# *Fuzzy Logic in Medical Imaging*

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## Malayaia

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- **What is Fuzzy Logic**
- **Fuzzy Logic in Image Processing**
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- **Fuzzy Logic in Medical Imaging**
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# Introduction of Fuzzy Logic

• Fuzzy Logic was initiated in 1965 by Professor Lotfi Zadeh.

• It is basically a multi-valued logic that allows intermediate values to be defined between conventional boolean logic like true/false, yes/no, black/white.

• Human-like way of thinking e.g. warm, hot, very hot.

|  | Boolean Logic | | | Fuzzy Logic | |
|---|---|---|---|---|---|
| IF | TRUE | FALSE | IF | TRUE | FALSE |
| AND/OR | TRUE | FALSE | AND/OR | TRUE | FALSE |
| THEN | TRUE | FALSE | THEN | TRUE | FALSE |

# Fuzzy Predicates

- **Expensive**
- **Safe**
- **Old**
- **Rare**
- **Dangerous**
- **Educated**
- **Tall**
- **Heavy**
- **Smooth**
- **Rough**
- **Beautiful**

# *Fuzzy Quantifiers*

- **Many**
- **Few**
- **Almost**
- **All**
- **Usually**
- **Almost nobody**
- **Almost everybody**

# *Fuzzy Truth Values*

- **Extremely True**
- **Quite True**
- **Very True**
- **Almost True**
- **More or less True**
- **Mostly True**
- **Mostly False**
- **More or less False**
- **Almost False**
- **Quite False**
- **Very False**
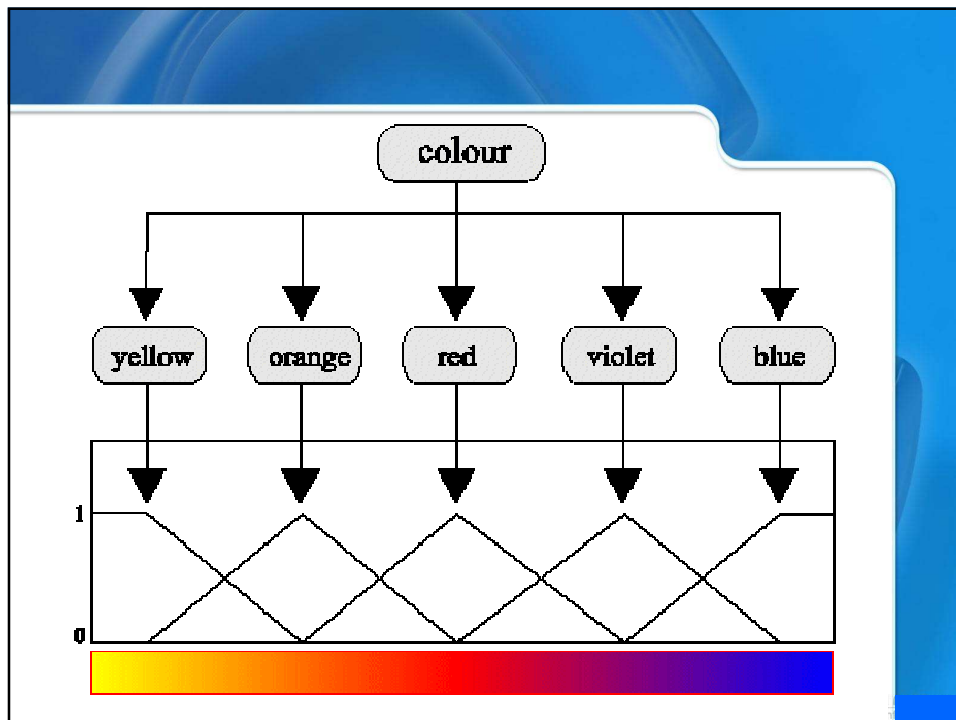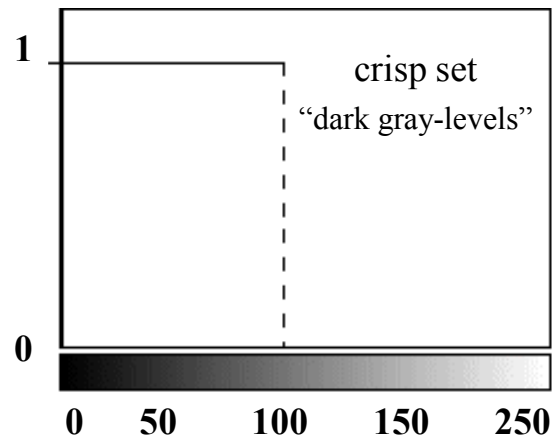- **Quite False**
- **Extremely False**

# *Fuzzy Modifiers*

- **Likely**
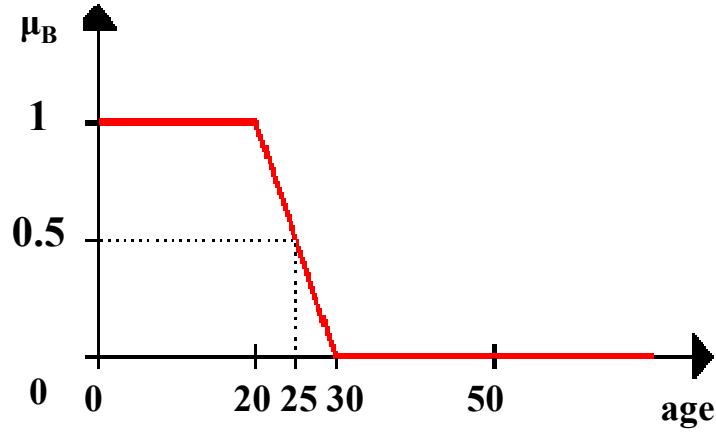- **Extremely Unlikely**
- **Almost Impossible**

# *Fuzzy Relational Operators*

- **Equal**
- **Slightly greater than**
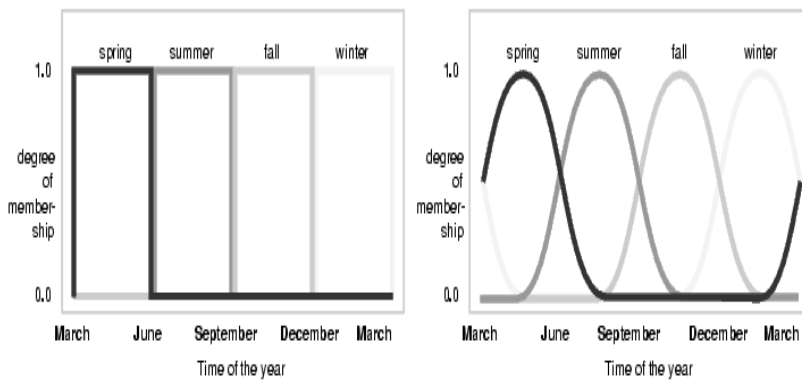- **Much greater than**
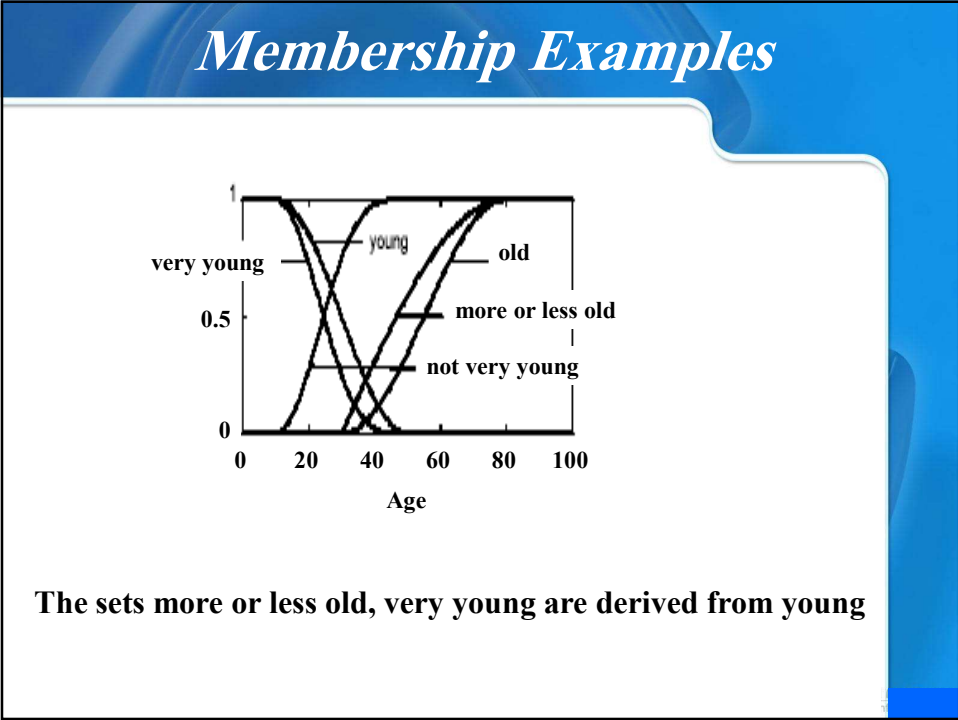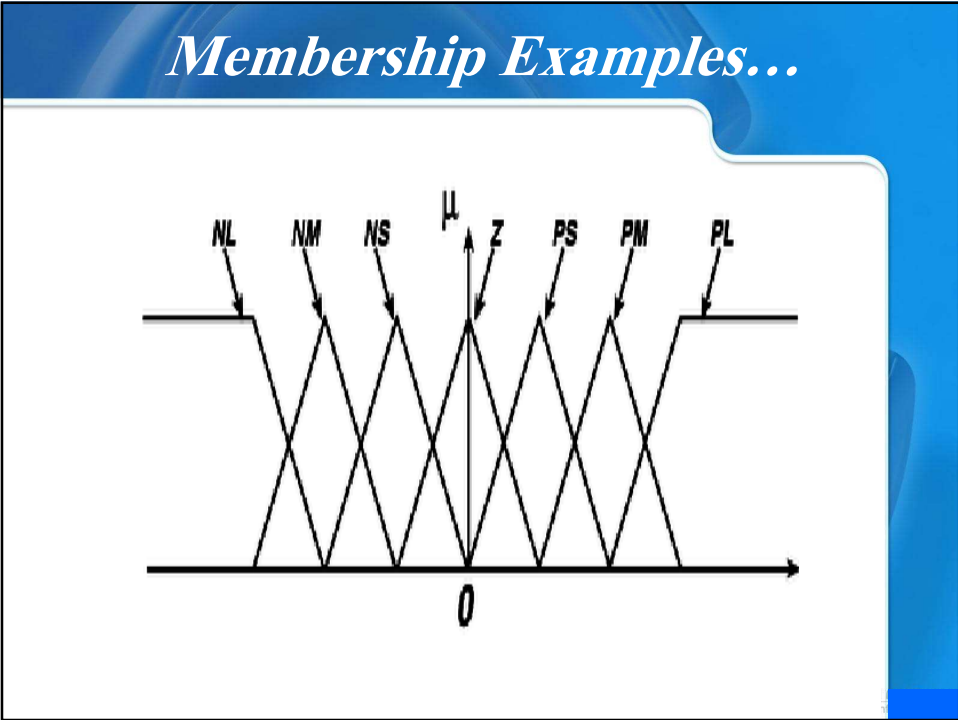- **Much less than**

# Gray Level Crisp and Fuzzy

crisp set
"dark gray-levels"

