Intelligent Systems

An introduction to Fuzzy Systems

Dra. Elisa Guerrero Vázquez
Universtiy of Cadiz

Objetives

To create Fuzzy Sets using different membership functions

To design Fuzzy Rules Based Systems (FRBS)

To apply Fuzzy Operators

To know different approaches to Infer and Defuzzify FRBS

To implement FRBS

Activities

Fuzzy sets vs. Crisp sets

- Understanding the difference between fuzzy and crisp sets

Watch the video *The egg boiling robot*

- Introducing the main steps of a fuzzy system

Membership functions

- Modelling linguistic variables

Designing a problem: *Tipping in a restaurant*

- Fuzzification using Matlab toolbox

1. Basic definitions

What's the meaning of …

Crisp

- firm, dry …

  Crisp potato chips

- briskly decisive… without hesitation or unnecessary detail

  Her answer was crisp

- clearly defined, clear, sharp

  How to get crisp images

Fuzzy

- Difficult to perceive

  the picture is very fuzzy

- Indistinct or vague

  that fuzzy line between right and wrong

Crisp versus Fuzzy

I have just a vague and _____ idea of the world of finance.

He wrote short _____ letters with a decisive position on all questions at hand.

Getting clean and _____ images from old pictures can be a difficult goal.

I don't keep too many memories of this, just a _____ recollection of past events.

You can try denoising tecnhiques to improve that _____ image.

Crisp versus Fuzzy

I have just a vague and fuzzy idea of the world of finance.

He wrote short crisp letters with a decisive position on all questions at hand.

Getting clean and crisp images from old pictures can be a difficult goal.

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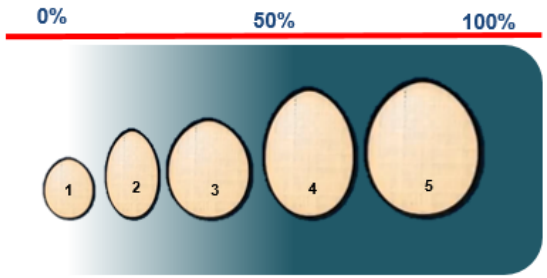
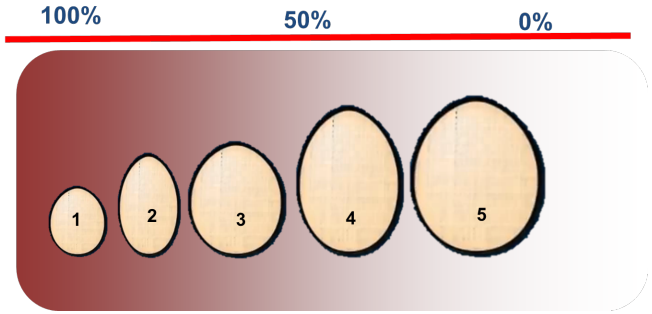
2. Crisp and Fuzzy Sets



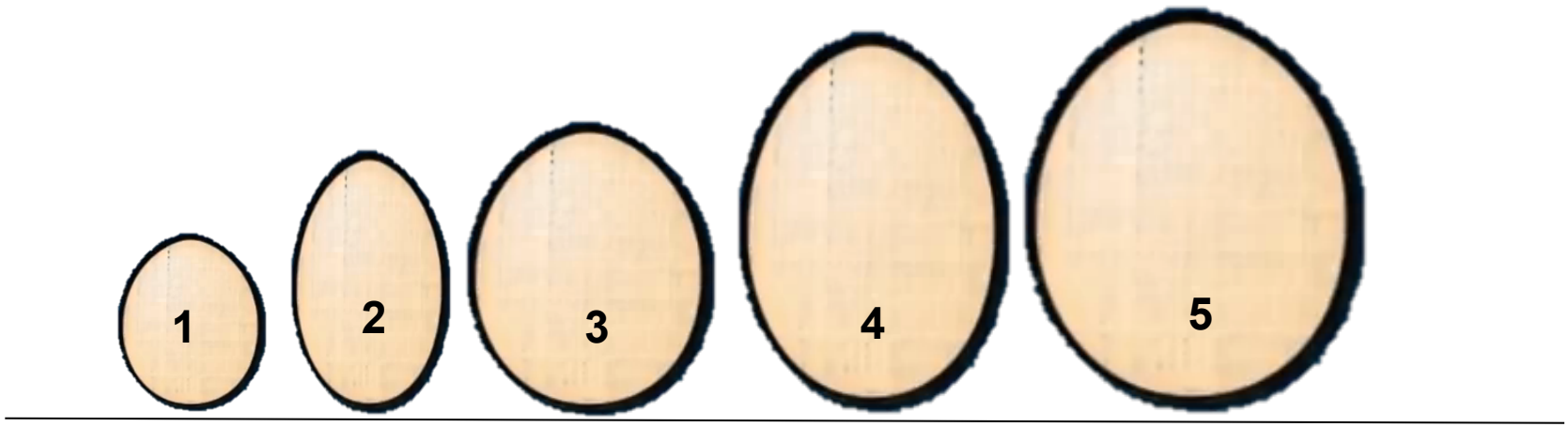


Crisp and Fuzzy sets

- Consider a set of eggs that we would like to categorize by size: large, small, …

When is an egg considered

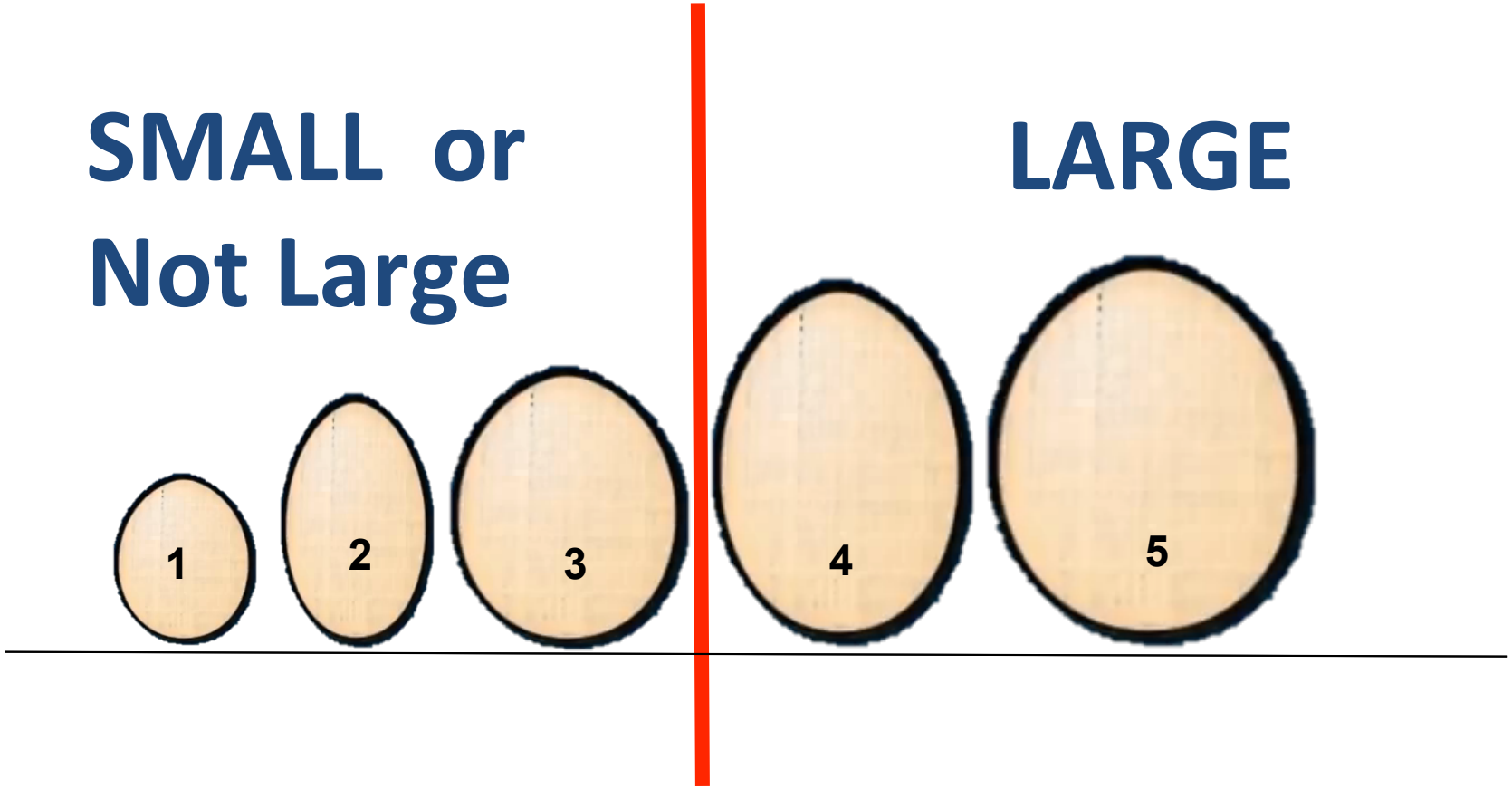
large ?



