Computational Intelligence
Introduction

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Fall 2011

- Computational Intelligence provides us the opportunity to find a solution for the problems which were merely solvable by human intelligence.
- Computational intelligence machine can learn, remember, and justify similar to human

What are Fuzzy Systems?

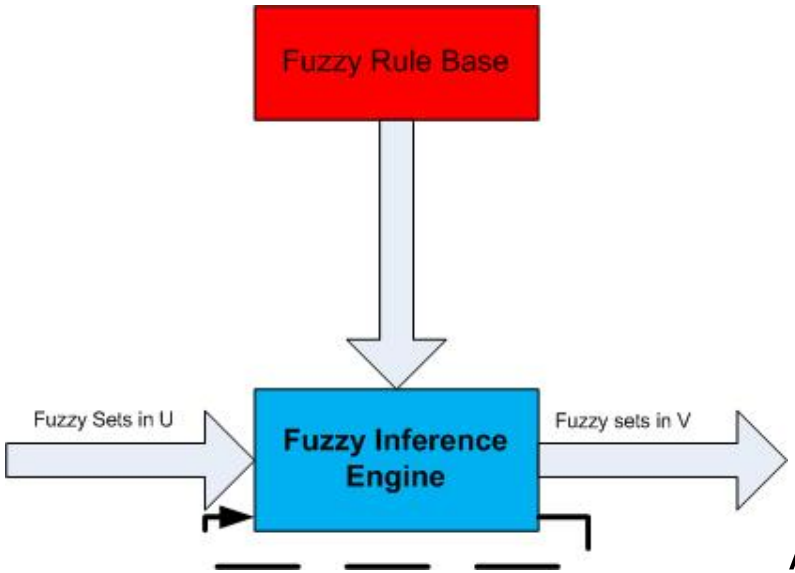
- As a word, fuzzy is defined as "blurred, indistinct; imprecisely defined; confused, vague." !!!
- **The fuzzy systems** is defined based on precise theory and applies to describe complex system which cannot be defined simply by precise models.
- The justification for fuzzy systems theory:
  1. The real world is too complicated for precise descriptions to be obtained, $\rightsquigarrow$ approximation (or fuzziness) must be introduced to obtain a reasonable, yet trackable model.
  2. As we move into the information era, human knowledge becomes increasingly important. We need a theory to formulate human knowledge in a systematic manner and put it into engineering systems, together with other information like mathematical models and sensory measurements.

What are Fuzzy Systems?

- A good engineering theory should make use of all available information effectively.
- For many practical systems, important information comes from:
  1. Human experts who describe their knowledge about the system in natural languages
  2. Sensory measurements and mathematical models that are derived according to physical laws.
- An important task: combining these two types of information into system designs.
- **Fuzzy Systems** transform a human knowledge base into a mathematical formula

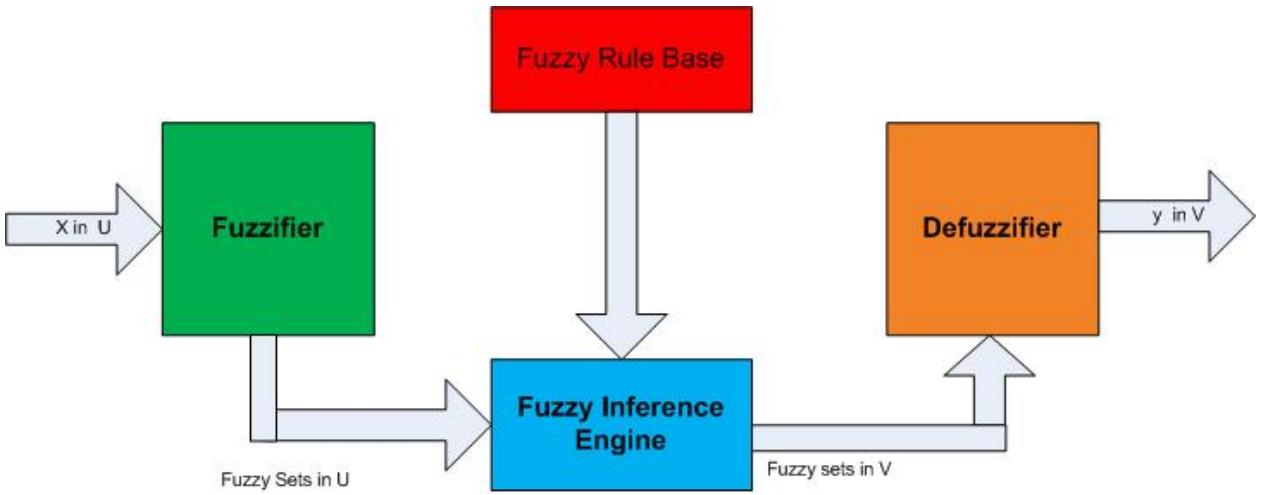
What are Fuzzy Systems?