1

0

0    50    100    150    250

colour

yellow    orange    red    violet    blue

1

0

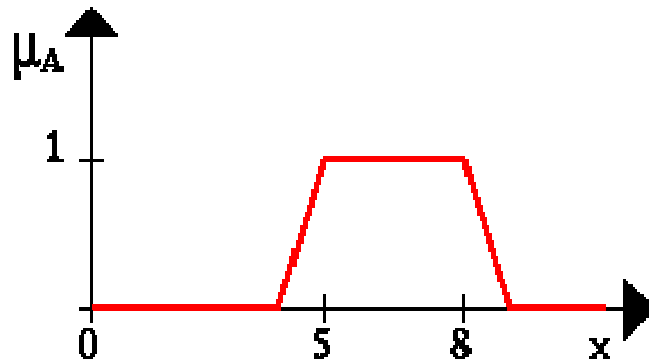# Membership of Young age



# Membership Examples…

## Membership Examples…

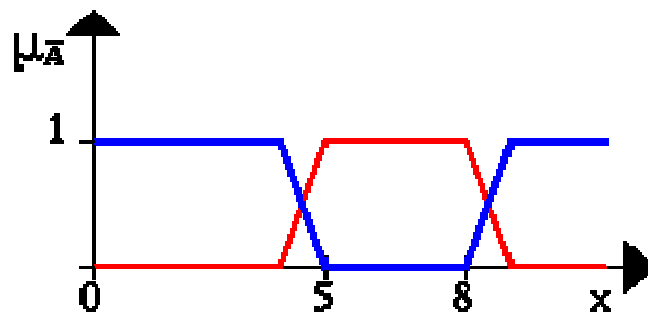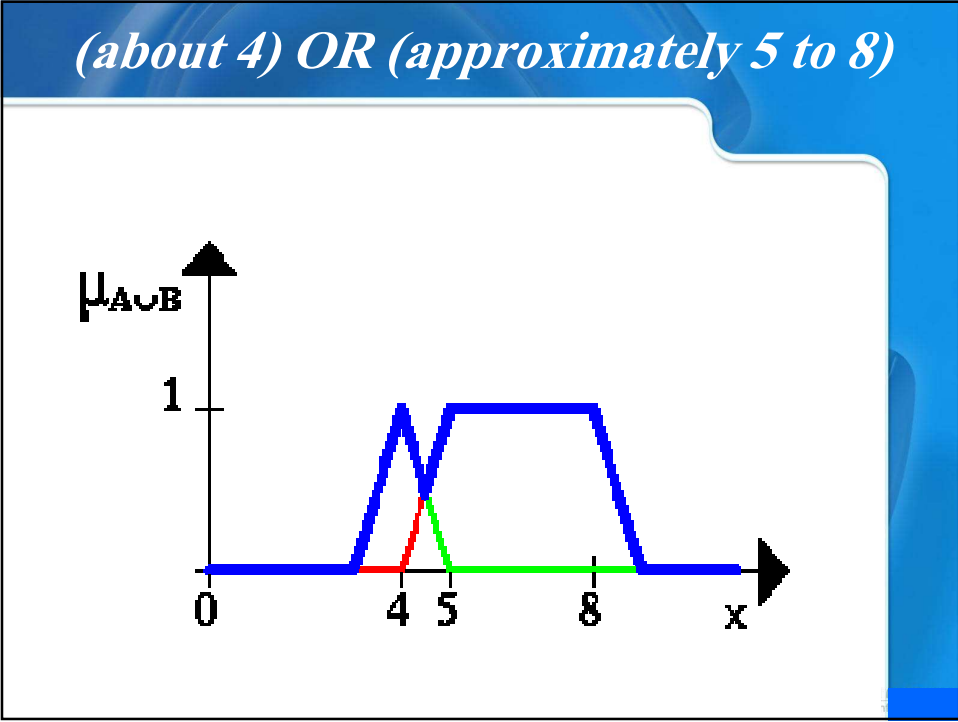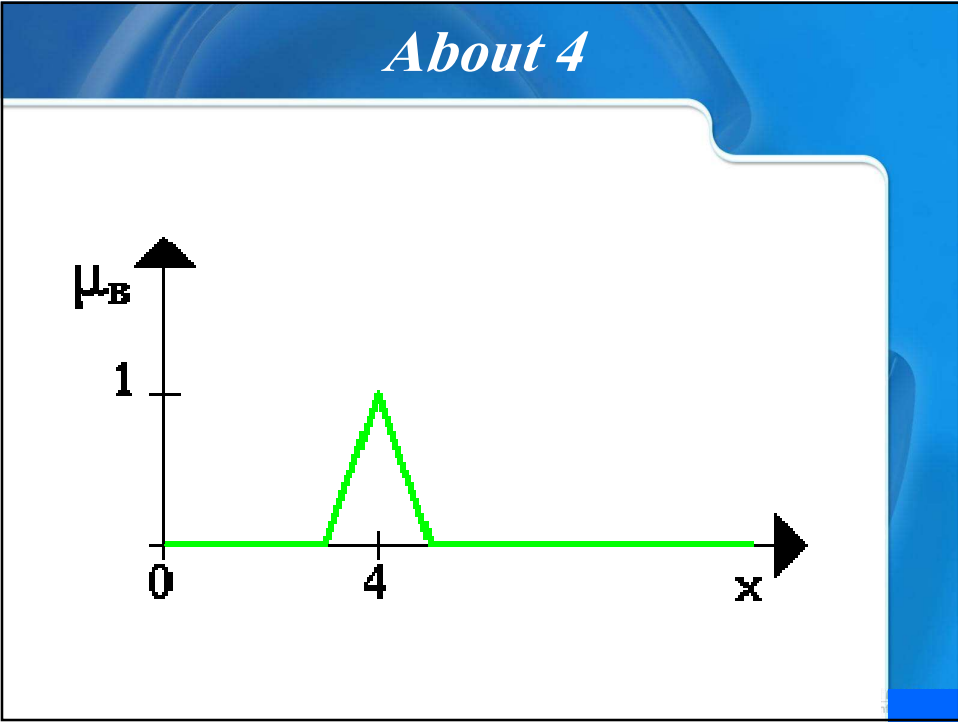

## Membership Examples



**The sets more or less old, very young are derived from young**

# Membership (approximately Five to Eight)



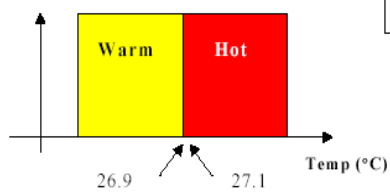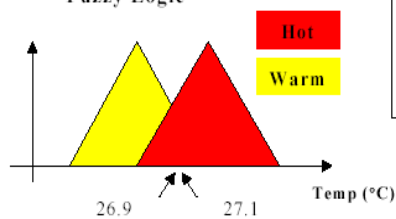# (approximately 5 to 8) and not (approximately 5 to 8)

## About 4



## (about 4) OR (approximately 5 to 8)

*(about 4) AND ( approximately 4 to 8)*
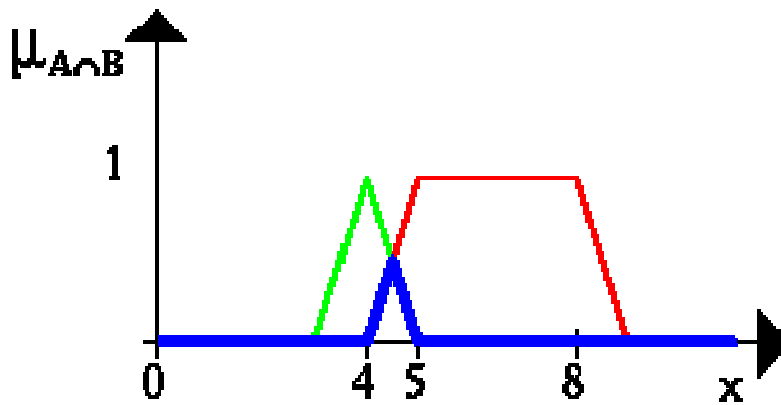
# The three primitive set operations.
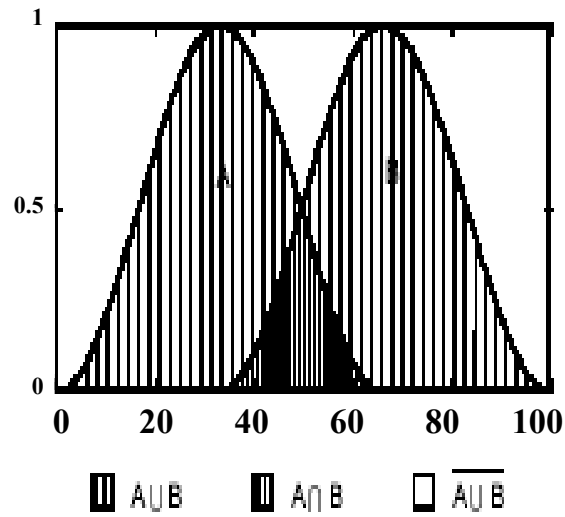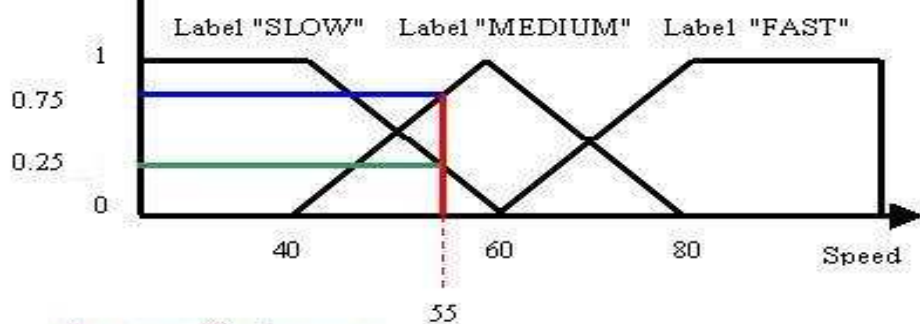
# Rule Based System Architectures

- Rules**: IF : Condition-i** and **Condition-2** and **Condition-3**
  Then **: Take Action-4**

**Examples:**

- IF  **Temperature> 32C,** and **Outlet- pressure- of- the- gases>
  10 Atmosphere** and **valve-i is closed** THEN **open valve-2**
- IF **The shunt- field- current <0.01 A** and **Armature- current
  >20A** Then  **shut- down- the- Supply**
- IF **Resistance-i is hot** and **Vottage-2 <6V** Then  **Capacitor-2
  is faulty** Because **Capacitor-2 fault causes excessive
  current through Resistance-i**

# (i) Create Rule Base

- **Fuzzy processor uses linguistic rules to
  determine what control action should occur in
  response to a given set of input values**

- **Rule evaluation also referred as fuzzy inference,
  evaluates each rule with the inputs that were
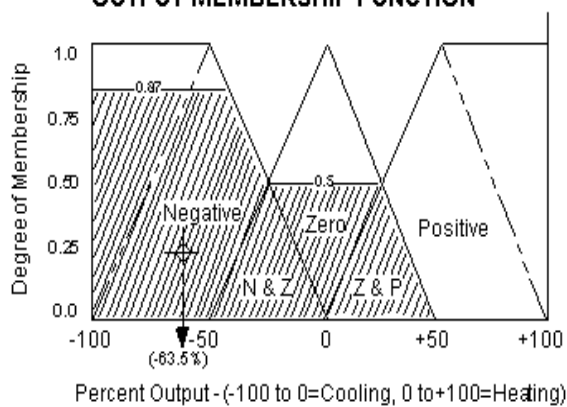  generated from the fuzzification process.**

**Syntax of rules**

- **IF *antecedent 1* AND *antecedent 2* AND …. THEN
  *Consequent 1* AND ……...**