Crisp Sets

- When is an egg considered large?

We establish a Crisp Boundary

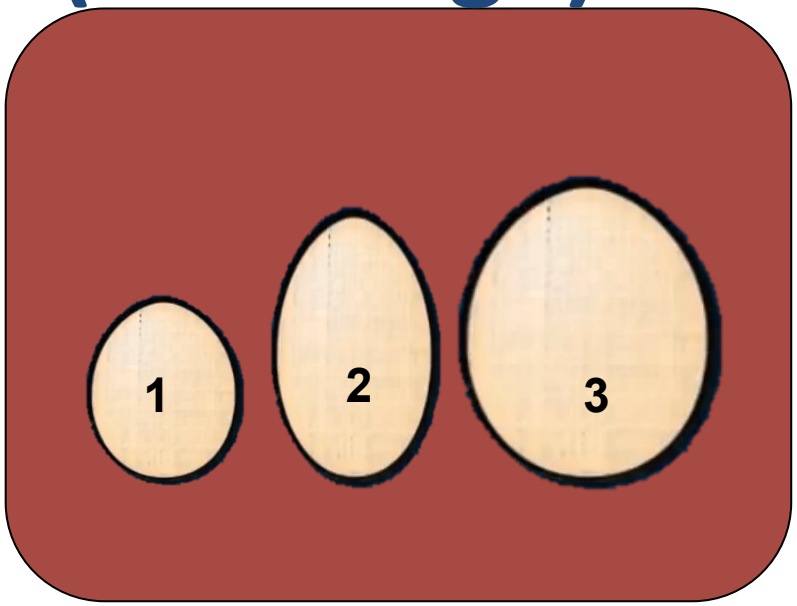


Crisp Sets

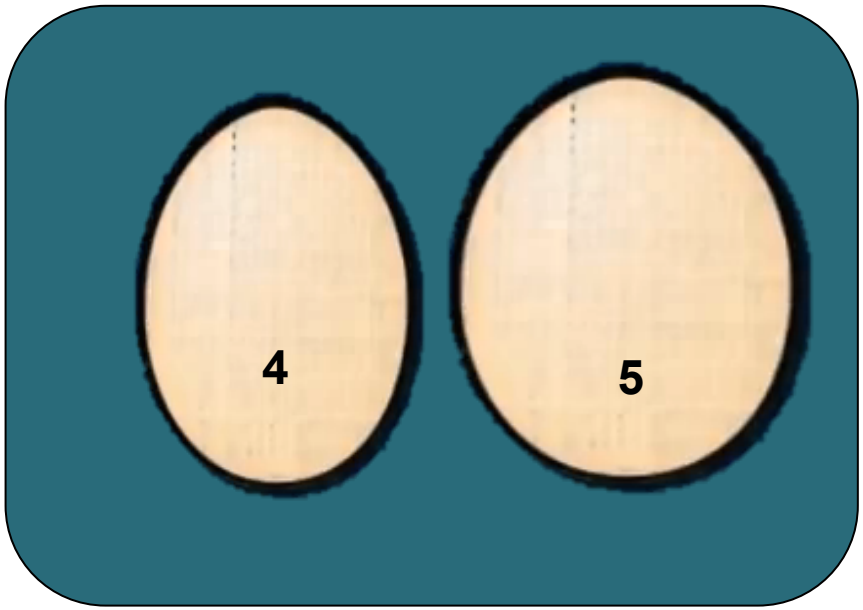
- When is an egg considered large?

an element can belong to a unique set

SMALL (Not Large)