- To construct a fuzzy system:
  1. Obtain a collection of fuzzy IF-THEN rules from human experts or based on domain knowledge.
  2. Combine these rules into a single system.
- **Example:** For designing a controller to automatically control the speed of a car based on a driver knowledge the rules are
  - *IF speed is low, THEN apply more force to the accelerator*
  - *IF speed is medium, THEN apply normal force to the accelerator*
  - *IF speed is high, THEN apply less force to the accelerator*



A fuzzy system

- fuzzy rule base consists of the rules
- fuzzy inference engine combines the fuzzy IF-THEN rules into a mapping from fuzzy sets in the input space to fuzzy sets in the output space based on fuzzy logic principles.
  - If the dashed feedback line exists, the system becomes the named fuzzy dynamic system.
  - The main problem:(the inputs and outputs are fuzzy sets (words in natural languages), but in engineering systems the inputs and outputs are real-valued variables.



- Fuzzifier transforms a real-valued variable into a fuzzy set at input
- Defuzzifier transforms a fuzzy set into a real-valued variable at output.

- Fuzzy theory was initiated by Lotfi A. Zadeh in 1965 with his seminal paper "Fuzzy Sets" [1].
  - he wrote that to handle biological systems "*we need a radically different kind of mathematics, the mathematics of fuzzy or cloudy quantities which are not describable in terms of probability distributions*"
- The fuzzy controllers was born for real systems, in 1975, by Mamdani and Assilian [2].
- In early 80's Japanese engineers found the fuzzy controllers very user friendly.

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- The fuzzy controllers was born for real systems, in 1975, by Mamdani and Assilian [2].
  - They designed a fuzzy controller to control a steam engine.
- In early 80's Japanese engineers found the fuzzy controllers very user friendly.

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- In early 80's Japanese engineers found the fuzzy controllers very user friendly.
  - It does not require a mathematical model of the process
  - In 1980, Sugeno began to create "Japan's first fuzzy application-control of a Fuji Electric water purification plarit [3].
  - He was pioneer designing on a fuzzy robot, a self-parking car.

- When is it appropriate to use fuzzy logic?
  - A mathematical model of the process does not exit or too complex or expensive to be evaluated fast in real time
  - There are high ambient of noise
  - When the process involves human interaction and an expert can specify some rules underlying the system behavior
- Some Fuzzy Applications
  1. Pattern recognition
     - image, audio, signal processing
  2. Quantitative analysis
     - operation research, management
  3. Inference
     - expert systems for digenesis, planning, prediction, software engineering in medicine, business, and etc
  4. Control (the most popular)
     - modeling and identification of nonlinear systems, observation and control

Examples of Fuzzy Control

- Fuzzy Washing Machines at Matsushita Electric Industrial Company in Japan(1990)
  - a fuzzy system automatically set the proper cycle (output) according to kind and amount of dirt and the size of the load (3 inputs).
- Digital Image Stabilizer in camcorder
- Fuzzy Car at Mitsubishi (1992)
- Fuzzy Control of Subway Train at Sendai in Japan