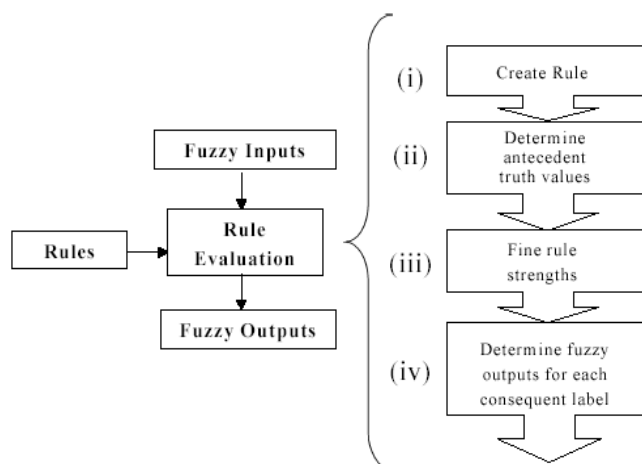## A two Input, two rule Mamdani FIS with a fuzzy input
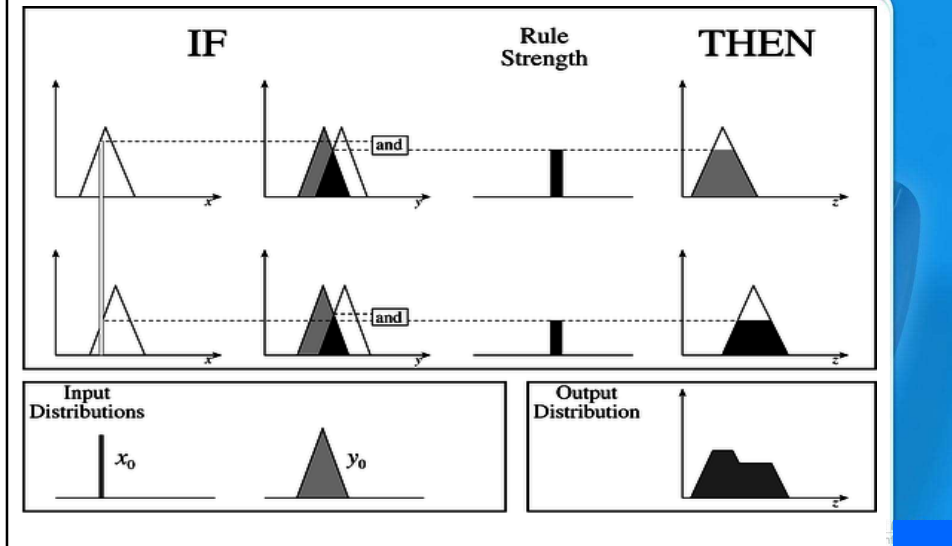
## *(iii) Find Rule Strength*

- Rule 1: If **temperature is** *hot(0.3)* AND **soil is** *dry(0.7)*, then **water duration is** *long*.

- Rule 2: If **temperature is warm***(0.8)* AND **soil is** *dry(0.7)*, then **water duration is** *long.*

- **To acquire the rule strength each rule, using MIN method to get the min.**

- **value of fuzzy inputs.**

- **For Rule 1, the rule strength = MIN(0.3,0.7) = 0.3**

- **For Rule 2, the rule strength = MIN(0.8,0.7) = 0.7**

## *Rule Evaluation/Interface (Step 2)*

## Example of creating a Water sprinkler system

Input membership function

Air Temperature

Soil Moisture

Fuzzy Input

Rule Inference

Fuzzy Output

Output membership function

Input membership function
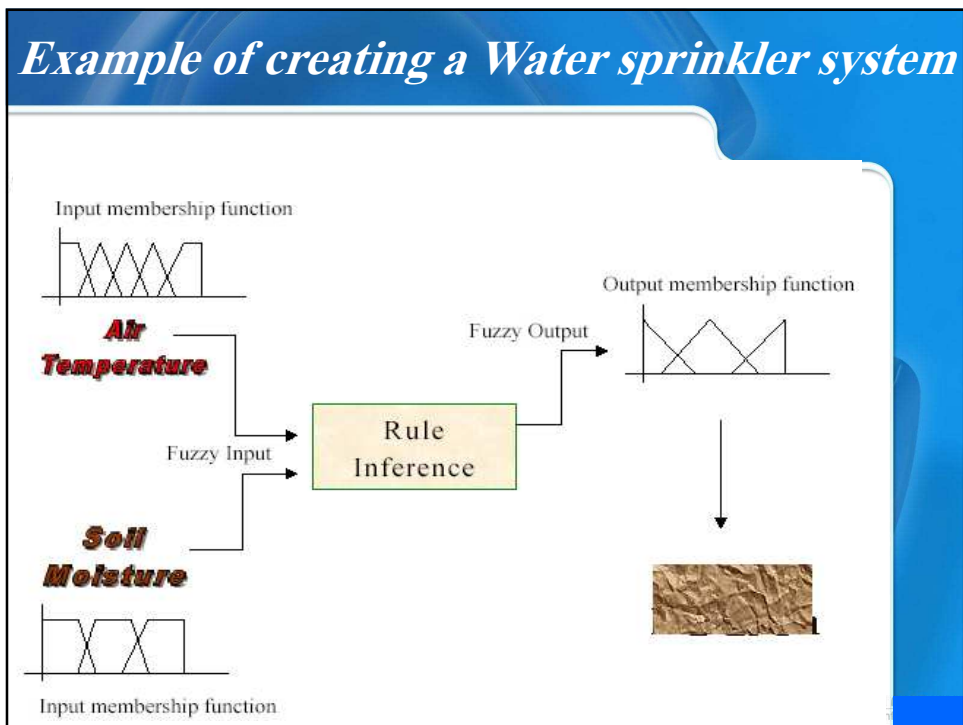
## Rule Evaluation

(i) Create Rule Base

Antecedent 1

| Moisture | Temperature | | | | |
|---|---|---|---|---|---|
| | Cold | Cool | Normal | Warm | Hot |
| Wet | short | short | short | short | short |
| Moist | short | med. | med. | med. | med. |
| Dry | long | long | long | long | long |

Antecedent 2

Sample rules extract from the table in above table
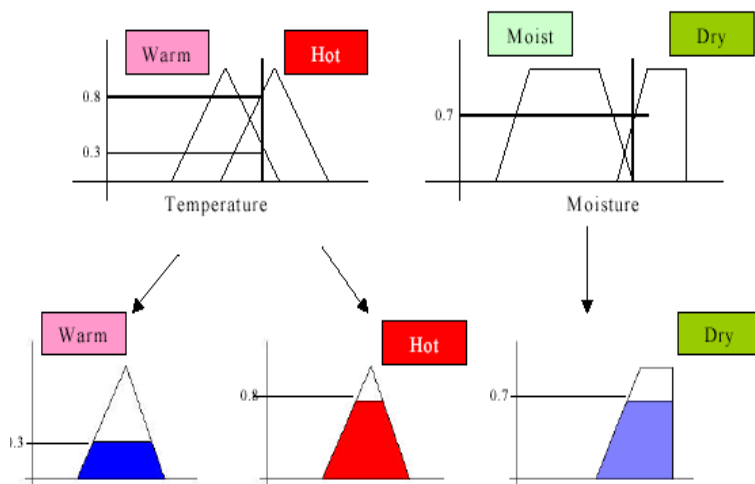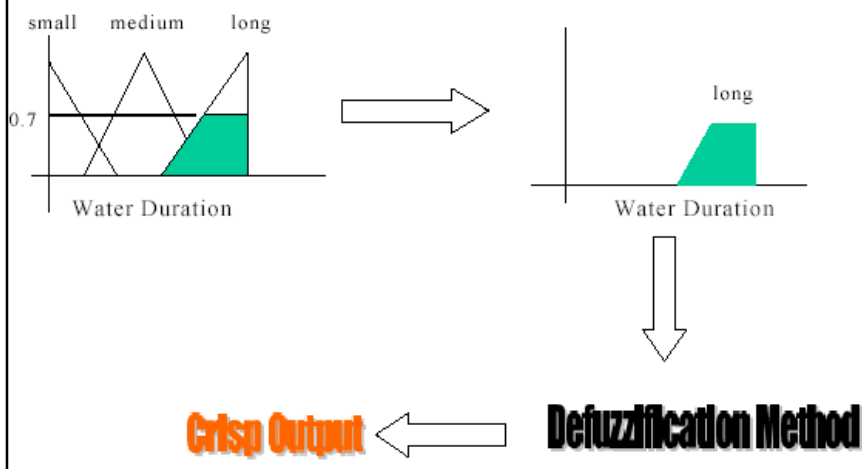
• **If** temperature is *hot* **AND** soil is *dry*, **then** water duration is *long*.

• **If** temperature is *cold* **AND** soil is *dry*, **then** water duration is *long*.
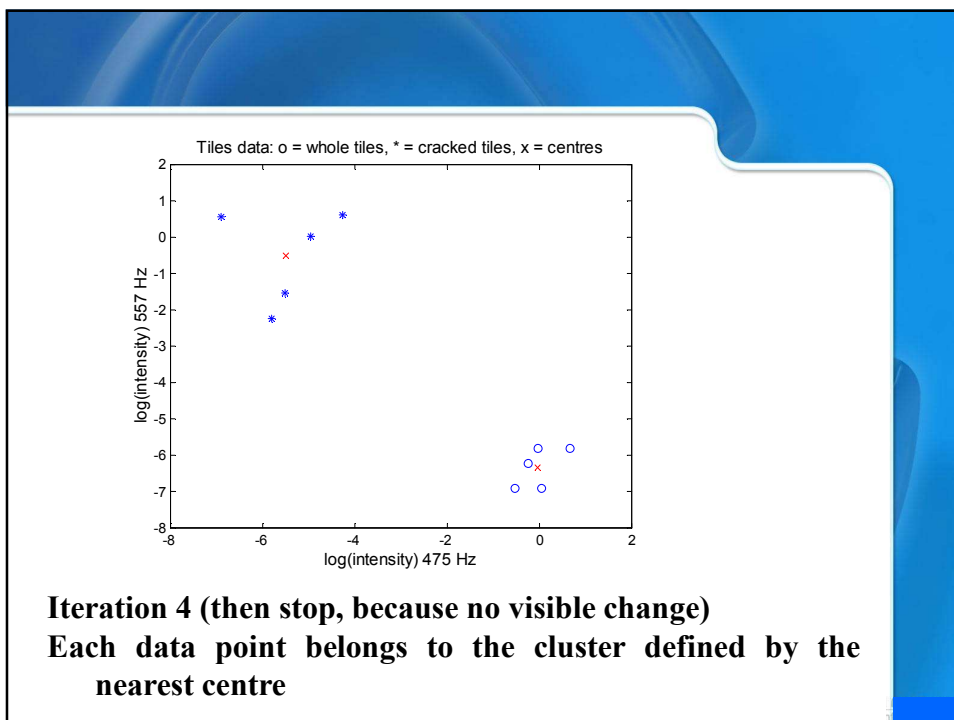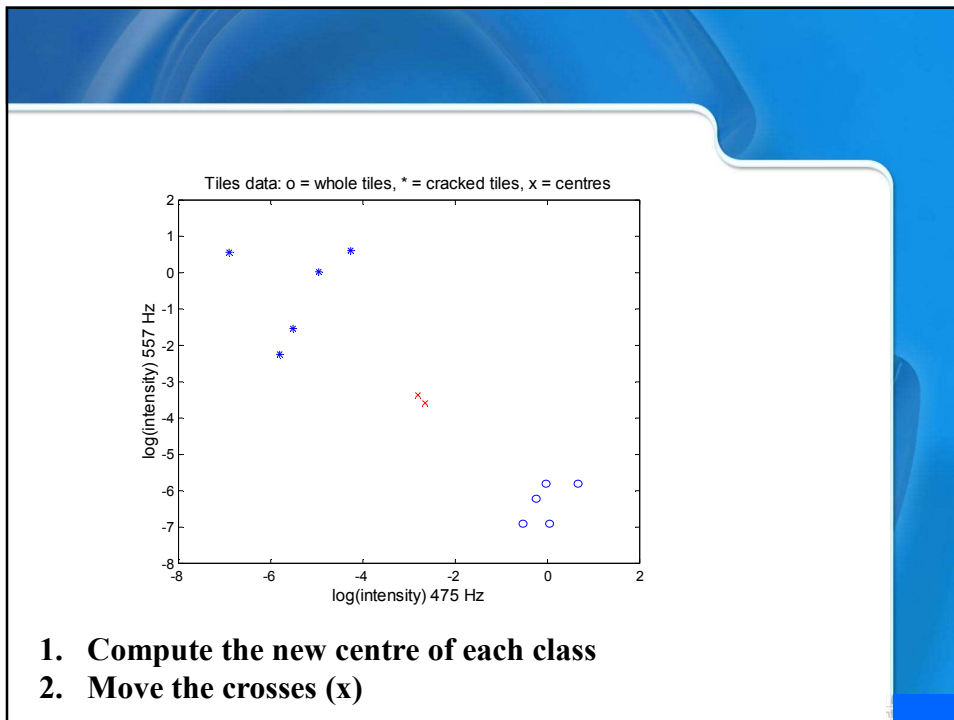
(ii) Determine antecedent truth values