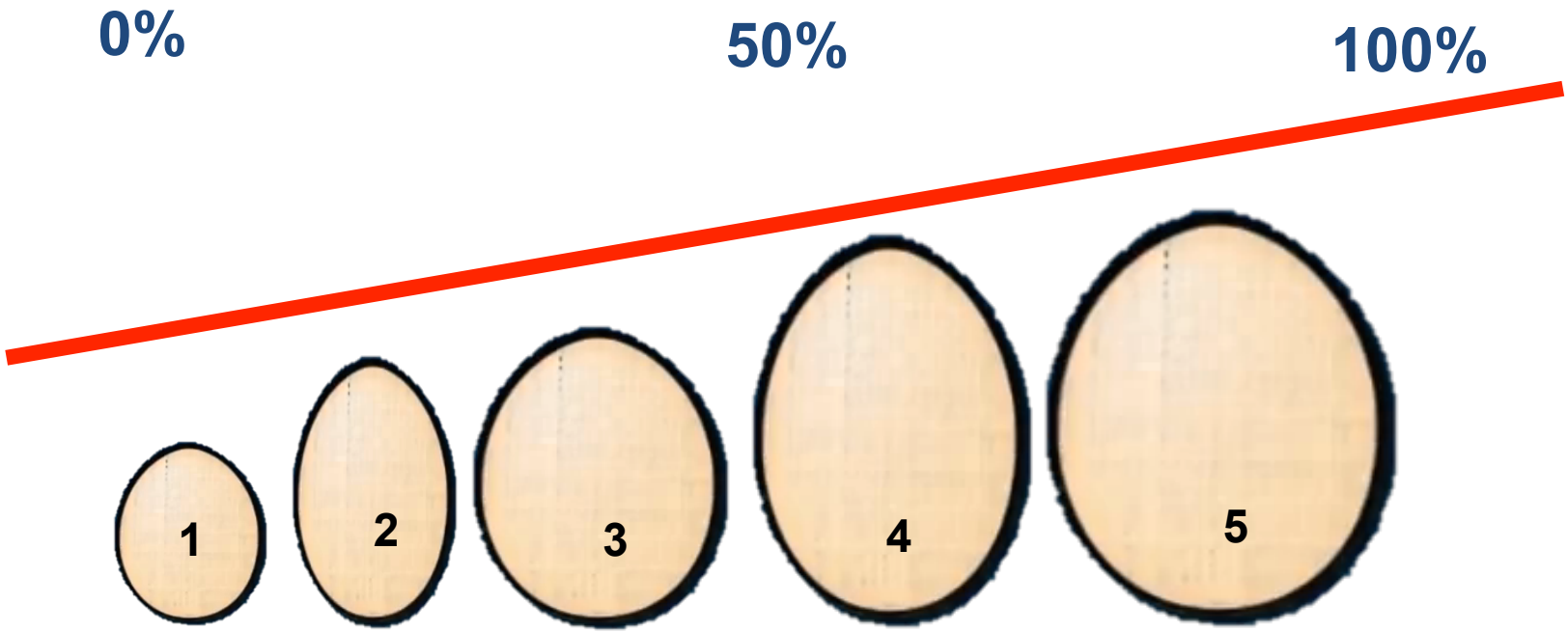


LARGE



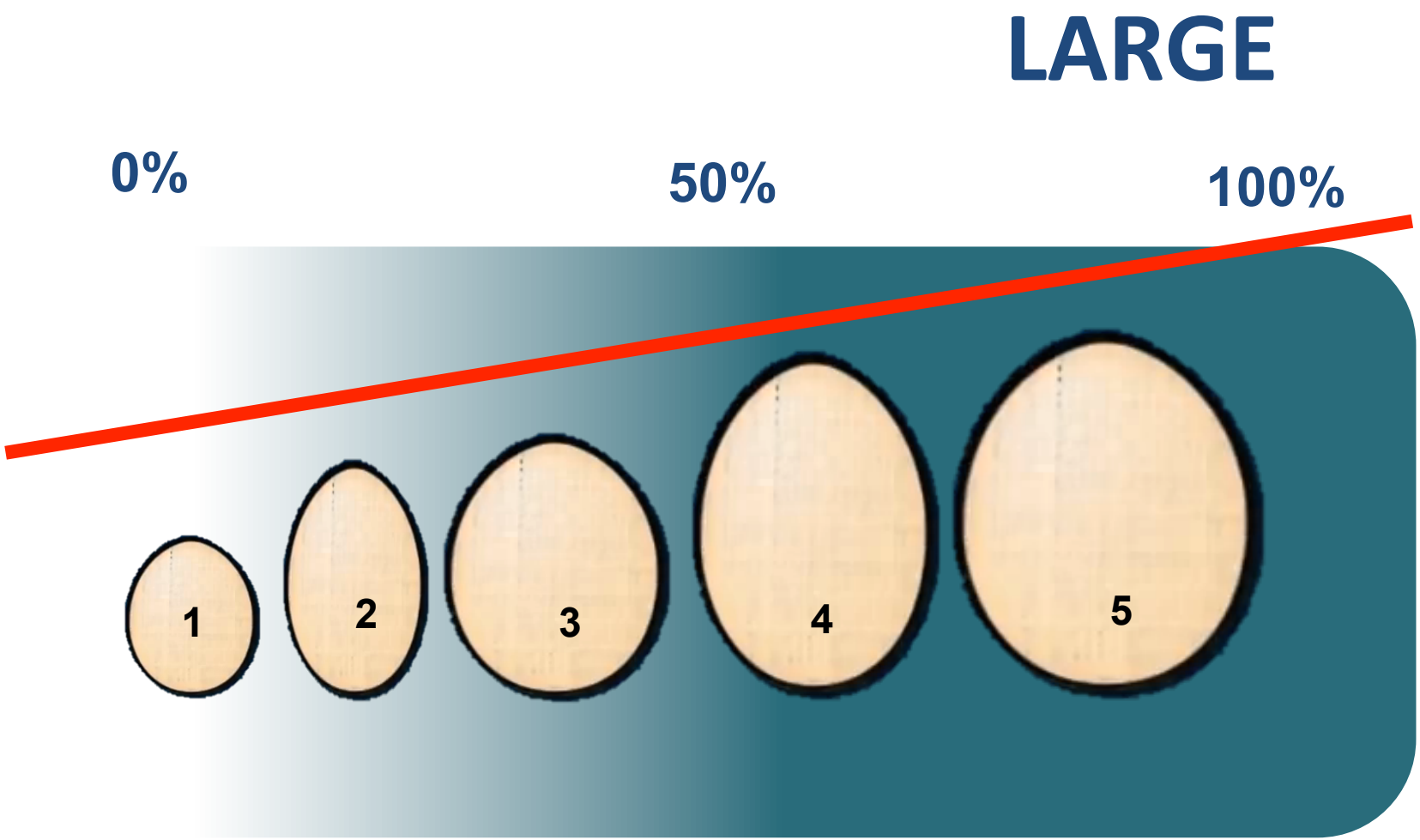
- When is an egg considered large?

Membership degrees

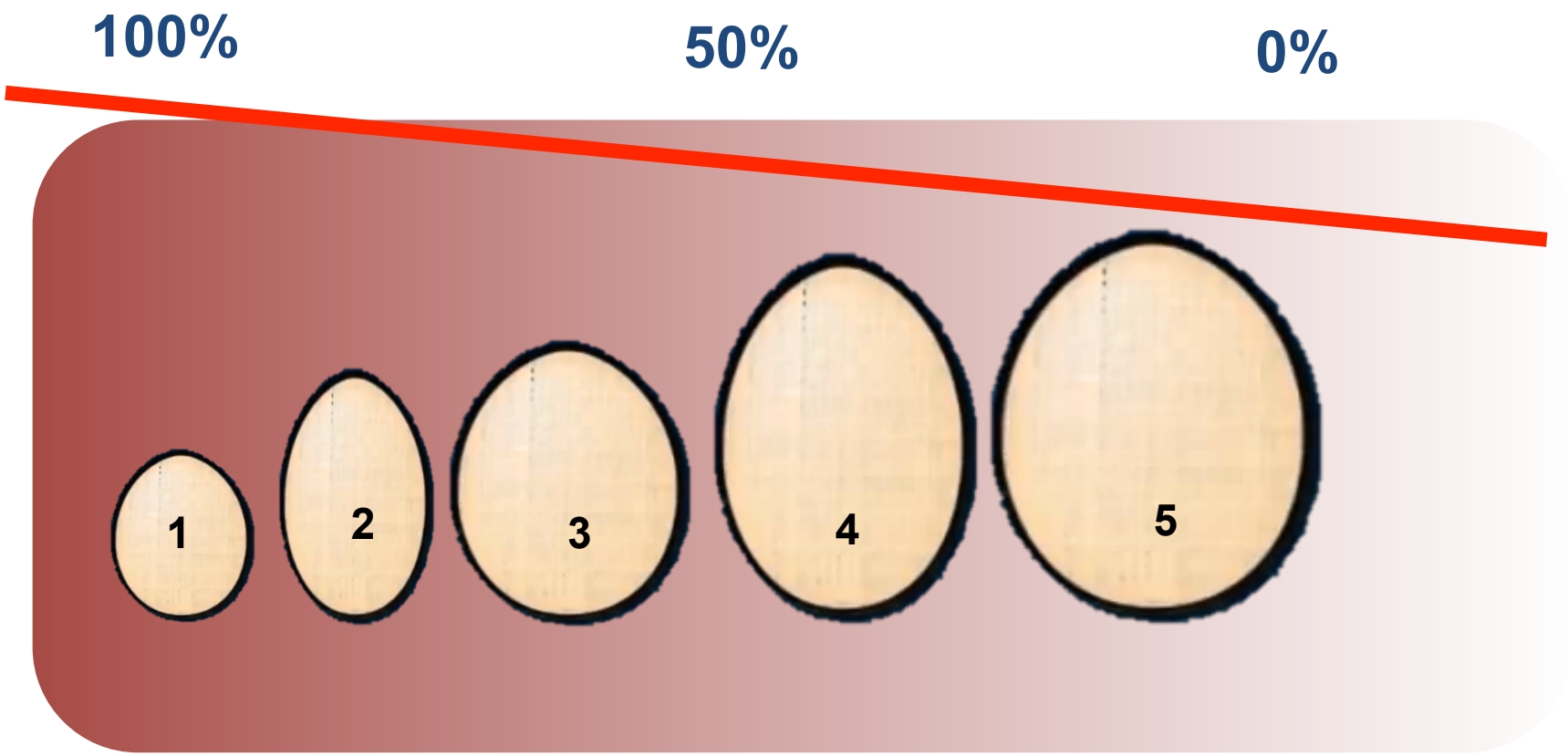


FUZZY Sets

- When is an egg considered large?

