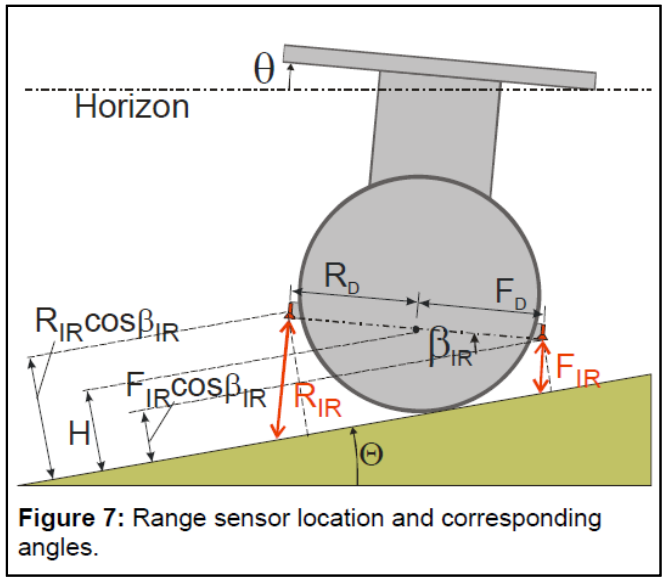
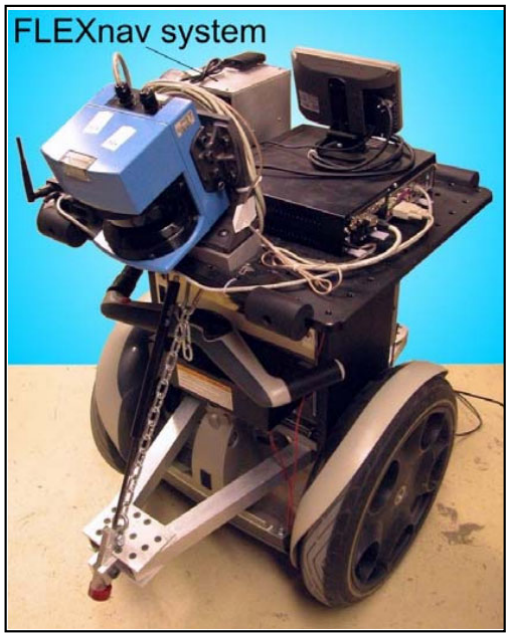


Figure 7: Range sensor location and corresponding angles.



2004, FLEXnav: A Fuzzy Logic Expert Dead-reckoning System for the Segway RMP
Lauro Ojeda, Mukunda Raju and Johann Borenstein
The University of Michigan, Advanced Technologies Lab

Sample Applications

What about hoverboards? how to build its control system?

- self-balancing, two-wheeled scooters
- you just lean to move forward and put weight on whichever foot to go left or right.

Sample Applications

In high-end washing machines, dishwashers and refrigerators, fuzzy logic is now commonplace.

- These machines offer the advantages of performance, simplicity, productivity, and less cost.
- Sensors continually monitor varying conditions inside the machine and accordingly adjust operations for the best wash results.
- Typically, fuzzy logic controls the washing process, water intake, water temperature, wash time, rinse performance, and spin speed. This optimises the life span of the washing machine.
- (Neuro-Fuzzy) Some machines even learn from past experience, memorising programs and adjusting them to minimise running costs.

GE WPRB9110WH Top Load Washer

Haier ESL-T21 Top Load Washer

LG WD14121 Front Load Washer

Miele WT945 Front Load All-in-One Washer / Dryer

AEG LL1610 Front Load Washer

Zanussi ZWF1430W Front Load Washer

Others: Samsung, Toshiba, National, Matsushita, etc.

- Fuzzy Logic: The Revolutionary Computer Technology That Is Changing Our World, by Daniel Mcneill, Paul Freiberger
- http://www.samsung.com/in/support/skp/faq/138486

Sample Applications

Fuzzy logic washing machines vs. PID washing machines

- Standard **PID controller** would require [**1,000-2,000**] rules to build the controller.
- **Fuzzy Logic** achieve the same results with **200** rules. (Productivity gain!)

Fuzzy logic dishwashers

- Using Fuzzy Logic the dishwasher can determine the dishwasher load. The duration and the water usage are then adapted accordingly, to ensure that no excess water is used. Rest assured that whether you wash a full load or a half load the dishwasher will adapt accordingly.