# *Defuzzification*

# *FUZZY IMAGE PROCESSING*
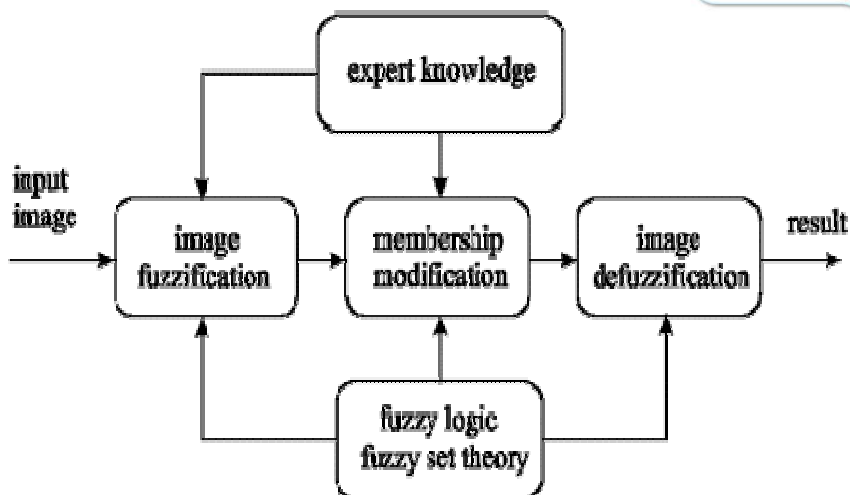
- *Fuzzy Clustering*
- *Line Pattern Matching*
- *Optimal Image Thresholding*
- *Fuzzy Rule-based Systems*
- *Combined Classifiers*
- *Fuzzy Contrast Adjustment*
- *Fuzzy Image Segmentation*
- *Fuzzy Edge Detection*

# Fuzzy Clustering

- C-Means Algorithm
- Fuzzy C-Means Algorithm
- Comparison between Hard and Fuzzy Clustering Algorithms
- Cluster Validity
- Applications

Tiles data: o = whole tiles, * = cracked tiles, x = centres

1. **Compute the new centre of each class**
2. **Move the crosses (x)**



Tiles data: o = whole tiles, * = cracked tiles, x = centres

**Iteration 4 (then stop, because no visible change)**
**Each data point belongs to the cluster defined by the nearest centre**

## *The general structure of fuzzy image processing*



# Fuzzy Rule-Based Systems

- **Learning from Examples**
- **Decision Tree Approach**
- **Fuzzy Aggregation Network Approach**
- **Minimization of Fuzzy Rules**
- **Defuzzification  and Optimization**

## *Fuzzy Logic in Medical Decision Making*

- *The sugar level in the blood, for a normal human being, should be between 80-120mg per 100 ml. If it exceeds 120mg the person is said to be diabetic. But there are certain situations when the person may not be diabetic even if the sugar level in the blood exceeds 120mg. As examples, after a person exercises hard, the sugar level increases over 120mg, and for a pregnant woman, in her normal course of pregnancy, the sugar level in her blood may be more than 120mg. But in both these cases we cannot say that the patients are diabetic. Hence uncertainty arises, and fuzzy decision making can be applied here.*

## *Fuzzy Presentation of Medical Data*

- mean arterial pressure (MAP)
- systolic arterial pressure (SAP)
- heart rate (HR)

  into mutually exclusive very low (VL), low (L), normal (N), high    (H), and very high (VH) categories.

## Fuzzy membership functions for MAP
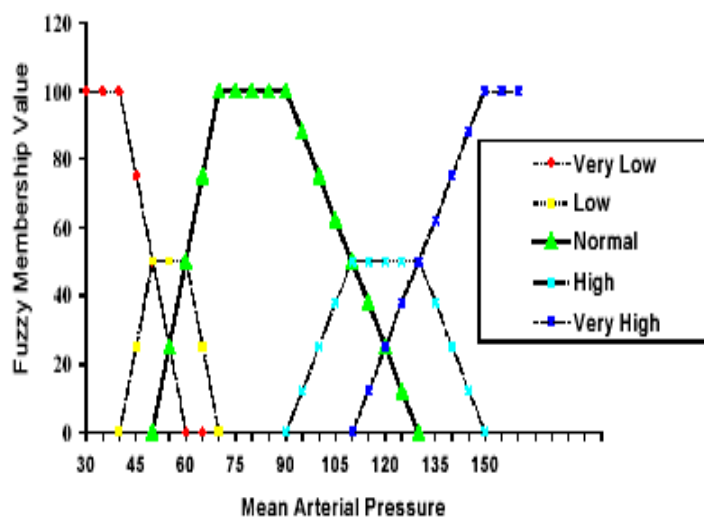


## Fuzzy Logic Control of Inspired Oxygen Concentration in Ventilated Newborn Infants
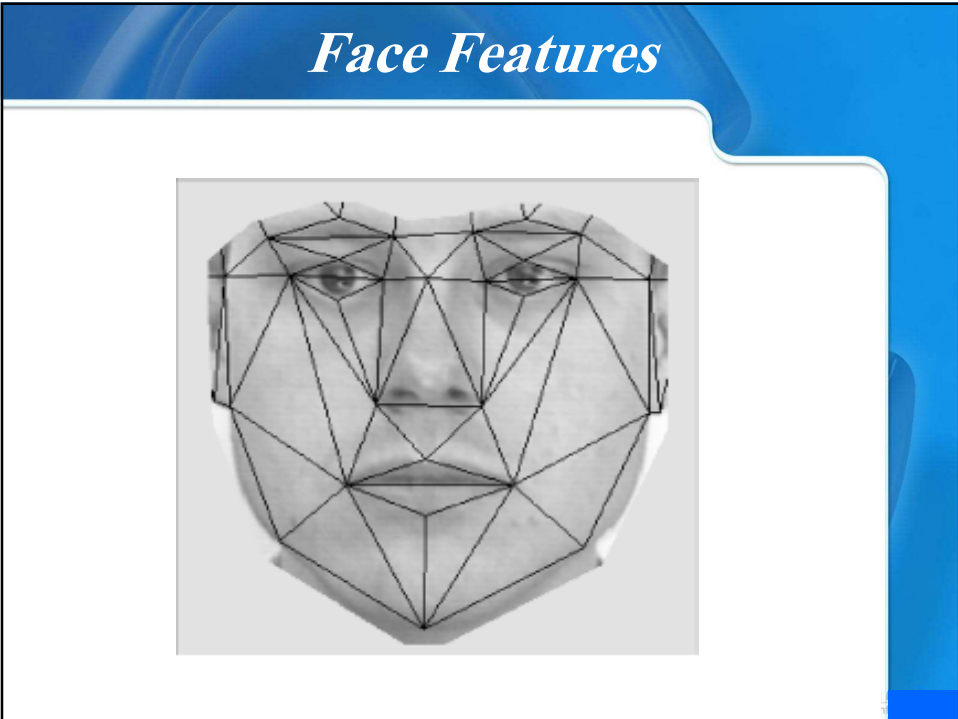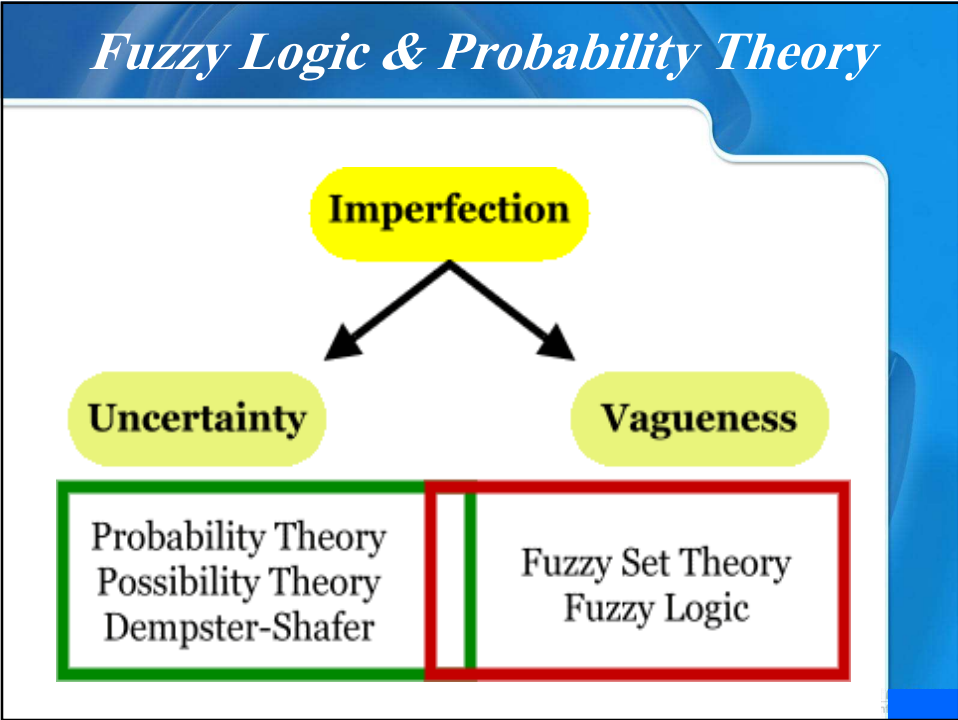
- Rule: IF the [[Delta]]SaO2 is small-negative
- AND the SaO2-slope is medium-negative
- *(situation)*
- THEN increase the FIO2 by a
- medium-positive amount.
- *(action)*
- Rule: IF the [[Delta]]SaO2 is large-negative
- AND the SaO2-slope is large-negative
- THEN increase the FIO2 by an
- extremely-large-positive amount.
- Rule: IF the [[Delta]]SaO2 is small-negative
- AND the SaO2-slope is small-positive
- THEN do nothing.