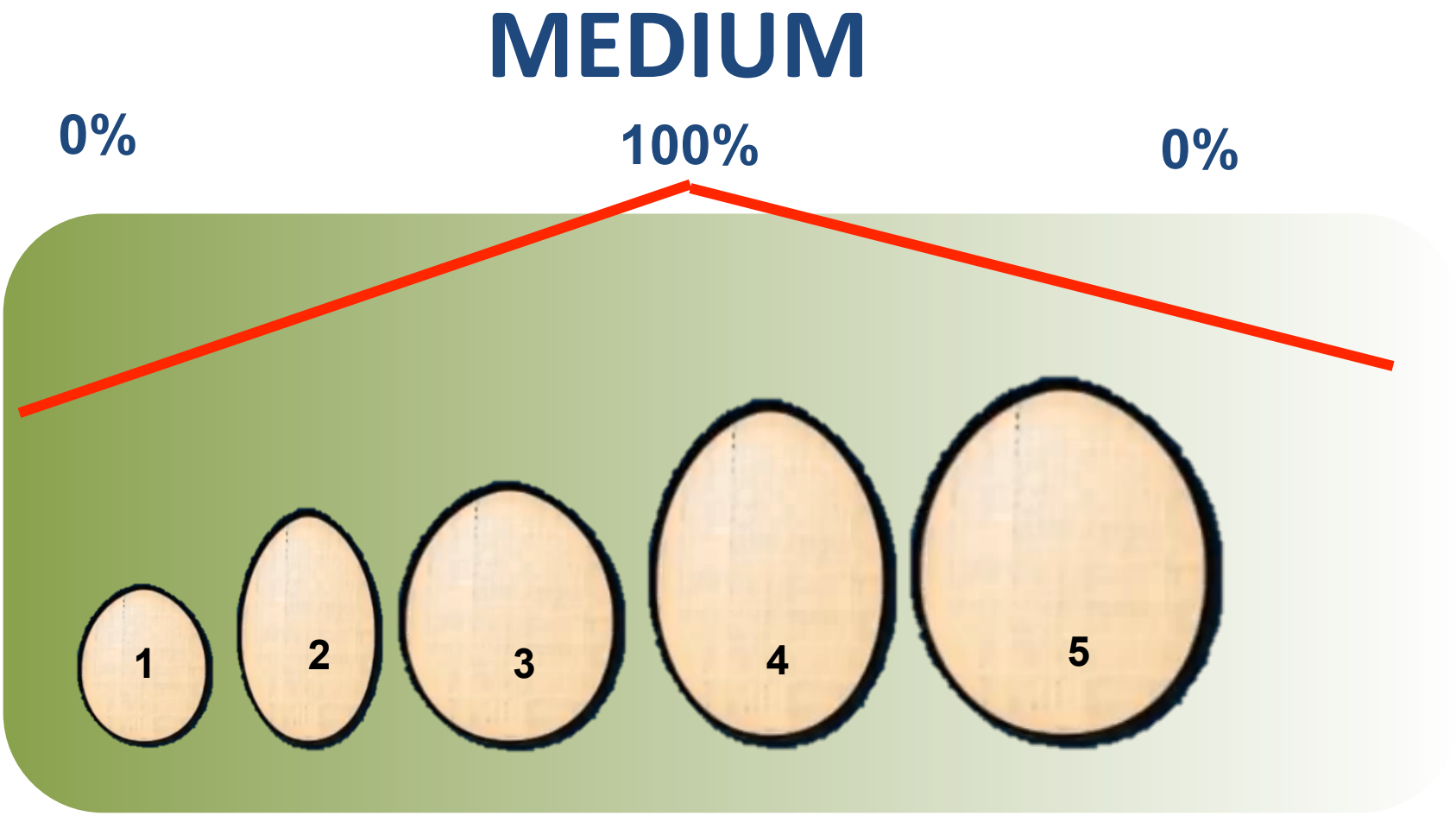


SMALL



FUZZY Sets

- We can have differente **tags**: Large, Small, Medium …

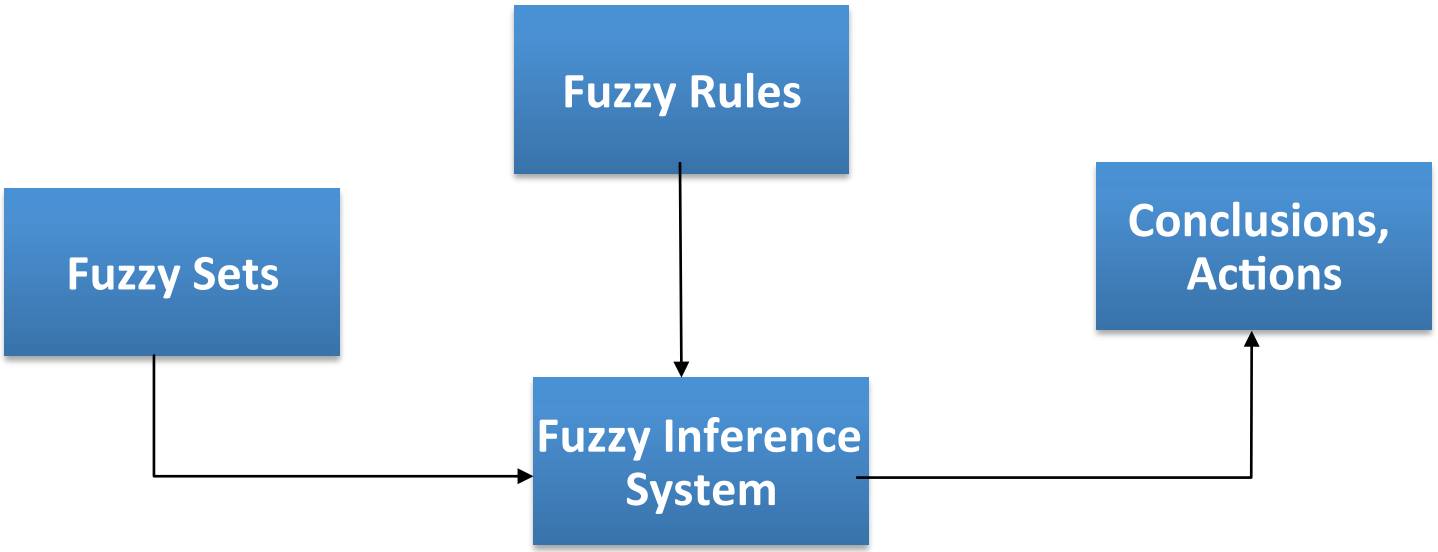


Fuzzy Inference Systems

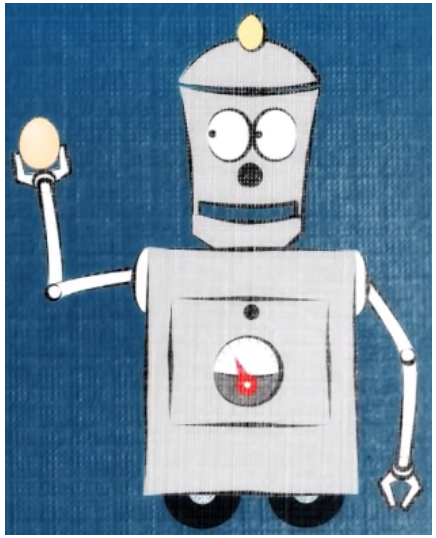
Fuzzy logic uses

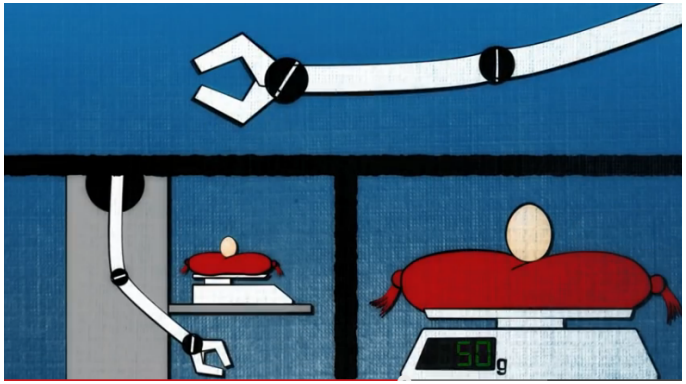
- Fuzzy sets: Large, Small, Medium, More, Less,
- Fuzzy rules: IF … THEN …

to model the world and make decisions about it



3. The egg boiling robot

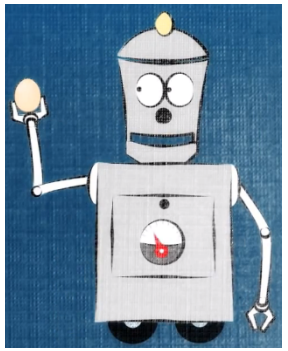




An Egg-Boiling Fuzzy Logic Robot

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

- Watch the video and pay attention to:



1. Which is the **crisp process**?

2. Three main steps to design a Fuzzy System

3. Which are **the fuzzy rules**:

   IF the egg size is _____

   THEN boil the egg for _____ 5 minutes

   IF the egg size is _____

   THEN boil the egg for _____ 5 minutes

An Egg-Boiling Fuzzy Logic Robot

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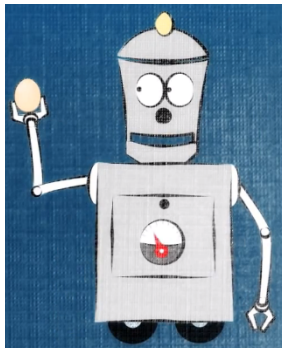
- Watch the video and pay attention to:



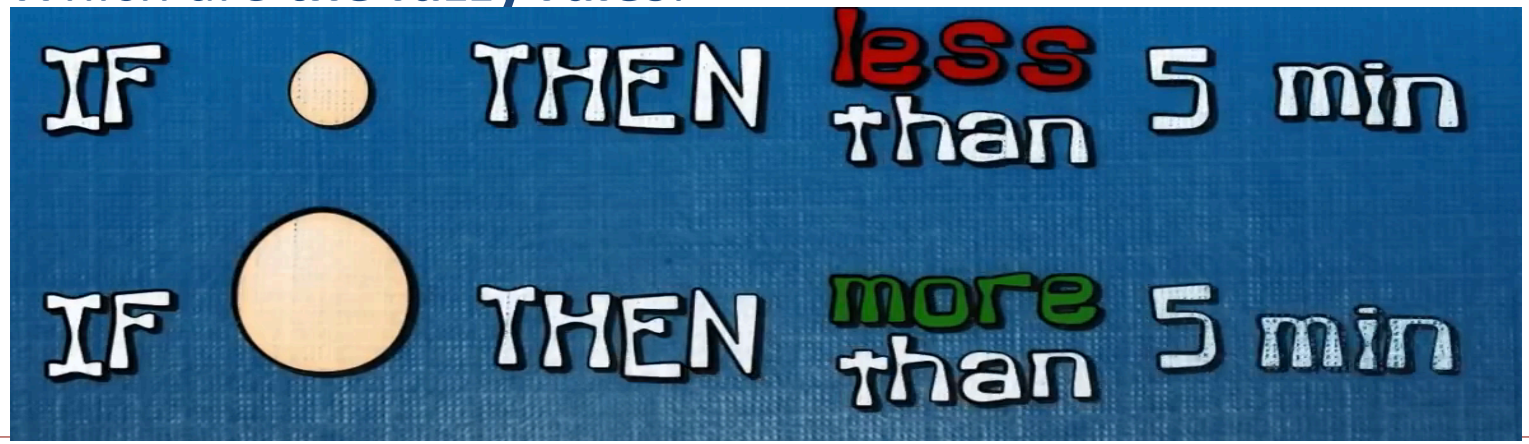
1. Which is the **crisp process**?