Examples of Fuzzy Control

- Fuzzy Washing Machines at Matsushita Electric Industrial Company in Japan(1990)
- Digital Image Stabilizer in camcorder based on simple rules:
  - IF all the points in the picture are moving in the same direction, THEN the hand is shaking
  - IF only some points in the picture are moving, THEN the hand is not shaking
- Fuzzy Car at Mitsubishi (1992)
- Fuzzy Control of Subway Train at Sendai in Japan

Examples of Fuzzy Control

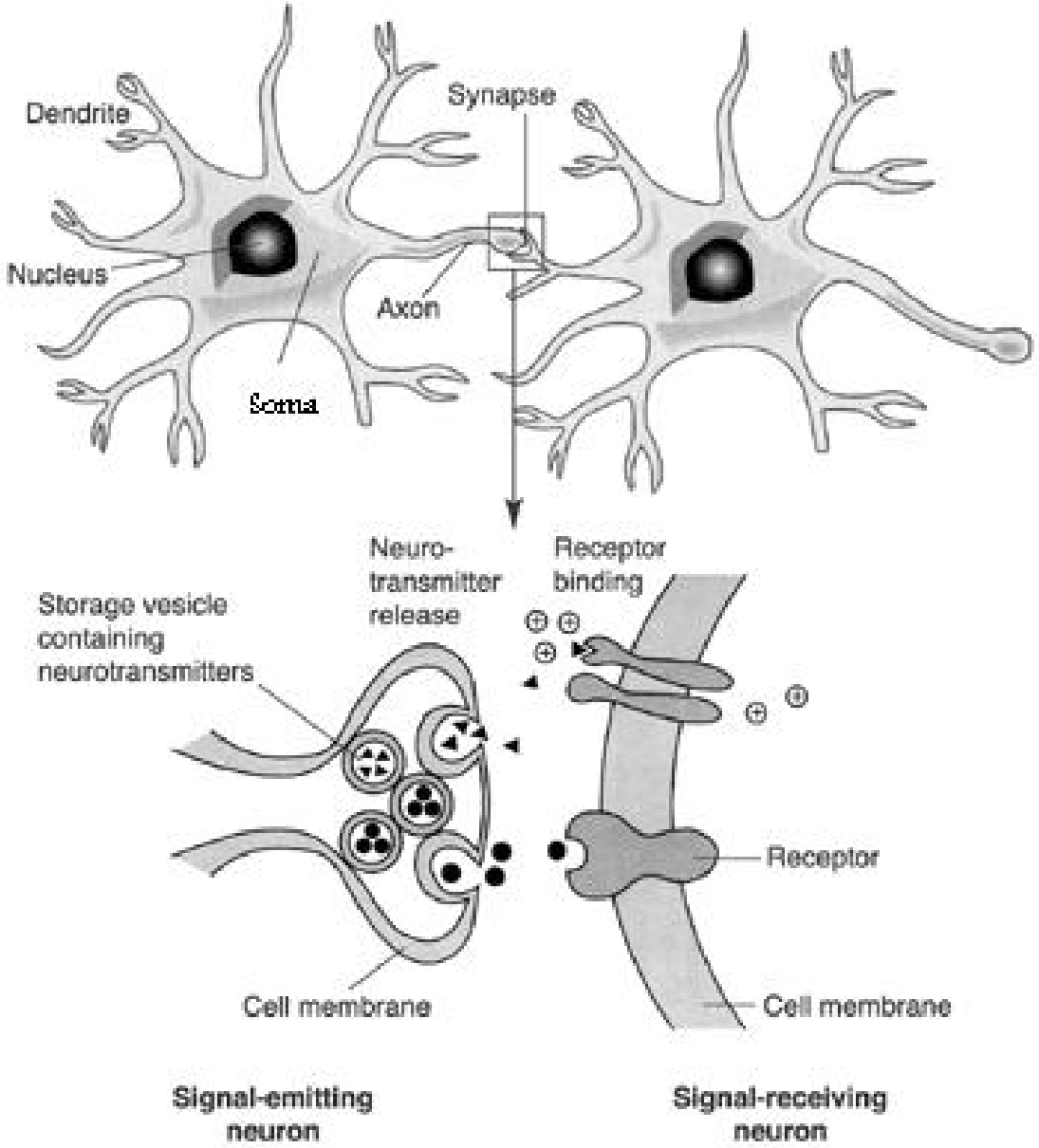
- Fuzzy Washing Machines at Matsushita Electric Industrial Company in Japan(1990)
- Digital Image Stabilizer in camcorder
- Fuzzy Car at Mitsubishi (1992) controls:
  - car's automatic transmission (downshifts on curves and also keeps the car from upshifting inappropriately)
  - suspension (register vibration and height changes in the road and adjusts the suspension for a smoother ride)
  - traction (prevents excess speed on corners and improves the grip on slick roads by deciding whether they are level or sloped)
  - four-wheel steering (adjusts the response angle of the rear wheels according to road conditions and the car's speed)
  - air conditioner (monitors sunlight, temperature, and humidity to enhance the environment inside the car).
- Fuzzy Control of Subway Train at Sendai in Japan