# Line Pattern Matching

- **Similarity Measures between Line Segments**
- **Basic Matching Algorithm**
- **Dealing with Noisy Patterns**
- **Dealing with Rotated Patterns**
- **Applications**

# *Optimal Image Thresholding*

- *Optimal Image Thresholding*
- **Threshold Selection Based on Statistical Decision Theory**
- **Non-fuzzy Thresholding Algorithms**
- **Fuzzy Thresholding Algorithm**
- **Formulation Thresholding Algorithms**
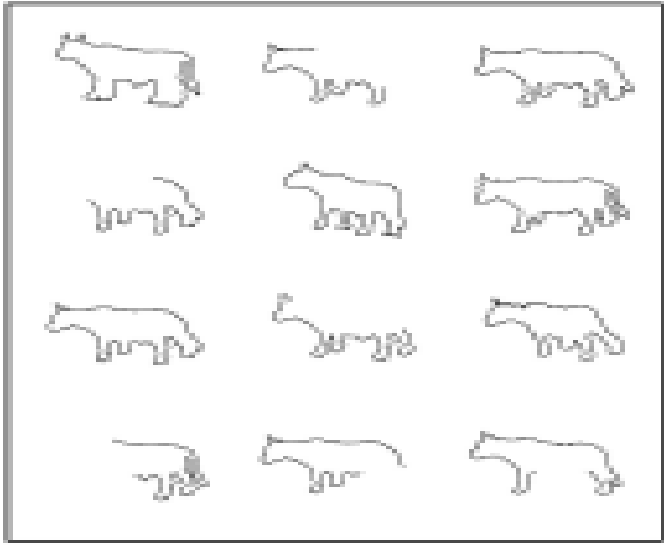- **Multilevel Thresholding**
- **Applications**

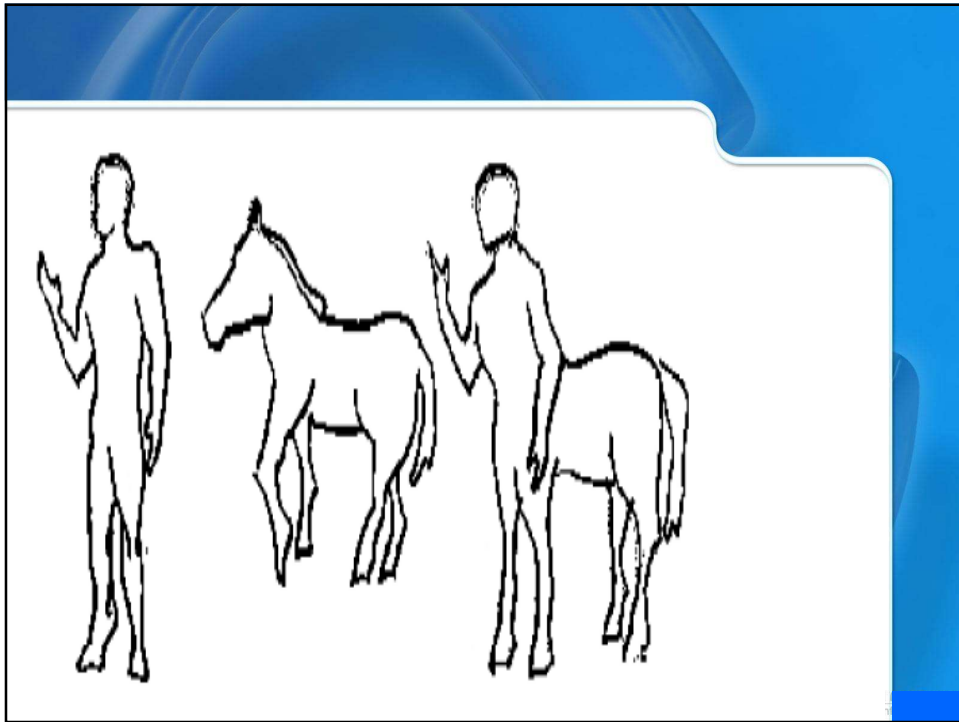## Fuzzy Logic & Probability Theory

**Imperfection**

**Uncertainty**

**Vagueness**

Probability Theory
Possibility Theory
Dempster-Shafer

Fuzzy Set Theory
Fuzzy Logic

## Face Features
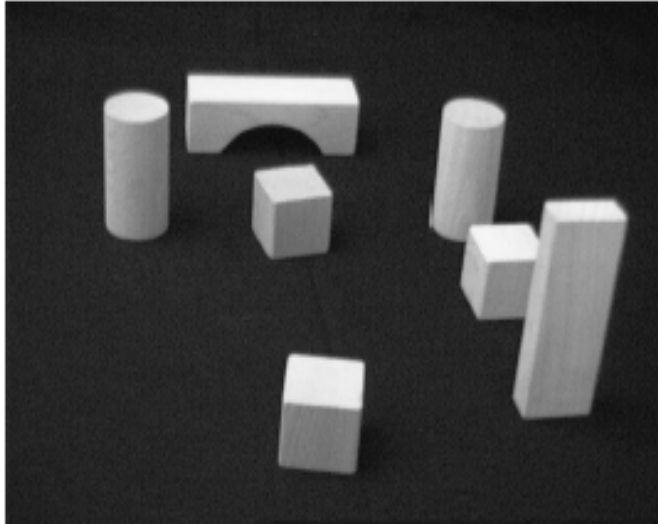
# Face Recognition

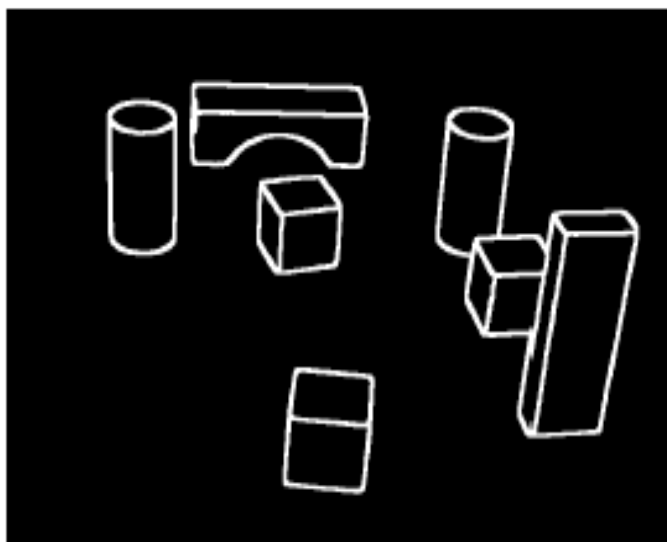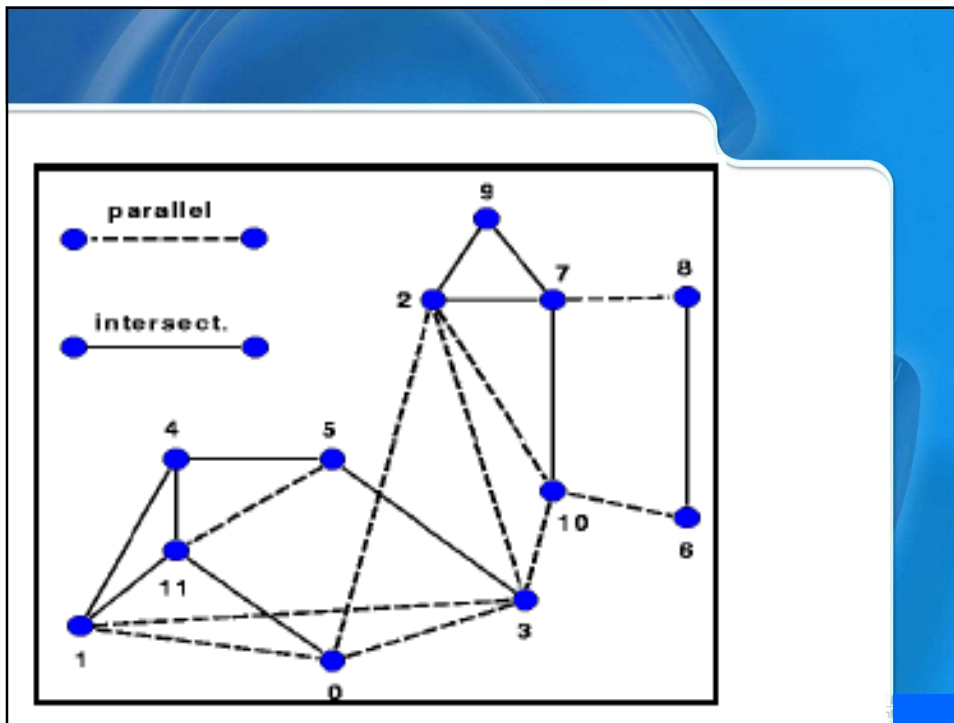# Fuzzy Relational Structures
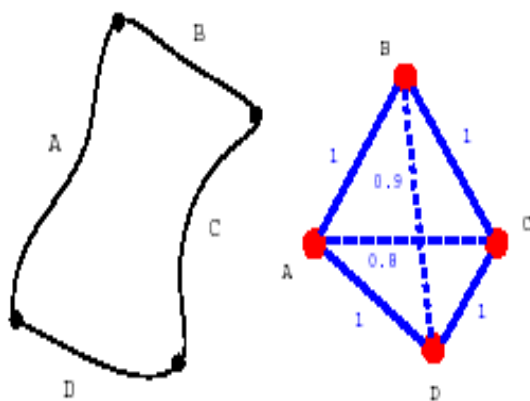


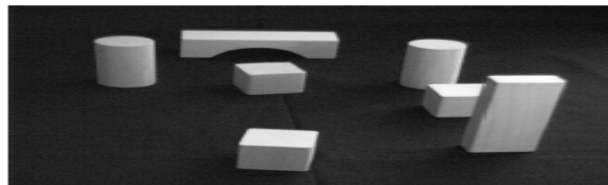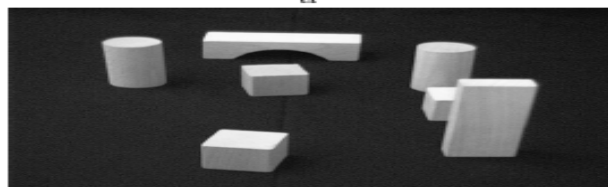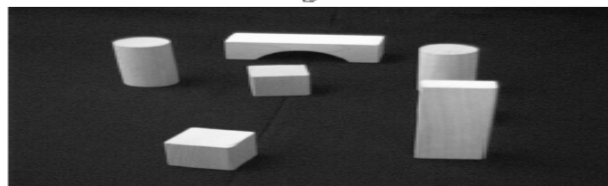**Controls and associated fuzzy graph.**

# A Set of objects
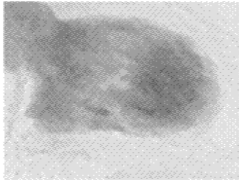

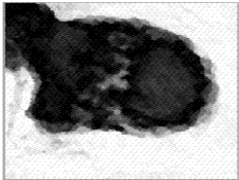
# Outer Edges of the Objects
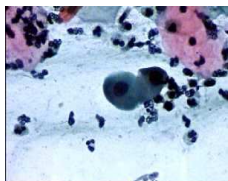
## The objects with slight movements

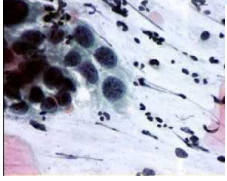## SEGMENTATION OF VENTRICULAR ANGIOGRAPHIC IMAGES USING FUZZY CLUSTERING



- (a) Original image after logarithmic subtraction and median filtering;
- (b) Fuzzy membership function of the ventricle region;
- (c) Segmentation obtained from the fuzzy membership function in
- (b) by using neighborhood processing.

# Example: Classify cancer cells



Normal smear



Severely dysplastic smear

Using a small brush, cotton stick, or wooden stick, a specimen is taken from the uterin cervix and smeared onto a thin, rectangular glass plate, a slide. The purpose of the smear screening is to diagnose pre-malignant cell changes before they progress to cancer. The smear is stained using the Papanicolau method, hence the name *Pap smear*. Different characteristics have different colours, easy to distinguish in a microscope. A cyto-technician performs the screening in a microscope. It is time consuming and prone to error, as each slide may contain up to 300.000 cells.

Dysplastic cells have undergone precancerous changes. They generally have longer and darker nuclei, and they have a tendency to cling together in large clusters. Mildly dysplastic cels have enlarged and bright nuclei. Moderately dysplastic cells have larger and darker nuclei. Severely dysplastic cells have large, dark, and often oddly shaped nuclei. The cytoplasm is dark, and it is relatively small.

# Fuzzy Classifier (FCM)
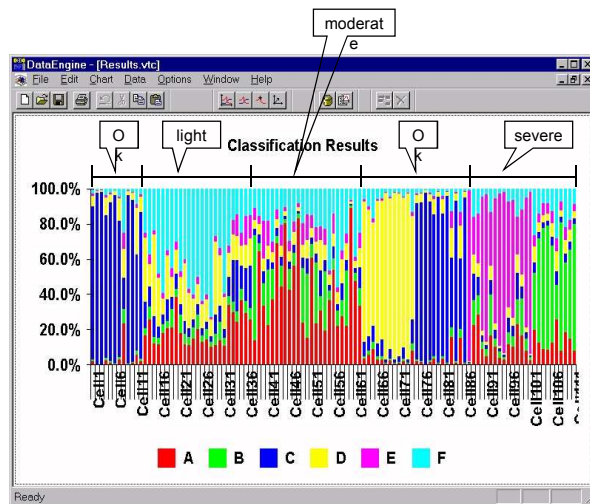


A cell can belong to several classes to a Degree, i.e., one column may have several colours.