   Boil the egg for 5 minutes

2. Three main steps to design a Fuzzy System

   1. Fuzzification
   2. Inference
   3. Defuzzification

3. Which are **the fuzzy rules**:



IF .... THEN ...

Input Condition

Output Action

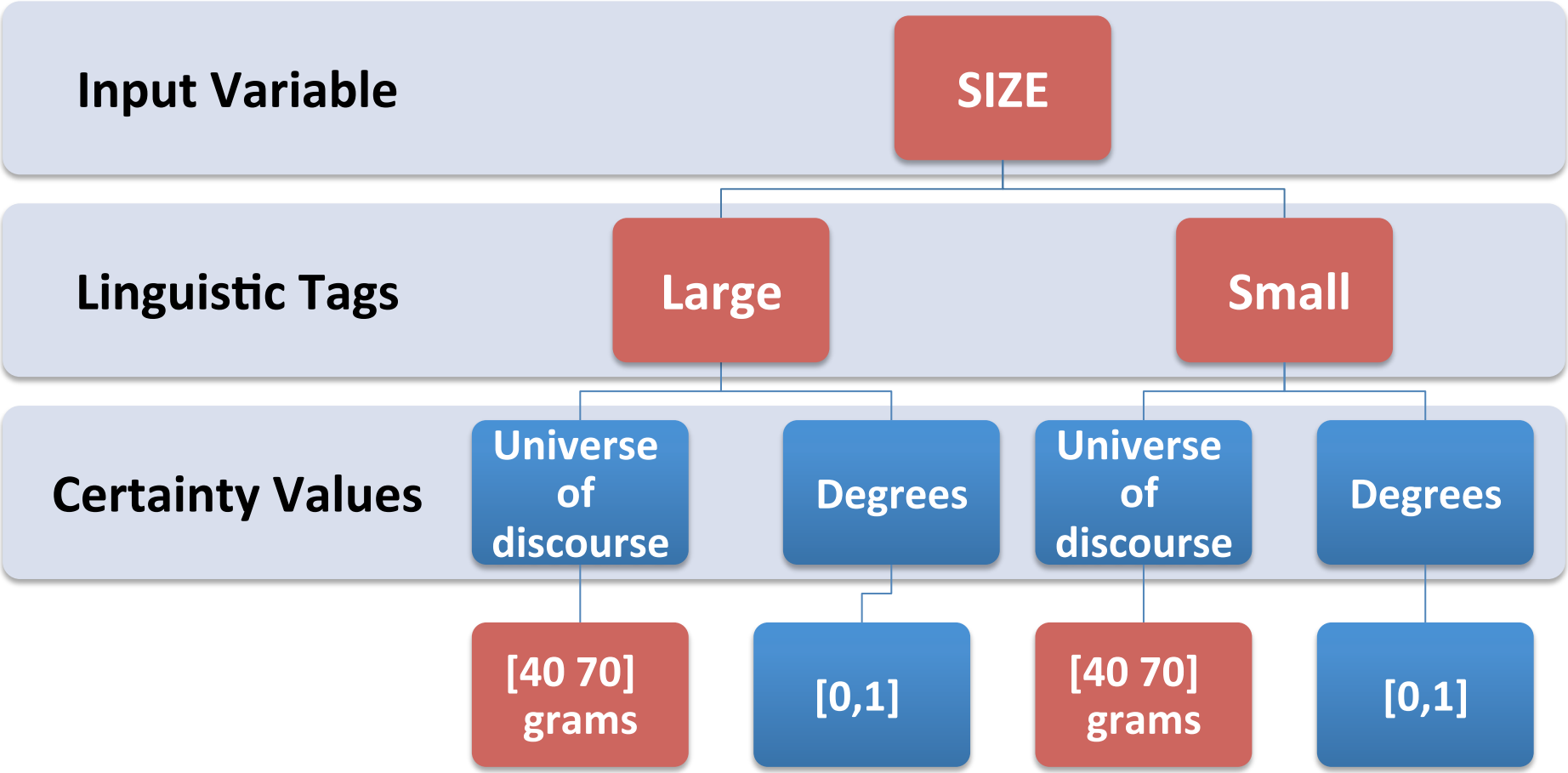
- **IF** the egg size is **SMALL**

  THEN boil the egg for **LESS than 5 minutes**

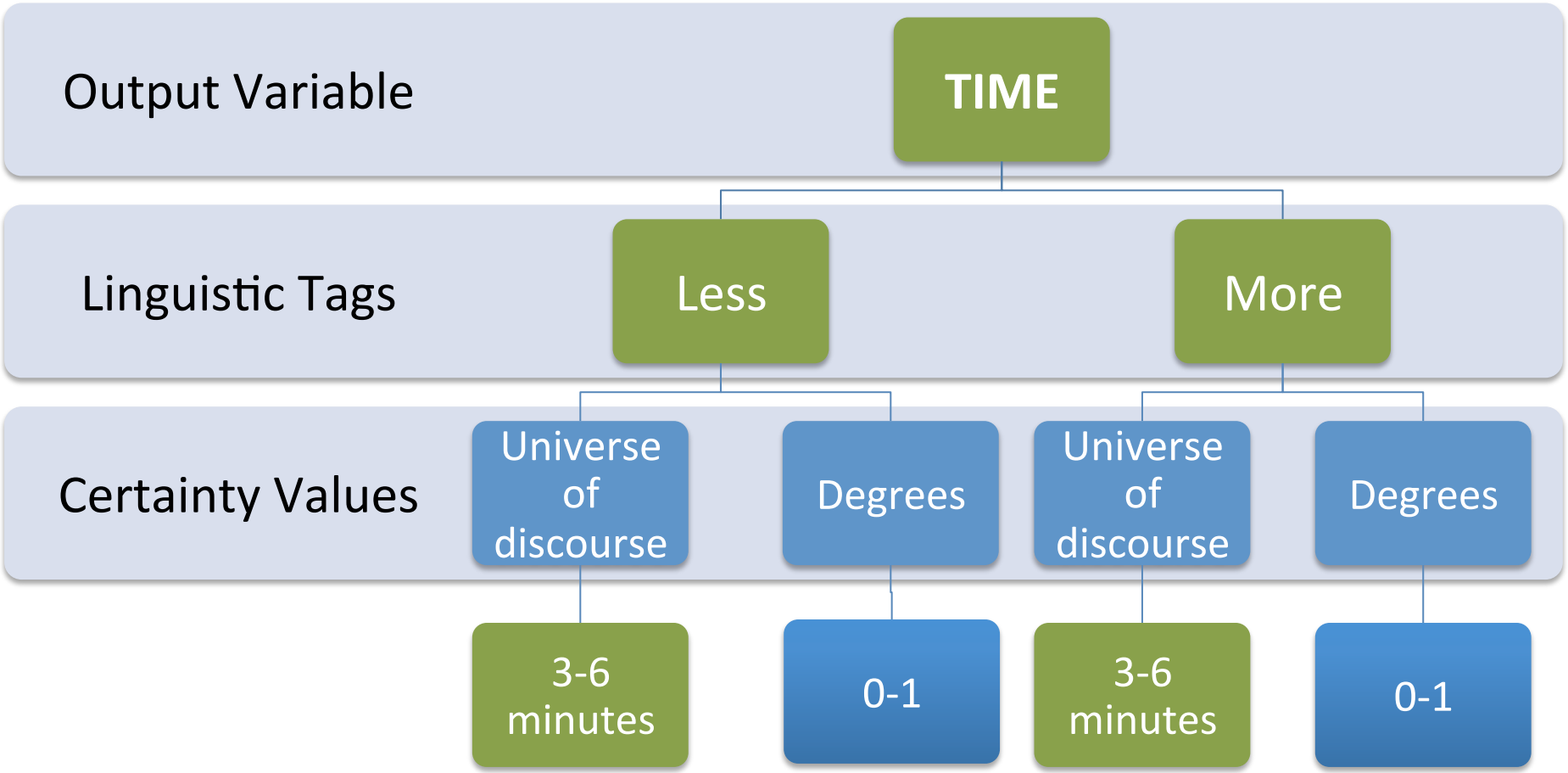
- **IF** the egg size is **LARGE**

  THEN boil the egg for **MORE than 5 minutes**

1. Fuzzification



1. Fuzzification



More Examples

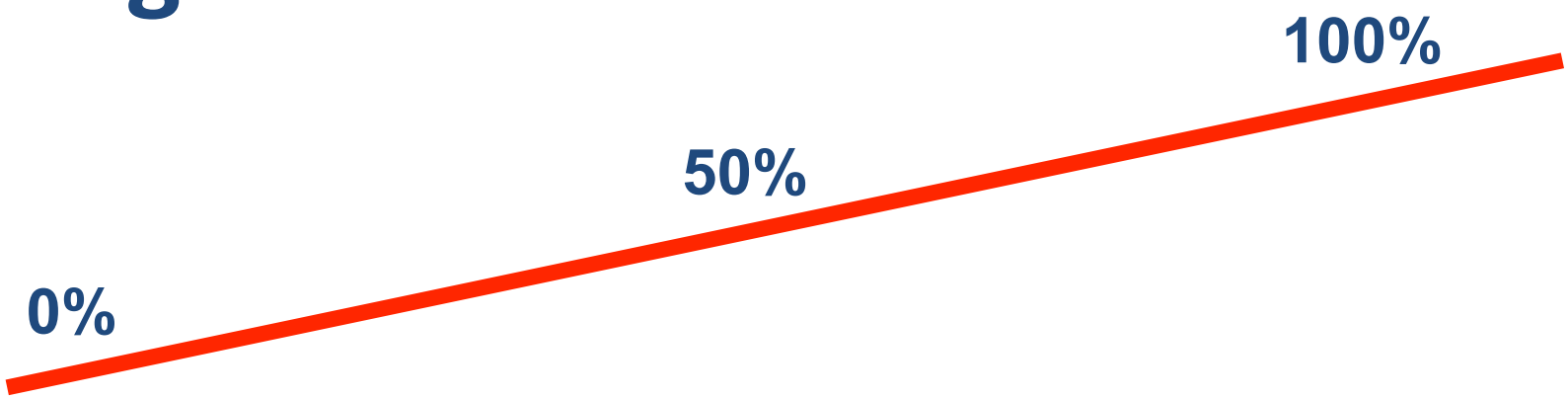
- With information about how good your service was at a restaurant, a fuzzy logic system can tell you what the tip should be: Good service, bad service, Rancid food, Good food, Bad food, etc.