- (Accessed 2018) http://www.electrolux.co.nz/support/usage-advice/dishwashers/

Heat Pumps

consumer. RECOMMENDS
Mitsubishi Heavy Industries SRK20ZSXA-W

Cooling ENERGY RATING
Heating ENERGY RATING

Recommended by Consumer and with an industry leading 7 star "Super Efficiency" energy rating the 2.0kW Avanti PLUS® heat pump is one of the most efficient split system heat pumps on the market.

Incorporating a range of advanced features including an energy saving motion sensor and eco-operation, improved automatic mode for precise temperature control, LED display with adjustable brightness and optional wi-fi control, the 2.0kW Avanti PLUS® split system heat pump is perfect for smaller spaces such as a single bedroom, guest bedroom, kid's room or a home office.

ENERGY SAVING

FUZZY AUTO MODE

Using fuzzy logic algorithms, the unit determines the operating mode and temperature settings automatically and adjusts the inverter frequency.

KEY FEATURES

- 7 star "Super Efficiency" energy rating
- Award winning, modern design
- Energy saving motion sensor and eco operation as standard
- Allergen clear system to eliminate airborne allergens and deliver clean air throughout your home
- Improved auto mode allowing for precise temperature control

(Accessed, 2021) https://mhiheatpumps.co.nz/products/model/split-system-heat-pump-avanti-plus-srk20zsxa-w/

Meeting Lotfi in Germany

My Fuzzy Logic-based Research

- Navigation in unknown terrain (Hybrid Fuzzy-D*Lite)
- Robot soccer navigation
  - Real-time path-planning (Hybrid Fuzzy A*)
- Machine Vision
  - Real-time colour-object recognition
  - Fuzzy Colour Contrast Fusion

9th Fuzzy Days (2006), Dortmund, Germany

Meeting Prof. Yamakawa in Japan

ICONIP 2007, Kitakyushu, Japan

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Control Systems in General

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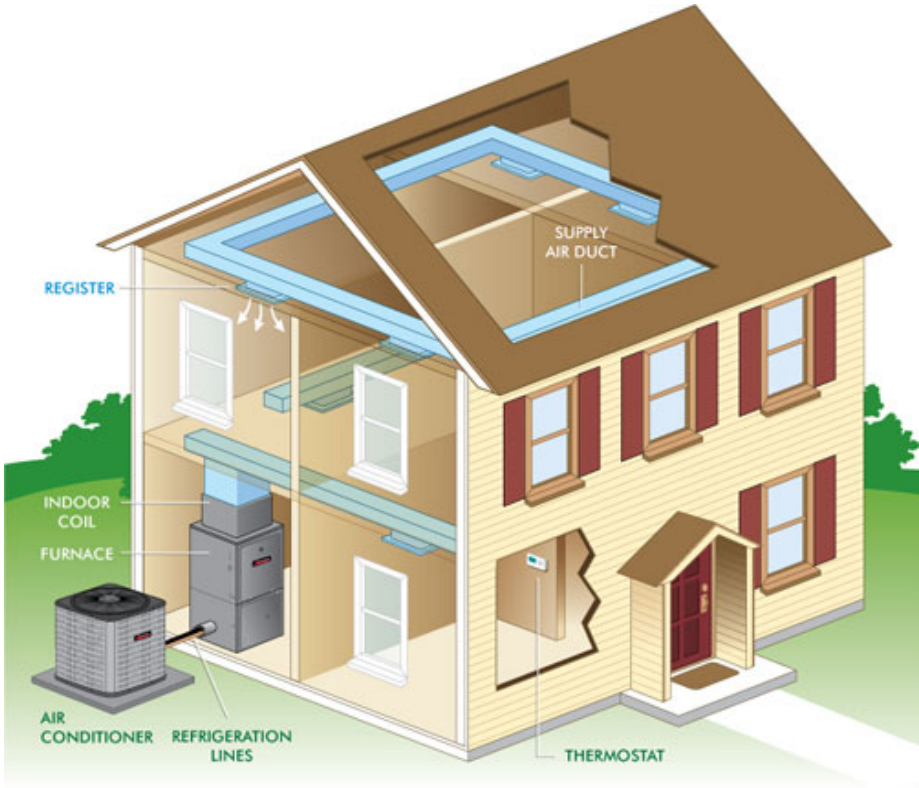
Control Systems in General

Objective

The aim of any control system is **to produce a set of desired outputs for a given set of inputs**.