# Prostate Tissue differentiation in Ultrasound Images

- **Cancer Diagnosis and Surgery Planning of the Female Pelvis**

## *Fuzzy Segmentation of Magnetic Resonance Images*



(a)　　　(b)　　　(c)　　　(d)
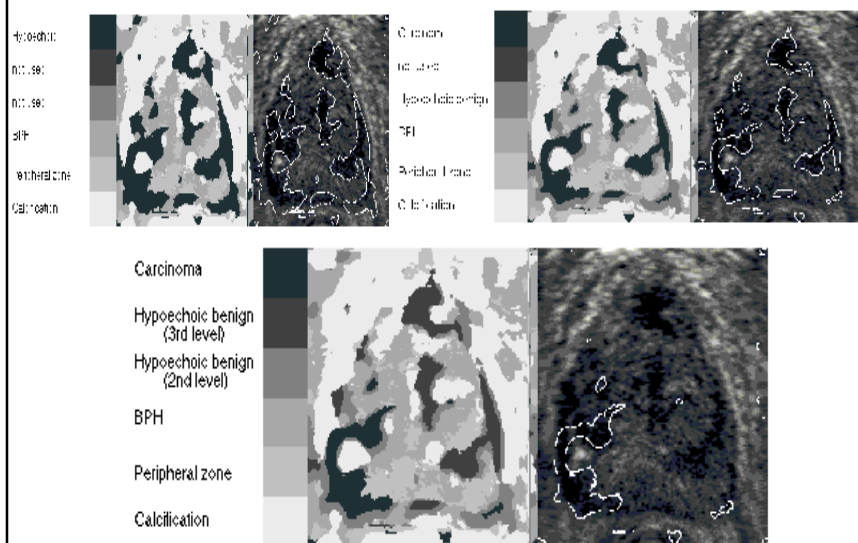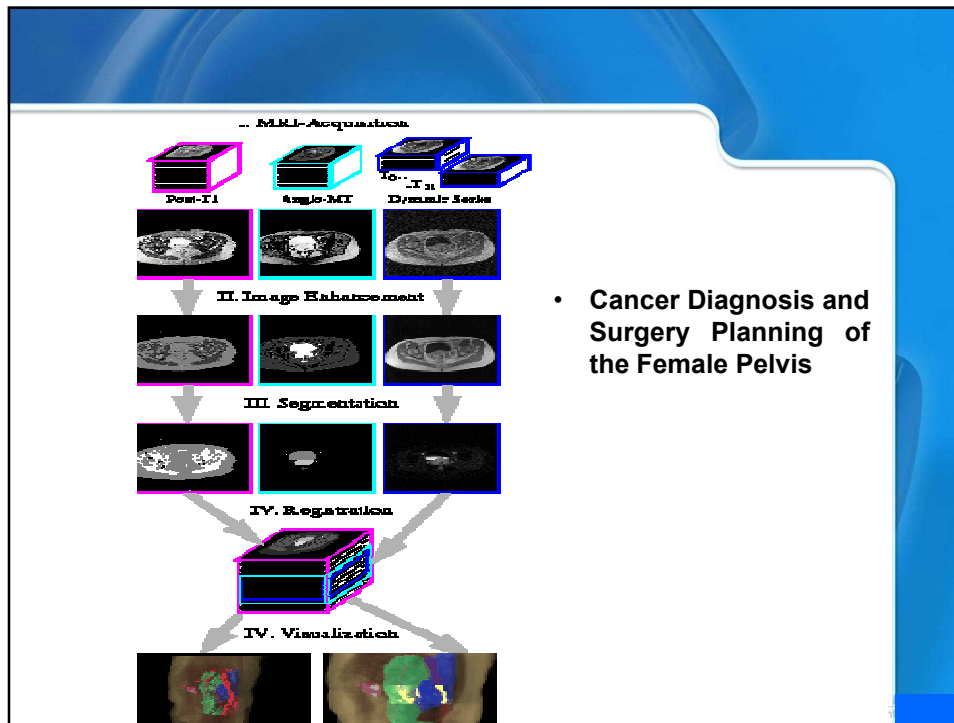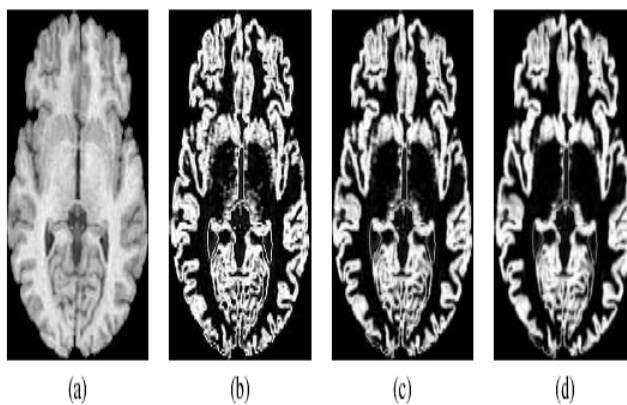
Figure 1: Application of FANTASM to MR image: (a) original image, (b) FCM gray matter membership, (c) FANTASM gray matter membership ($\beta = 100$), (d) FANTASM gray matter membership ($\beta = 250$)

## *Fuzzy Relative Position Between Objects in Image Processing*

- **fuzzy "landscape" around the reference object *R* as a fuzzy set**

- **compare the object *A* to the fuzzy landscape attached to *R***

## *Fuzzy Connectedness*



(a.)

**Figure 1. Illustration of the key ideas behind iterative relative fuzzy connectedness.**

Figure 3. (a) A MIP rendition of original MRA scene from a patient. (b),(c) The arterial and the veinous trees separated using iterative relative connectedness. (d) The veinous tree obtained by thresholding the connectivity scene. Note that the images in (b)—(d) are renditions of the 3D fuzzy objects obtained by respective segmentation strategies.
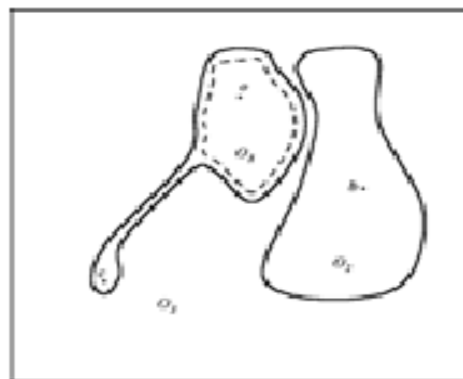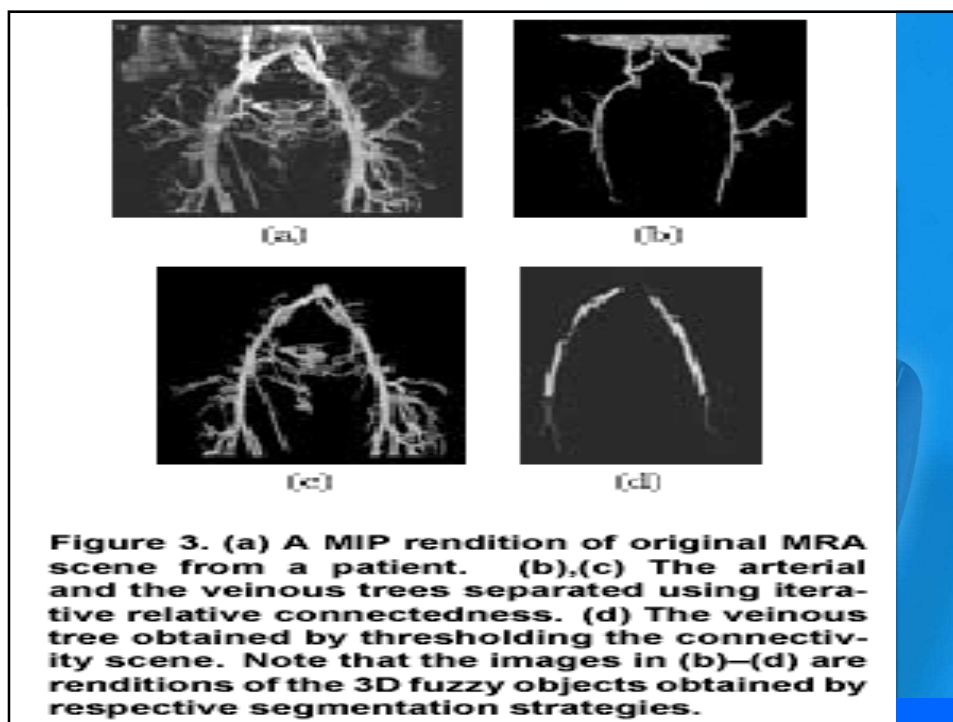
# *Relational region matching*

- **Image region attributes: perimeter, area, shape, mean/max/min radius, centre of gravity, and amplitude, histogram, average gray values**
- **attributes of the regions, or calculable inter-relationships between them**
- **compares similarities between weighted region property values in the reference and the target images in order to find the best match**

# Combined Classifiers

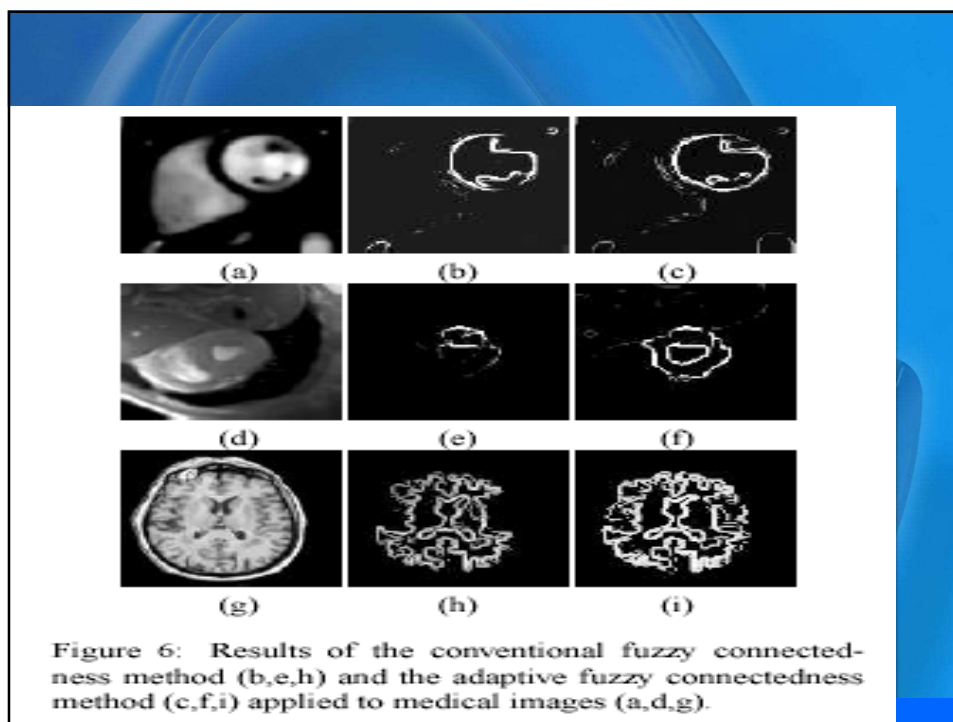- **Voting Schemes**
- **Maximum Posteriori Probability**
- **Multilayer Perceptron Approach**
- **Fuzzy Measures and Fuzzy Integrals**
- **Applications**

# *Medical Imagery Inexact Relational Matching*

- *Matching/fusion strategies*
- *Inexact matching*
- *2D/3D medical imagery*
- *Rule-based knowledge representation*
- *Tree search*
- *Segmented into non-touching and non-overlapping regions,*
- *Image region attributes and their inter-relationships (relations) Region matches are obtained using a tree search*
- *Error is minimised by evaluating a "goodness of matching" Spline geometric transform*
- *Regional centers of gravity*

Figure 6: Results of the conventional fuzzy connected-ness method (b,e,h) and the adaptive fuzzy connectedness method (c,f,i) applied to medical images (a,d,g).