- With your specification of how hot you want the water, a fuzzy logic system can adjust the hot water valve to the right setting.

- With information about how far away the subject of your photograph is, a fuzzy logic system can focus the lens for you.

- With information about how fast the car is going and how hard the motor is working, a fuzzy logic system can shift gears for you.

4. How to determine membership degrees?

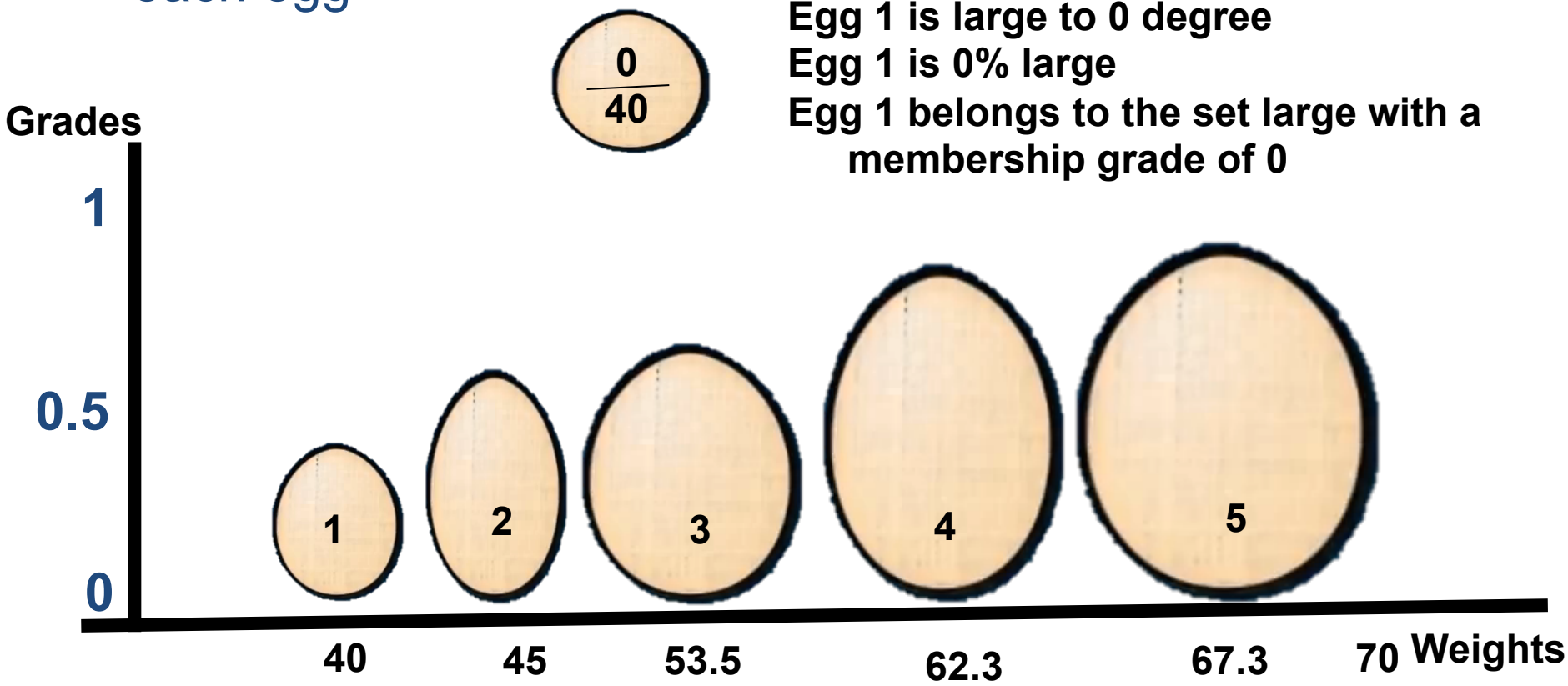


Membership degrees

To which degree is the egg large?

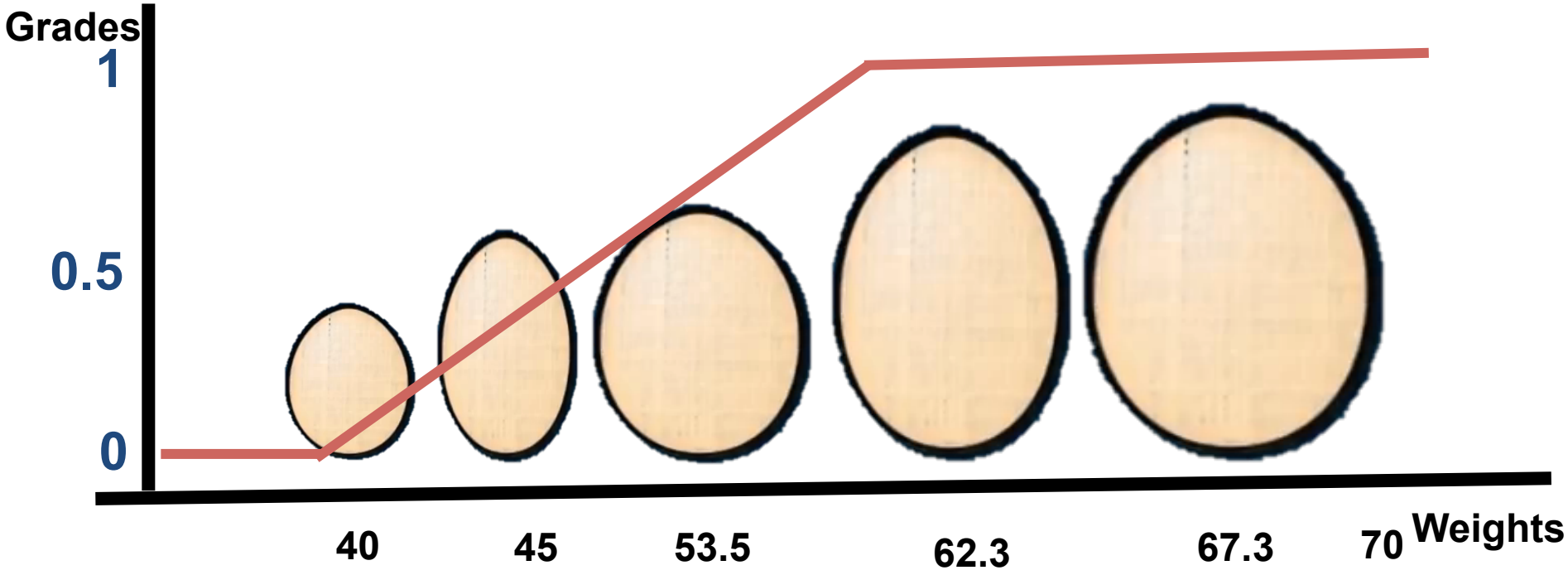
Construct sentences to define the membership values for each egg