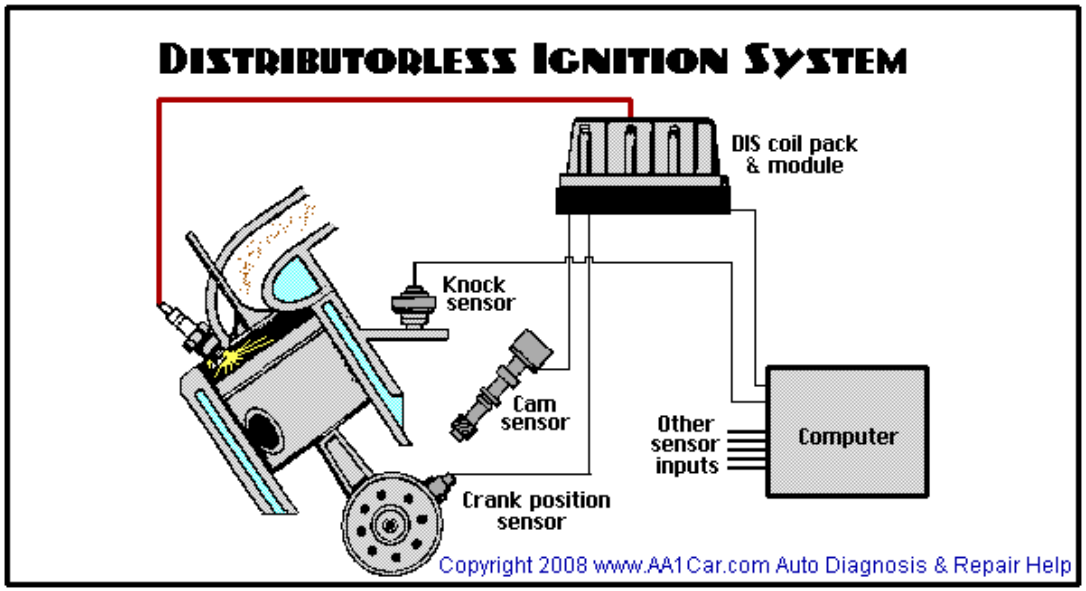
Example

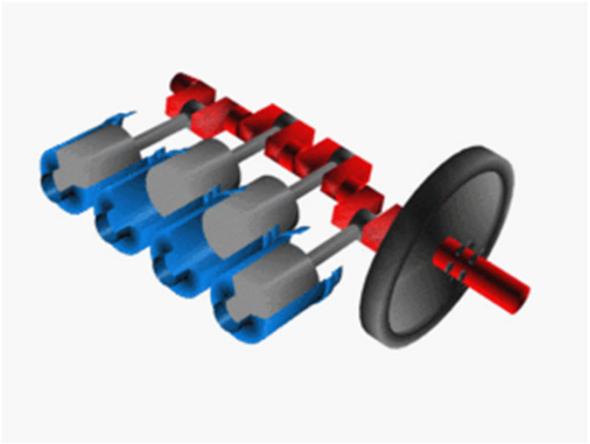
A household thermostat takes a temperature input and sends a control signal to a furnace.



Control Systems in General

Example





Crankshaft (red), pistons (gray) in their cylinders (blue), and flywheel (black)

Image: http://en.wikipedia.org/wiki/Crankshaft

A car engine controller responds to variables such as engine position, manifold pressure and cylinder temperature to regulate fuel flow and spark timing.

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Control Systems

Conventional Control vs. Fuzzy Control

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Conventional Control vs. Fuzzy

1. Look-up table

In the simplest case, a controller takes its cues from a look-up table, which tells what output to produce for every input or combination of inputs.

Sample

The table might tell the controller,
"**IF temperature is 85, THEN increase furnace fan speed to 300 RPM.**"

Drawbacks

The problem with the tabular approach is that the **table can get very long**, especially in situations where there are many inputs or outputs. And that, in turn, **may require more memory than the controller can handle**, or more than is cost-effective.

Tabular control mechanisms may also give a **bumpy, uneven response**, as the controller jumps from one table-based value to the next.

Conventional Control vs. Fuzzy

2. Mathematical formula

The usual alternative to look-up tables is to have the controller execute a mathematical formula – **a set of control equations that express the output as a function of the input**.