Examples of Fuzzy Control

- Fuzzy Washing Machines at Matsushita Electric Industrial Company in Japan(1990)
- Digital Image Stabilizer in camcorder
- Fuzzy Car at Mitsubishi (1992)
- Fuzzy Control of Subway Train at Sendai in Japan The fuzzy control:
  - The constant speed controller (it starts the train and keeps the speed below the safety limit),
  - the automatic stopping controller (it regulates the train speed in order to stop at the target position).

Biological Neural Networks

- Although the processor elements of a computer (semi-conductors) act much faster than processor elements of human brain (neurons), human response is faster than a computer.
  - In human brain, neurons work in parallel and are tightly connected together
  - In computer the calculations are doing sequential.
- Artificial neural networks mimic brain capability of calculations and decision making.
- The simplest unit of neural networks named *neurons*
- Neurons transfer the information from sense organs to brain and from brain to moving organs
- Each neuron is connected to other neurons and they totally make the neural network system.
- There are more than 100 billion neurons in human body which most of them are located in brain.

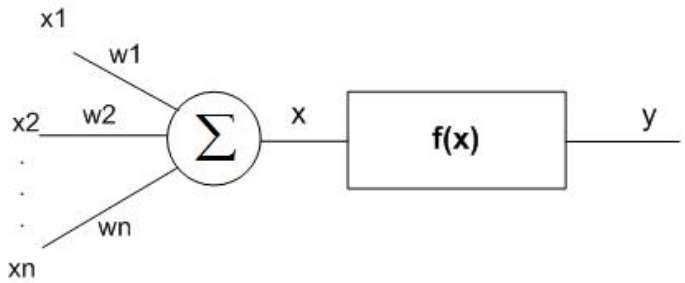


http://people.eku.edu/ritchisong/301images/synapseNAAA.gif

- A biological neuron includes three main parts:
  - **Dendrites:** Receive signals from other neurons.
    - The neurotransmitter chemicals are released to transmitted the signals through synaptic gaps
  - **Soma** or body of the cell which accumulates all input signals.
  - When the input signals reach an action potential threshold, they are transmitted to other neurons through **Axon**
- Each neuron can adapt itself with environment changes
- The neural network structure is changing based on reinforcement and weakening the synaptic connections.
- Learning is obtained by changing the synaptic gaps.

Artificial Neural Networks

- Artificial neural networks is inspired by biological neural networks.
- So the structure of artificial neural networks are based on:
  - Simple elements named neurons where information is processed.
  - Signals are transformed through the connections between neurons.
  - To each connection a *weight* is assigned which is multiplied to the transferring signal.
  - At each neuron there is an *activation function* which is normally a nonlinear function. This function provides the output of the neuron.



A neuron

- $x = w_1x_1 + w_2x_2 + ... + w_nx_n, \quad X = Wx, \quad y = f(X)$

- Each artificial neural network (NN) is distinguished by
  - Pattern of connection between neurons (Neural network structure)
  - Method of defining weights (Learning)
  - Activation function
- By adjusting the weights, (synaptic gaps in biological neurons) the neural network learn a pattern.
- How much the artificial neural networks are similar to the biological neural networks?
  - It varies in different type of artificial neural networks based on its application.
  - For some researchers such as engineers high performance of the network in calculations and function approximation is more important.
  - In some research areas like neurology, emulating the biological behavior is more attractive.