Egg 1 is large to 0 degree
Egg 1 is 0% large
Egg 1 belongs to the set large with a membership grade of 0



Membership functions

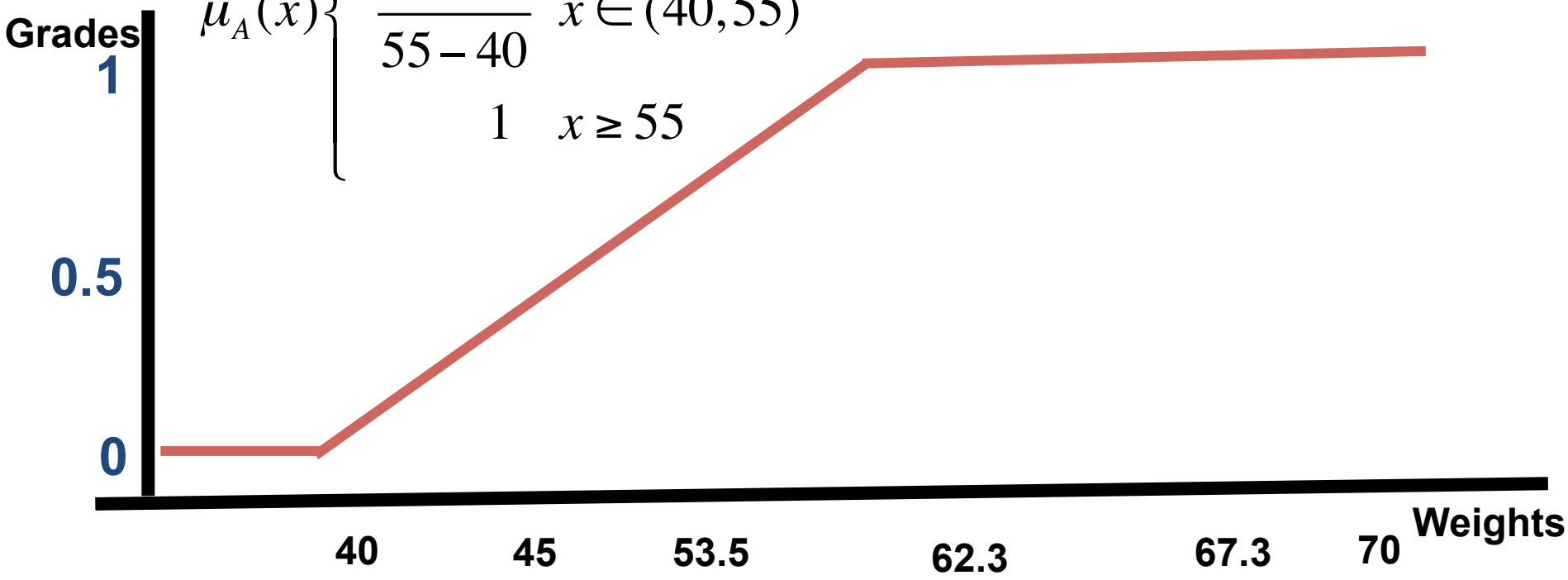
To which degree is the egg large?



Membership functions

To which degree is the egg large?

$$\mu_A(x)\begin{cases} 0, & x \le 40 \\ \dfrac{x-40}{55-40} & x \in (40,55) \\ 1 & x \ge 55 \end{cases}$$



Fuzzy sets

Given a fuzzy set **A** it can be represented by :

- **A set of pairs of values** $\mu(x)/x$

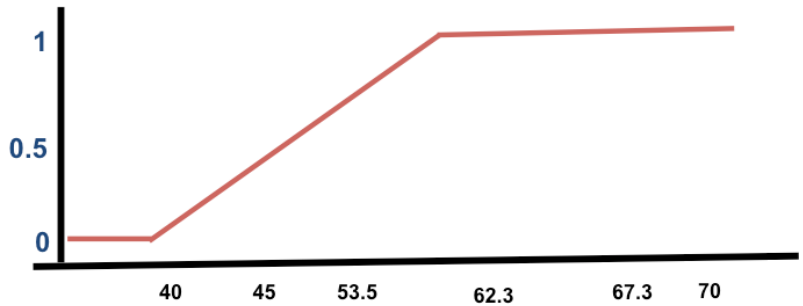
  Membership degree / element of X (Universe of Discourse)

$$A = \left\{ \int \frac{\mu_A(X_i)}{X_i} \right\}$$

E.g. the set of weight values to describe the concept SMALL egg:

A_{SMALL}*={ 0/40, 0.25/45 , 0.5/50 , 1/55 }*

- **A membership function**



Membership functions

A membership function for a fuzzy set A on the universe of discourse X is defined as:

$$\mu_A : X \rightarrow \{0,1\}$$

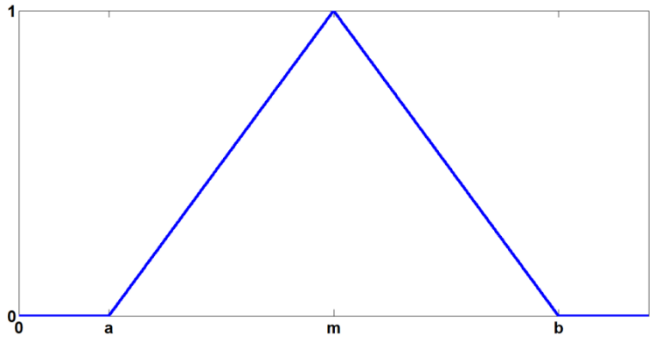
where each element of X is mapped to a value between 0 and 1

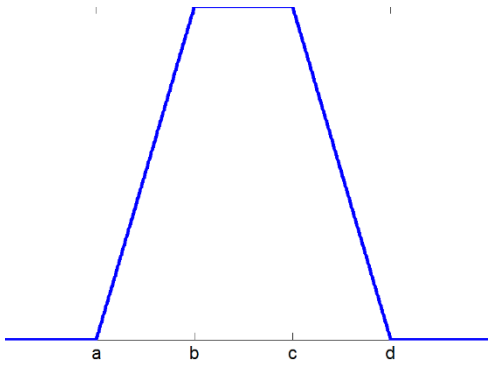
$$\mu_{Large}(x) \begin{cases} 0, & x \leq 40 \\ \dfrac{x-40}{55-40} & x \in (40,55) \\ 1 & x > 55 \end{cases}$$

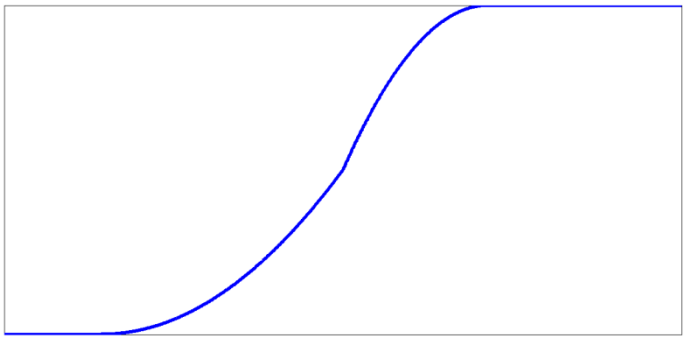
Universe of Discourse X

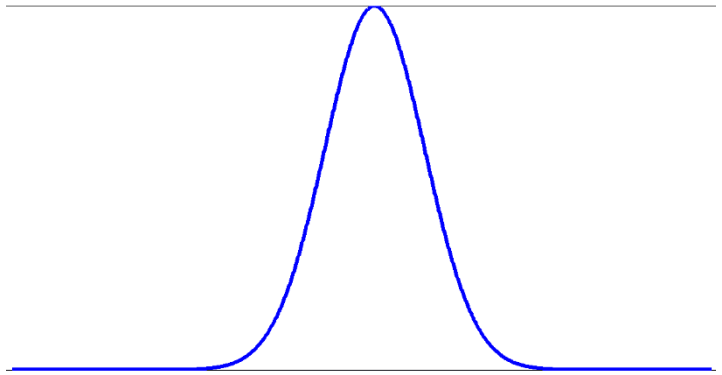
X $\in$ [40-70] grams

Typical Membership Functions









ACTIVITY: Determining fuzzy membership functions

Each group consists of a membership function, an equation and an example with a linguistic tag