Ideally, these equations represent an accurate model of the system behaviour.

For example:

$$\left[m \frac{\partial^2}{\partial t^2} (x + l \sin\theta) \right] l \cos\theta - \left[m \frac{\partial^2}{\partial t^2} (l \cos\theta) \right] l \sin\theta = mgl \sin\theta$$

Downside of mathematical modeling

The formulas can be very complex, and working them out in real-time may be more than an affordable controller (or machine) can manage.

It may be difficult or impossible to derive a workable mathematical model in the first place, making both tabular and formula-based methods impractical.

Conventional Control vs. Fuzzy

Why use Fuzzy Logic?

FL overcomes the disadvantages of both table-based and formula-based control.

Fuzzy has **no unwieldy memory requirements** of look-up tables, and **no heavy number-crunching demands** of formula-based solutions.

Troubleshooting a car (an analogy)

- A fuzzy system is analogous to a human expert who learned through experience.
- Though an automotive engineer might understand the general relationship between say, ignition timing, air flow, fuel mix and engine RPM, the exact math that underlies those interactions may be completely obscure.

Conventional Control vs. Fuzzy

Why use Fuzzy Logic?

FL can make development and implementation much simpler.

It needs no intricate mathematical models, only a practical understanding of the overall system behaviour.

FL mechanisms can result to **higher accuracy** and **smoother control** as well.

Fuzzy Set Theory

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Fuzzy Logic Explained

Fuzzy Set Theory

Fuzzy logic differs from classical logic in that statements are no longer black or white, true or false, on or off.
In traditional logic an object takes on a value of either zero or one.
In fuzzy logic, a statement can assume any real value between 0 and 1, representing the degree to which an element belongs to a given set.

In other words, FL recognizes not only clear-cut, black-and-white alternatives, but also the infinite gradations in between.

Fuzzy reasoning eliminates the vagueness by assigning specific numbers to those gradations. These numeric values are then used to derive exact solutions to problems.