- In general the artificial NNs and biological neural networks are similar in
  1. The processing elements (neurons) receive signals
  2. Signals can be modified by weights (synaptic gaps)
  3. Processing elements gather the weighed inputs
  4. Under specified condition, the neuron provides output signal
  5. Output of a neuron can be transferred to other neurons
  6. The power of each synapse (weights) varies in different experience.
- Neural Networks (NNs) capabilities
  - Learning
  - Parallel Processing
  - Generalization
    - When a NN is trained, it can generalized its knowledge to the inputs which has not seen before
    - For example if a NN is used for recognizing letters, if it receive a noisy input, it still can recognize it and deliver the letter without noise.
  - Fault toleration
    - NN can tolerate its malfunctioning in some circumstances.
    - Human is born with 100 billion neurons which some of them die but learning does not stop!!
    - Artificial NN should behave the same.

Neural Network Applications

1. Signal Processing
   - Such as eliminating echo on telephone lines
2. Control (NN can be applied for nonlinear systems)
   - Identification, unmodeled dynamics, variable parameters
   - Observation
   - Control of nonlinear system
3. Pattern Recognition
   - Handwriting
   - Finger print
4. Medical
   - Help in diagnosing diseases based on symptoms
5. Speech Recognition
   - In classic methods, some rules are defined for standard pronunciation of letters and a look-up table for exceptions.
   - In NN, there is no need to extract the rules and exceptions. NN is trained based on I/o data.

- Structure of NN
  - Single layer
  - Multiple layer
    - Feedforward
    - Feedback (Recurrent)
- Training NN
  - Supervised
  - Unsupervised
- Activation Function
  - Linear
  - Sigmoid, ...

Reference Books

- **Text Books:**
  1. A Course in Fuzzy Systems and Control, L. X. Wang, Prentice-Hall International, Inc,1997
  2. Introduction to Artificial Neural Systems, J. K. Zurada, West publishing company, 2nd edition 2006
- **Other Reference Books:**
  1. Fuzzy Logic with Engineering Applications, T. J. Ross, John Wiley and Sons, 2nd edition 2004
  2. Fundamentals of Neural Networks Architectures, Algorithms and Applications, L. Faussett, , Prentice-Hall, 1994
  3. Neural networks and learning machines, S. S. Haykin, Prentice Hall , third edition,2008
  4. Fundamentals of Neural Networks, M. B. Menhaj, Amirkabir University of Technology, 2009 (in Farsi)
  5. Fuzzy Computations, M. B. Menhaj, 2^{nd} edition, Danesh Negar, 1388 (in Farsi)

Topics

Topic	Date	Refs
Introduction to Neural Networks	Week 1	Chap. 2
Feed-forward Networks	Week 2,3	Chap. 3,4
Radial Bases Functions	Week 4	
Associative Memories, Competitive Networks	Week 5,6	Chap. 6,7
Introduction to Fuzzy Systems	Week 7	Chap. 1
Fuzzy Sets and Fuzzy Relations	Weeks 8,9	Chap. 2-4
Linguistic Variables and Fuzzy Rules	Week 10	Chap. 5
Fuzzy Systems(Inference Engine, Fuzzifier, Defuzzifier,, Nonlinear Mapping)	Weeks 11,12	Chap. 7,8
Design of Fuzzy Systems	Week 13	Chap. 13
Applications of Comp. Intelligence in Mechatronic Systems	Week 14,15	

- L. A. Zadeh, "Fuzzy sets," *Informat. Control*, vol. 8, , pp. 338–353, 1965.
- E. H. mamdani and S. Assilian, "An experiment in linguistic synthesis with a fuzzy logic controller," *Internationa Journal of Man Machin Studies*, vol. 7, no. 1 , pp. 1–13, 1975.
- T. Takagi and M. Sugeno, "Fuzzy identification of systems and its applications to modeling and control," *IEEE Trans. on Systems, Man, and Cybern.*, vol. 15, no 1 , pp. 116–132, 1983.