- (Individually) Read the given text
- (All the students) Talk to your classmates in order to form the most suitable group, according to the piece of a real world problem you have
- (In groups of three) Together you must propose another linguistic tag related to the same variable and fill in the fuzzy form, as in the given example

Example

- Student 1 has the following text: An egg is considered **large** when it weights is ….
- Student 2 has a ramp function plot
- Student 3 has the ramp function equation

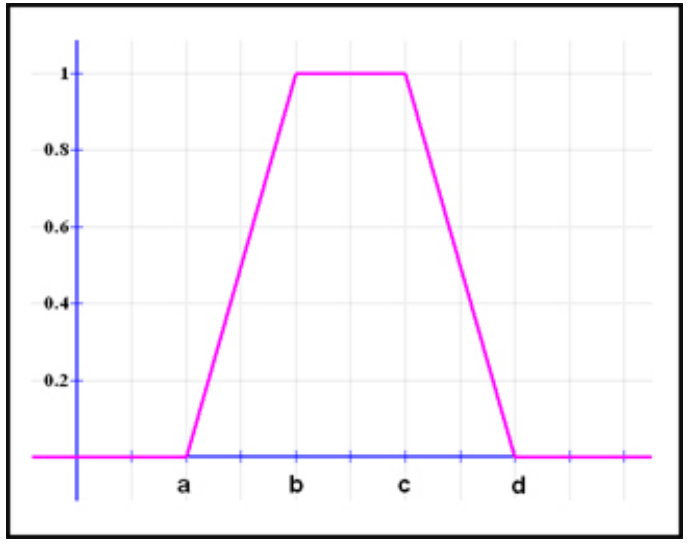
Together they complete the fuzzy form …

- FUZZY VARIABLE: **Egg Size**
- Linguistic Tag name: **Large**
- Universe of Discourse: **40-70 grams**
- Membership Function: Ramp (plot and write the equation of this function for this specific tag)

MEMBERSHIP FUNCTIONS (MF)

- One of the key issues in all fuzzy sets is how to determine fuzzy membership functions.
- The membership function fully defines the fuzzy set.
- A membership function provides a measure of the degree of similarity of an element to a fuzzy set.
- Membership functions can take any form, but there are some common examples that appear in real applications.
- Membership functions can
  - either be chosen by the user arbitrarily, based on the user's experience (MF chosen by two users could be different depending upon their experiences, perspectives, etc.)
  - Or be designed using machine learning methods (e.g., artificial neural networks, genetic algorithms, etc.)

Solutions

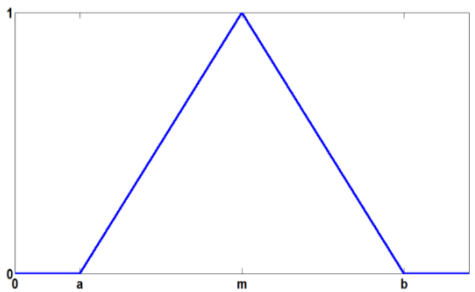


$$\mu_A(x) = \begin{cases} 0, & (x < a) \text{ or } (x > d) \\ \dfrac{x-a}{b-a}, & a \le x \le b \\ 1, & b \le x \le c \\ \dfrac{d-x}{d-c}, & c \le x \le d \end{cases}$$

Illumination in a classroom, is confortable between a range of values between 450-550 lux (lumens/m^2)

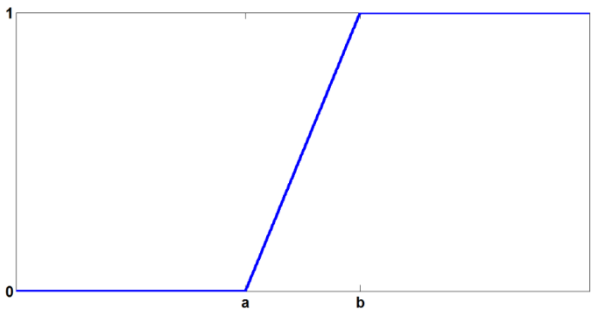
Temperature of a water system. Taking a shower with warm water between 29 ° C to 37 ° C, it is nice and does not cause skin damage.

Solutions



$$\mu_A(x) = \begin{cases} 0 & x \le a \\ \dfrac{x-a}{m-a} & x \in (a,m] \\ \dfrac{b-x}{b-m} & x \in (m,b) \\ 0 & x \ge b \end{cases}$$

The commonly accepted average core body temperature (taken internally) is 37.0 °C.



$$\mu_A(x) = \begin{cases} 0 & x \le a \\ \dfrac{x-a}{b-a} & x \in (a,b) \\ 1 & x \ge b \end{cases}$$

The physical state of water, water vapor (or steam) is the gas phase of water, which is reached at 100ºC, when it can change its state from liquid to gas state.

5. Summarizing …

F_ _ _ _ _ _ _ _ _ _ _ _

F u z z i f i c a t i o n

the process of determining grades of membership for linguistic terms of fuzzy sets

Fuzzy Concepts

(FIS): _ u _ _ _ I _ _ _ _ _ _ _ _ _ S_ _ _ _ _

(FIS): F u z z y I n f e r e n c e S y s t e m

a system that uses fuzzy set theory to map inputs to outputs

_ _ _ Z _ _ _ L _ _

F u z z y R u l e s

a collection of linguistic statements that describe how the FIS should make a decision

_ _ _ b _ _ _ _ _ _p _ _ _ _ _t _ _ _

Membership Function

provides a measure of the degree of similarity of an element to a fuzzy set

Seminar and Lab Practice: Tipping in a restaurant

Work in groups:

- Design a Fuzzy Inference System to tip in a restaurant

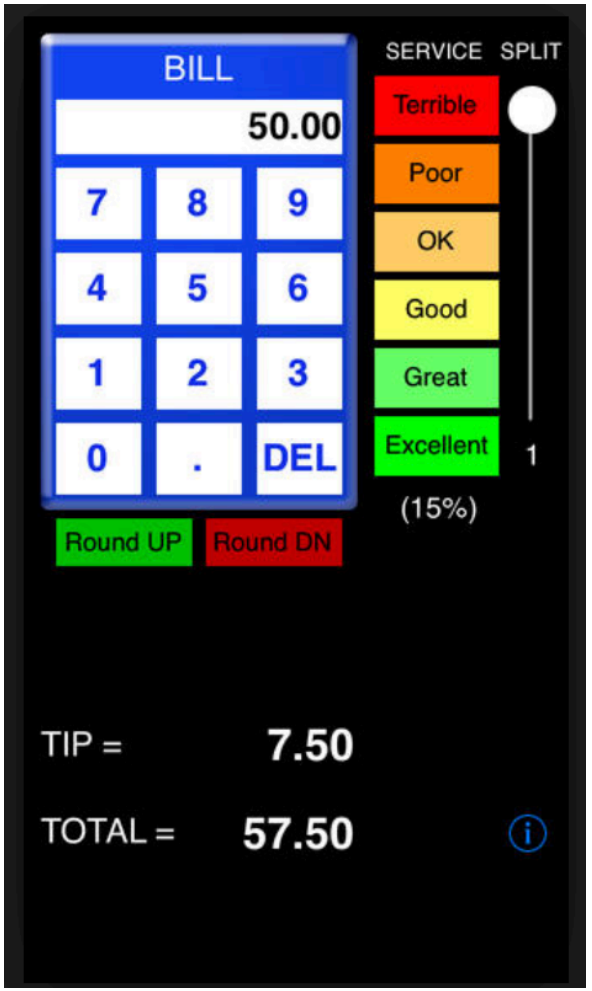
With information about how good your service and the food is at a restaurant, a fuzzy logic system can tell you what the tip should be*: cheap, average, generous*

On next lecture …

how to calculate the perfect tip!

Inference and

Defuzzification



References

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- Zadeh, L.A. *The Concept of Linguistic Variable and its Application to Approximate Reasoning*. Information Sciences, 8, pp. 199-249, 1975 (part I), 8, pp. 301-427, 1975 (part II), 9, pp. 43-80, 1976 (part III)

Links

Videos

- Fuzzy logic an introduction:

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

- The egg boiling robot

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

Other materials:

- http://www.cs.princeton.edu/courses/archive/fall07/cos436/HIDDEN/Knapp/fuzzy004.htm
- **http://www.dma.fi.upm.es/java/fuzzy/fuzzyinf/motivb_en.htm**
- http://www.wolfram.com/products/applications/fuzzylogic/qanda.html#fuzzyset