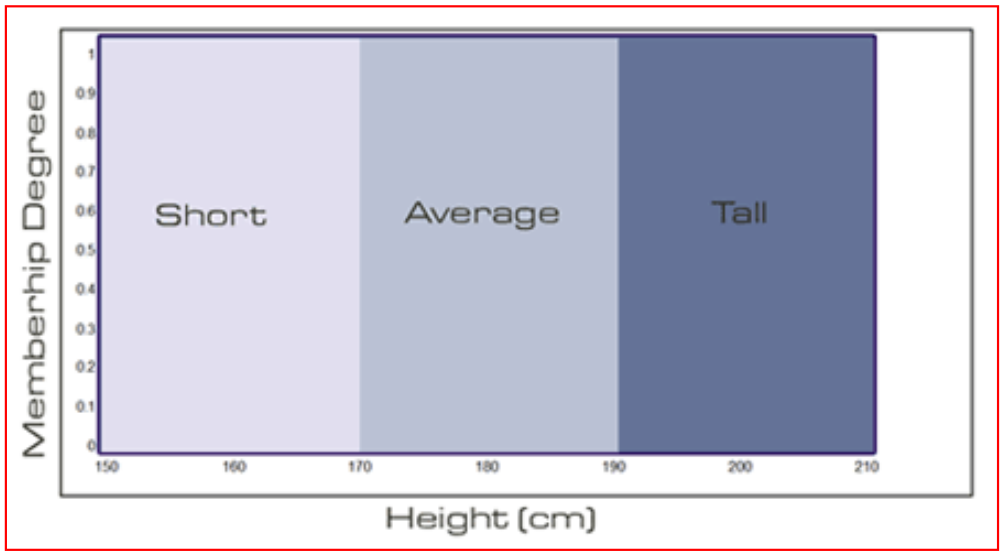
Fuzzy Logic Explained

Fuzzy Set Theory

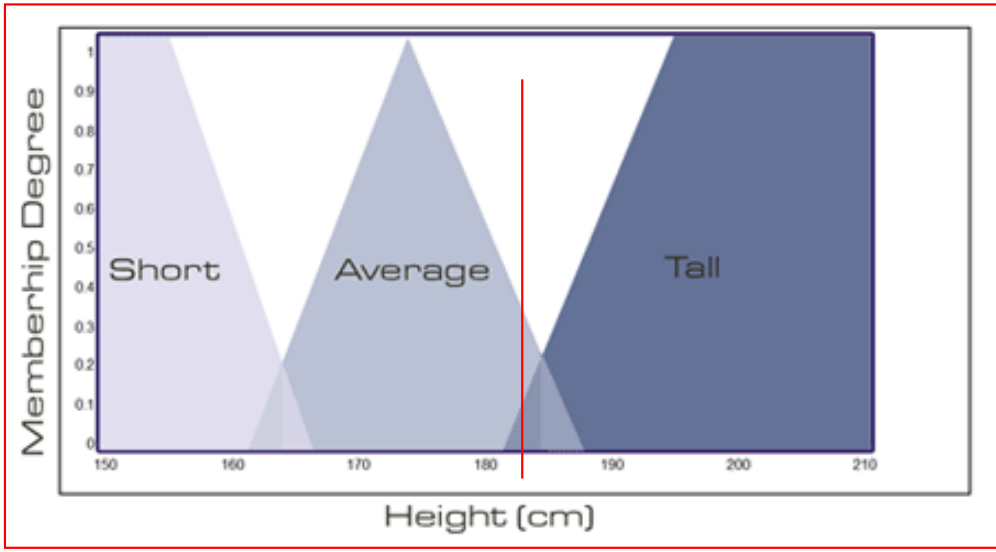
Is a man whose height is 5’ 11-1/2” average or tall?

A fuzzy system might say that he is partly medium and partly tall.

Boolean representation



Fuzzy representation



http://blog.peltarion.com/2006/10/25/fuzzy-math-part-1-the-theory/

In fuzzy terms, the height of the man would be classified within a range of [0, 1] as average to a degree of 0.6, and tall to a degree of 0.4.

Fuzzy Rules

Fuzzy rules may come in various forms

Examples:

(*a*) if pressure is high then volume is small — represents dependency

(*b*) if pressure is high and temperature is low then volume is very small — represents dependency, multiple antecedents

(*c*) if pressure is high then lower temperature slightly — command

(*d*) if pressure is high then volume is small unless temperature is high — represents dependency

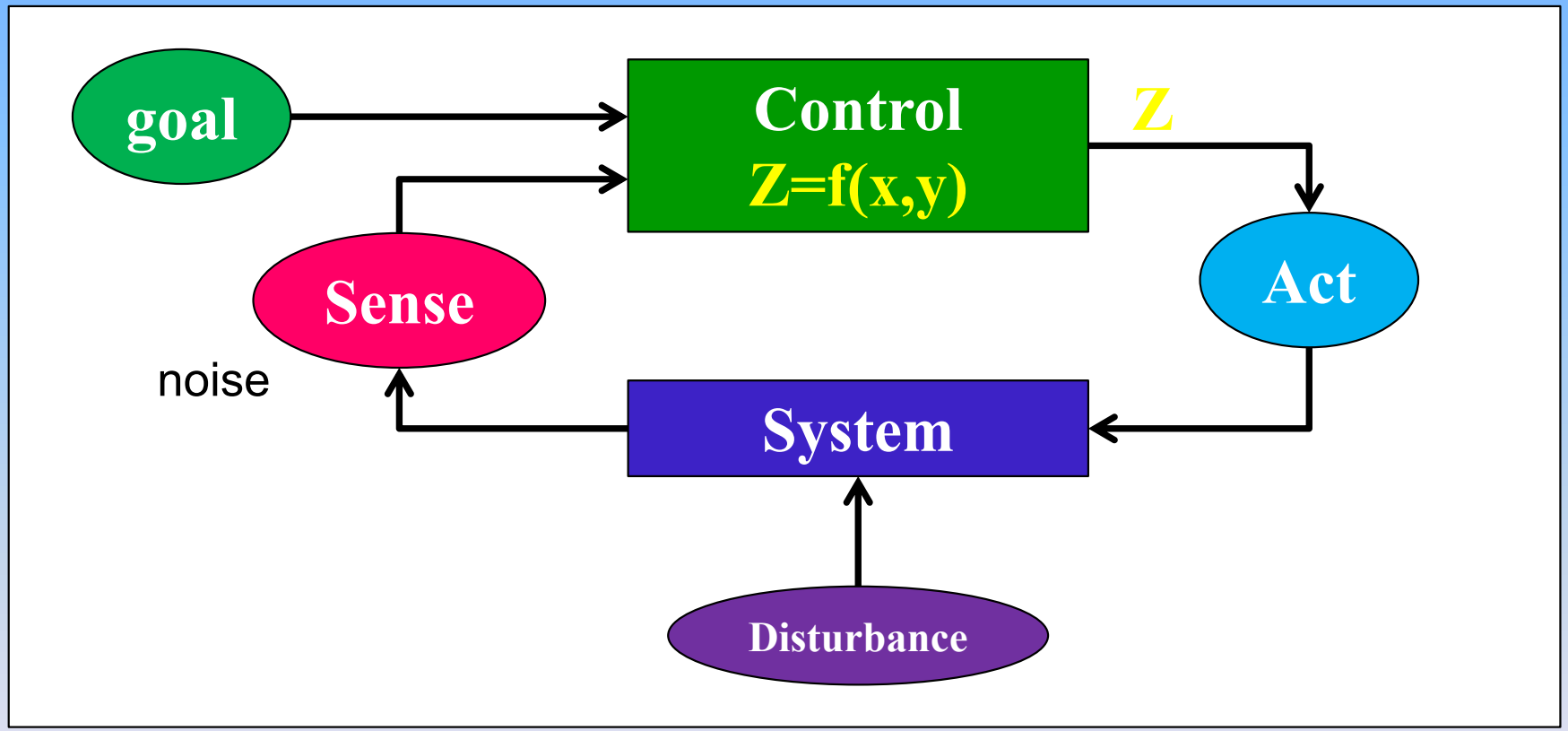
(*e*) if pressure is high then usually volume is small. — represents dependency, dispositional