# Reasoning with medical knowledge

– **Expert or knowledge-based systems are the most common type of AIM system in routine clinical use**

– **Contain medical knowledge about a very specifically defined task (like allergy)**

– **Able to reason with data from individual patients to come up with reasoned conclusions**

– **Knowledge within an expert system is typically represented in the form of a set of rules.**

– *Diagnostic assistance:* **An expert system can help come up with likely diagnoses based on patient data.**

# MYCIN's Certainty Factors

- **Uncertainty formalism developed for the early expert**
- *measure of belief:* **MB(h; e) 2 [0; 1]**
-  *measure of disbelief:* **MD(h; e) 2 [0; 1]**
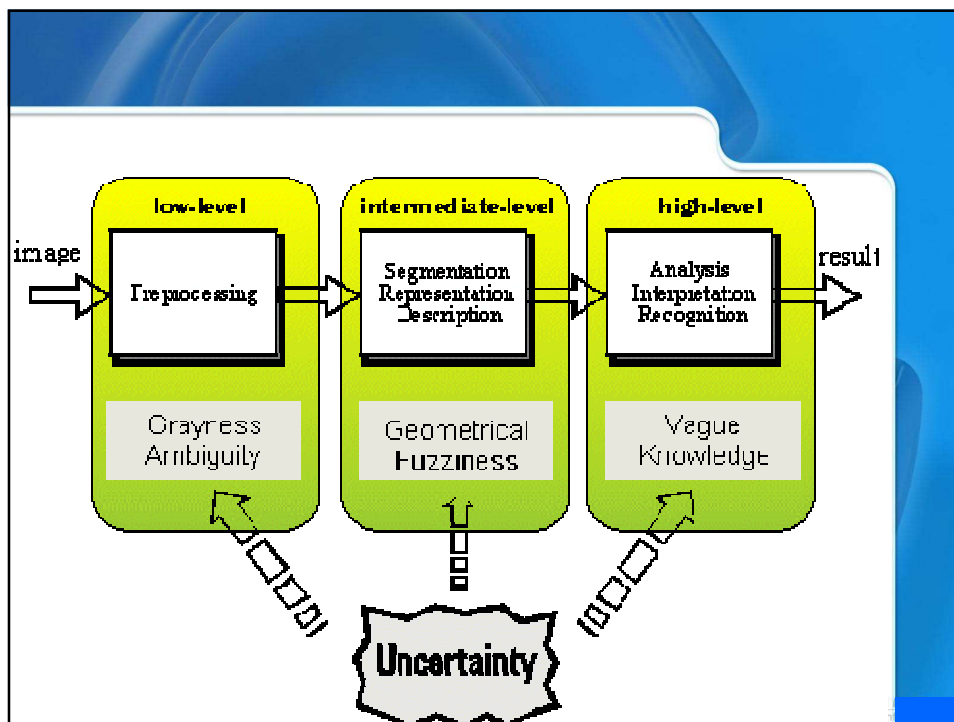
# *Fuzzy Health in Medical Theory*

- **Sadegh-Zadeh's statements on the present state of the theory of medicine, in particular with regard to assumptions ascribed to contemporary theorists.**

- **Sadegh-Zadeh's interesting idea that a person can have a disease to varying degrees, from not having it at all to having it completely. I argue that there are difficulties pertaining to the definition of particular diseases, which obstruct the application of this idea.**

- **Medical semantics**

- **Principles for definition in general.**

- **Social definition of health, illness and disease**

# *Fuzzy Conceptual Graphs for Image Matching*

- fuzzy conceptual graphs that is suited to image matching and retrieval

- match images against a conceptual model, allowing for fuzziness in the concepts and relations

# Expert Systems for Image Processing and Analysis

- There are two kinds of knowledge-based systems for image understanding :

1. Expert Systems for Image Processing and Analysis (ESIPA) which deal with low-level processing up to segmentation .

2. Image Understanding Systems (IUS) which have the symbolic description of an image as their goal .
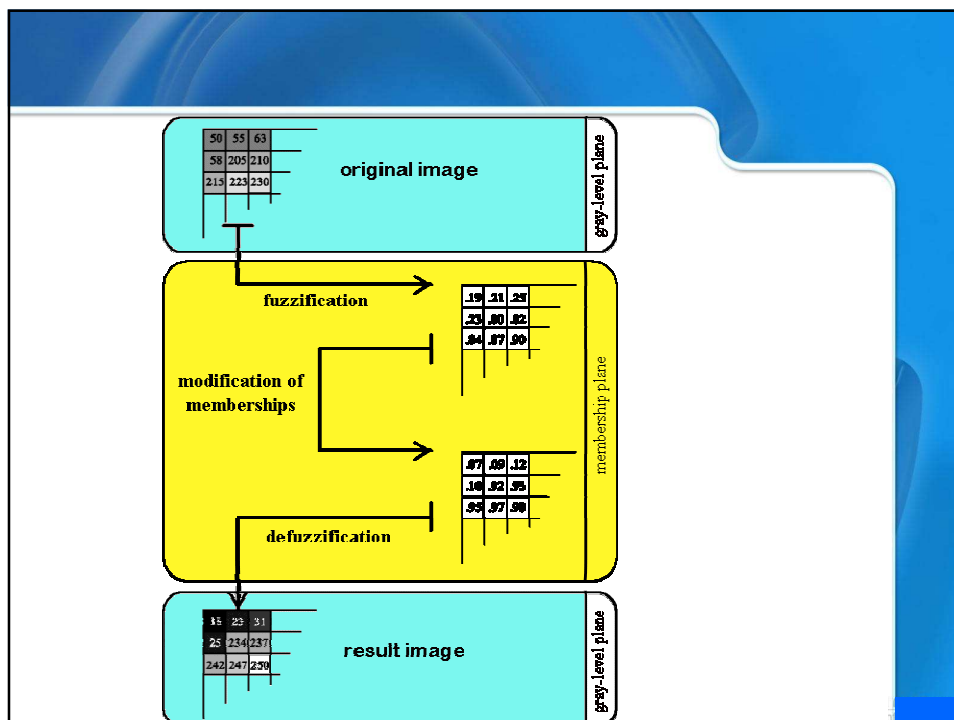
## Simulated MR phantom results
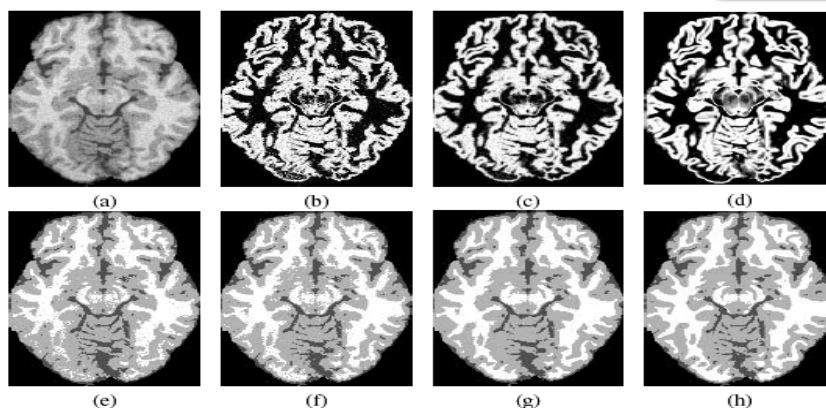


(a) original image,
(b) AFCM gray matter membership,
(c) FCM gray matter membership,
(d) true gray matter partial volume,

(e) FCM maximum membership segmentation,
(f) AFCM segmentation,
(g) FANTASM segmentation,
(h) true segmentation

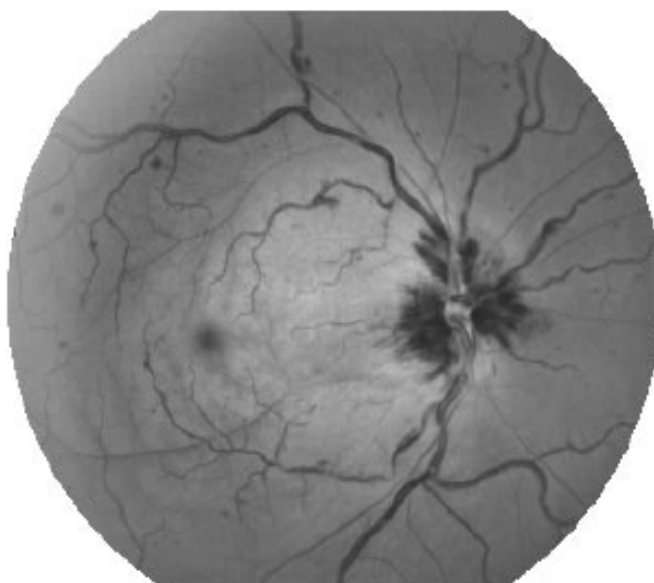## Application of Fuzzy and Noise Tolerant Adaptive Segmentation Method (FANTASM) MR image
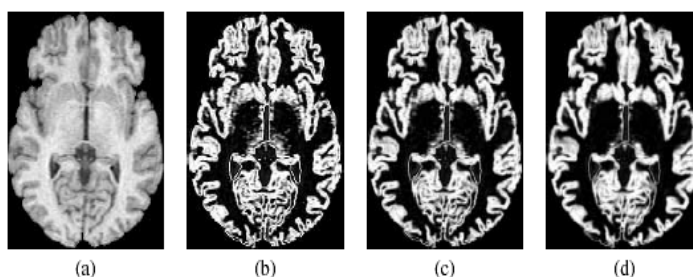


- (a) original image, (b) FCM gray matter
- membership, (c) FANTASM gray matter membership (β = 100), (d) FANTASM gray matter
- membership (β = 250)