In these examples, pressure, volume and temperature are linguistic variables and small, low and high are their linguistic values.

- All of the rules except (c) represent dependencies, with (c) representing a command.
- All of the rules except (d) and (e) are categorical.
- Rules (d) and (e) are qualified, with (d) qualified through an exception and (e) through usuality.
- (e) exemplifies what is referred to as a dispositional rule.
- All of the rules except for (b) involve a single variable in the antecedent

Feedback Control/Closed Loop Control

- Closed-loop control allows for **uncertainty** in the model as well as **noise** and **disturbances** in the system under control



*__Controllers__ are used in the industry to **regulate** temperature, pressure, flow rate, chemical composition, speed and practically every other variable for which a measurement exists.

Fuzzy Inference Process

- What are the steps involved in creating a Fuzzy Control System?

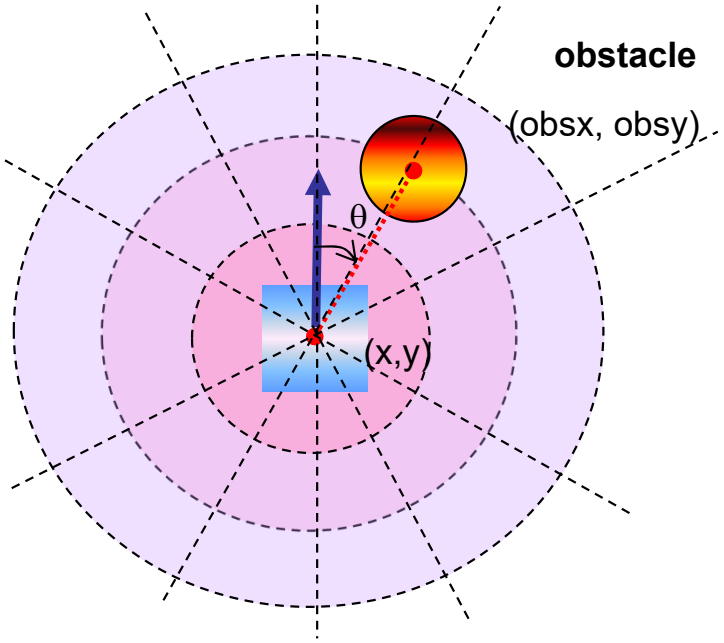
Fuzzy Inference Process

Fuzzy Inference Process

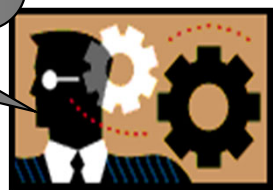
Fuzzification: Translate input into truth values
Rule Evaluation: Compute output truth values
Defuzzification: Transfer truth values into output

Obstacle Avoidance Problem

Robot Navigation



Can you describe how the robot should turn based on the position and angle of the obstacle?



Obstacle Avoidance & Target Pursuit

Demonstration

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