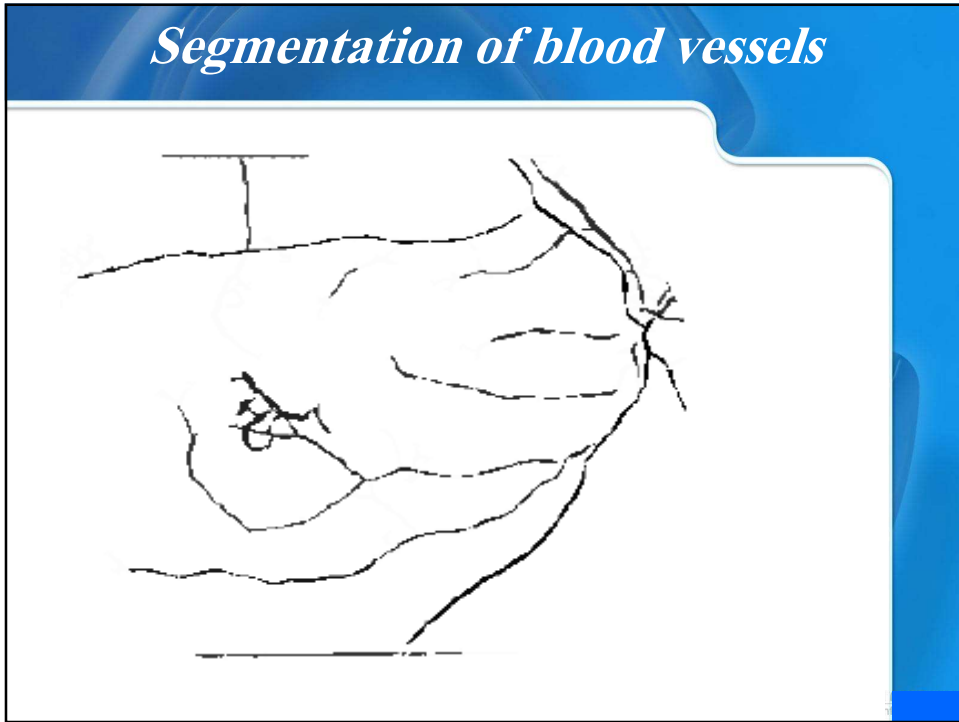## An ocular fundus image.
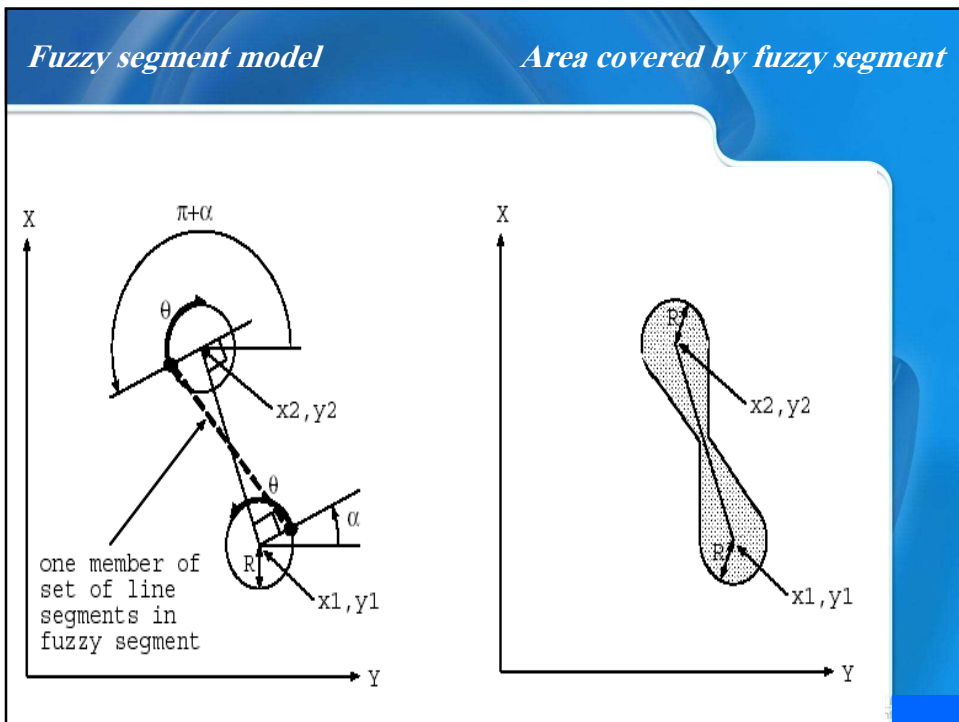


## The nerve is obscured
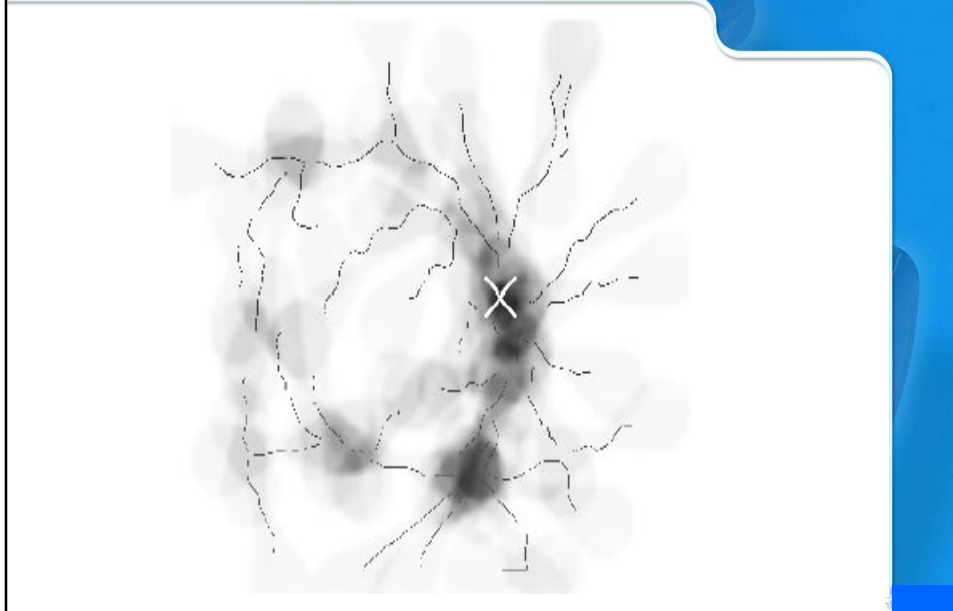
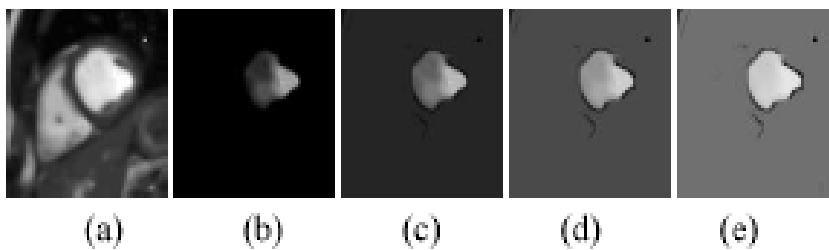# Segmentation of blood vessels



## Fuzzy segment model        Area covered by fuzzy segment

# Blurred convergence image with `X' over strongest pixel



# Fuzzy Connectedness-Based Medical Image Segmentation



(a)    (b)    (c)    (d)    (e)

- **Fuzzy affinity maps of short-axis cardiac MRI (a)for which the weight for intensity energy function is (b) 1.0,(c) 0.75, (d) 0.50, and (e) 0.25, respectively.**

# *Fuzzy Edge Detection*



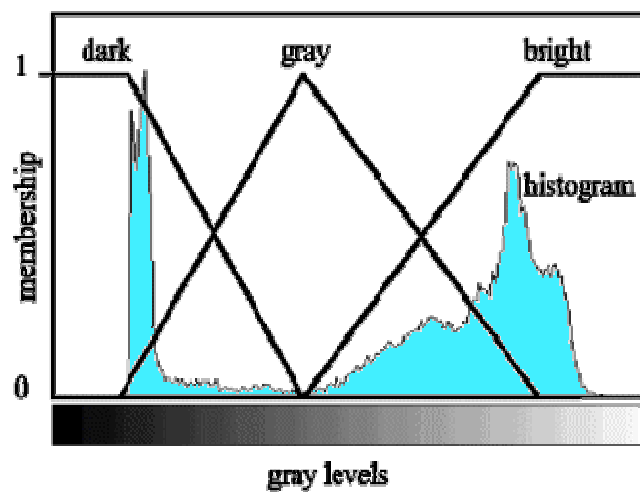* **Edge detection using a simple membership function**

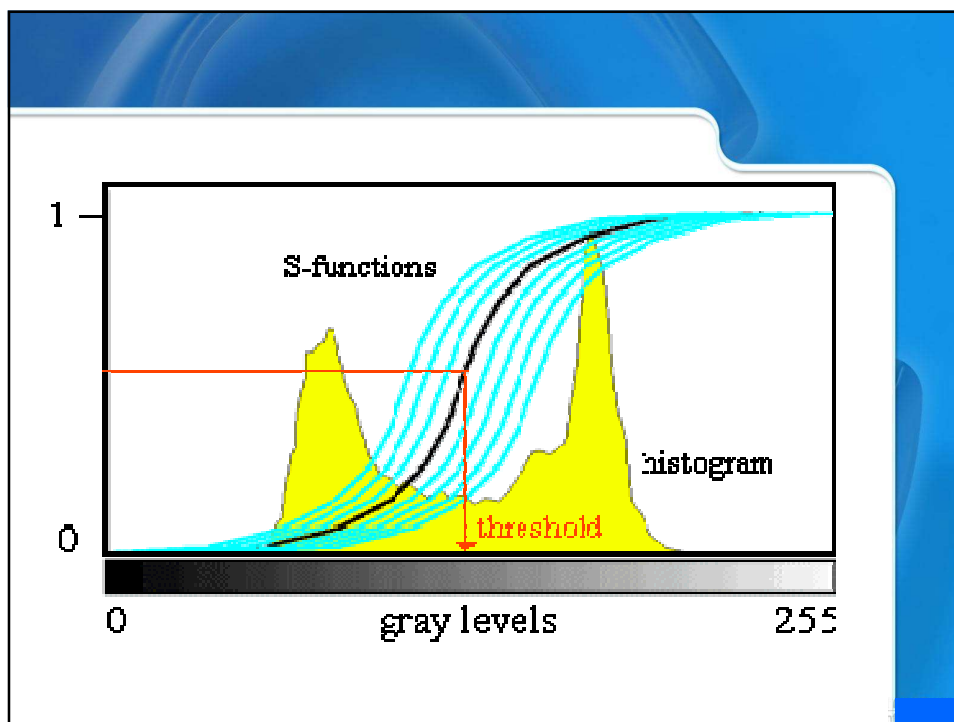# *Edge detection using a rule-based approach*

# Fuzzy Edge Detection
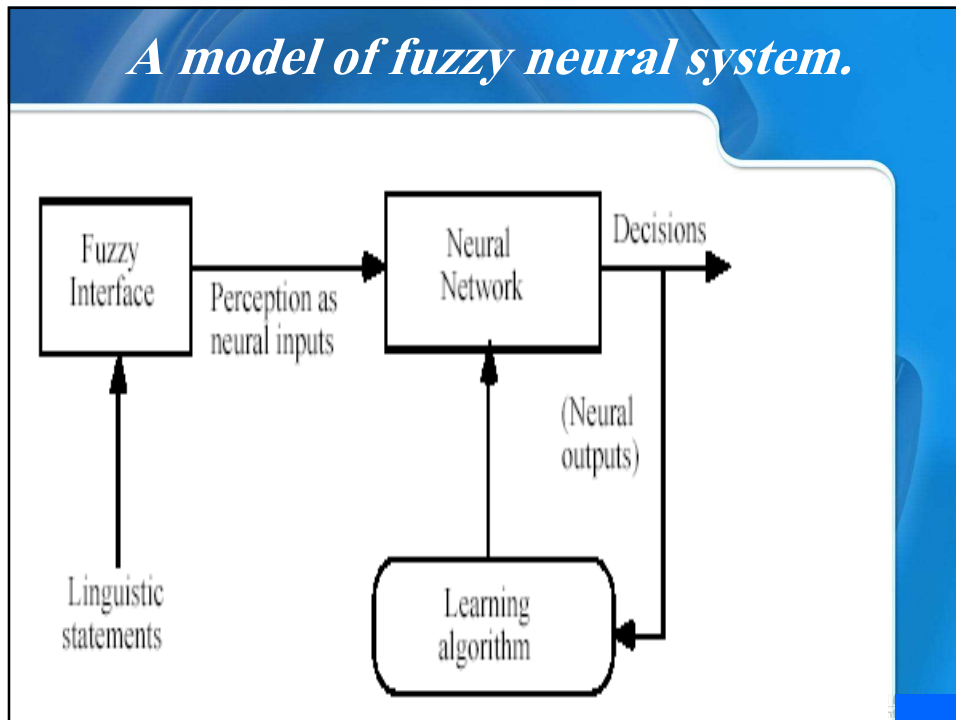


# Fuzzy Image Enhancement



• **Histogram fuzzification with three membership functions**

## Fuzzy Segmentation of Magnetic Resonance Images

- 1. Obtain initial estimates of the centroids
- 2. Compute membership functions
- 3. Compute gain field by solving the  spatially varying difference equation for $gj$ :
- 4. Compute centroids
- 5. Go to step 2 and repeat until convergence.

## A model of fuzzy neural system.



## Multilayer perceptron

# Pulse-Coupled Neural Networks for Medical Image Analysis