Artificial Intelligence

(Handling Uncertainty and structured knowledge representation)

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Syllabus-

- **Non Monotonic Reasoning**- Logics for Non Monotonic Reasoning, Justification based Truth Maintenance Systems,
- **Statistical Reasoning.**
  - **Fuzzy logic:** fuzzy set definition and types, membership function, designing a fuzzy set for a given application.
  - **Probability** and Bayes' theorem, Bayesian Networks.
- **Structured Knowledge representation-** Semantic net and Conceptual dependency

Non-monotonic reasoning

- **Definition:-**
- Reasoning effectively even when complete, consistent and constant model of the world is not available. (Read ABC murder story from Rich and knight page 195)
- Conventional systems (first-order predicate logic) are designed to work systems that has three properties.
  - Completeness:- It is complete wrt to domain of interest

  i.e all the facts necessary to solve a problem are either present in the system or can be derived
  - It is consistent.
  - New facts added never contradicts previous one
- If any one of the property is not satisfied then conventional logic system becomes inadequate.
- Reasoning under **uncertainty** is called **non-monotonic reasoning/Defeasible Reasoning.**

Non-monotonic and statistical reasoning definitions

- **Non-monotonic Reasoning:-** in which the axioms and/or rules of inference are extended to make it possible to reason with incomplete information. At any moment a statement is believed to be true, false or not believed to be either.

- **Statistical reasoning-** in which representation is extended to allow some kind of numeric measure of certainty (rather than only true or false) to be associated with each statement.

What is Monotonicity???

Let Σ be the set of formulae and $\Sigma^{'}$ be the superset of Σ, (i.e $\Sigma \subset \Sigma^{'}$) ($\Sigma^{'}$ is Σ plus some other facts)

then

If $\Sigma \models \theta$ (i.e if θ is logically followed from Σ)

then it is also true that $\Sigma^{'} \models \theta$.

Interpretation :- Σ *and* $\Sigma^{'}$ are consistent (monotonicity)

https://plato.stanford.edu/entries/logic-nonmonotonic/

Logics for Non-monotonic reasoning

- Non-monotonic logic
- Default logic
- Abduction
- Inheritance
- Closed world assumption

https://plato.stanford.edu/entries/logic-nonmonotonic/

*The term "**non-monotonic logic**" covers a family of formal frameworks devised to capture and represent **defeasible inference**, i.e., that kind of inference of everyday life in which reasoners draw conclusions **tentatively, reserving the right to retract them in the light of further information**. Such inferences are called "**non-monotonic**" because the set of conclusions warranted on the basis of a given knowledge base.*

Logics for Non-monotonic reasoning

- **Non-monotonic logic:-** is extension to the language of **predicate logic** with model **operator M**, which can be read as "**is consistent**"

$$\forall x,y{:}Related(x,y) \wedge M\ GetAlong(x,y) \rightarrow WillDefend(x,y)$$

Problems:-

1.What is meaning of "is consistent"? is un-decidable in first order logic

2. Multiple non-monotonic statements taken together may be inconsistent

Logics for Non-monotonic reasoning

2. Multiple non-monotonic statements taken together may be inconsistent

$$\forall x{:}\ Republican(x) \wedge M\ \neg Pacifist(x) \rightarrow \neg Pacifist(x)$$

$$\forall x{:}\ Quaker(x) \wedge M\ Pacifist(x) \rightarrow Pacifist(x)$$

$$\left.\begin{array}{l} Republican(Joe) \Longrightarrow \neg \mathit{Pacifist}(\mathit{Joe}) \\ Quaker(Joe) \Longrightarrow \mathit{Pacifist}(\mathit{Joe}) \end{array}\right\} \text{In-consistent}$$

Pacifist- A person believing that war and violence are unjustifiable

Quaker- A peaceful religious person

Logics for Non-monotonic reasoning

- **Default Logic**:- An alternative logic used for performing the **reasoning based on default assumptions**. Proposed by Canadian logician Raymond Reiter. It provides a new inference rule of the form.

$$\frac{A:B}{C}$$

If A is provable and it is consistent to assume B then conclude C

$$\frac{Bird(x):Flies(x)}{Flies(x)}$$

Default rule about the birds, which fails for Penguin

Bird(Penguin) ➔ Flies(Penguin)

Logics for Non-monotonic reasoning

- **Abduction**:- is using the implication in reverse order

$$\forall x: Engineer(x) \rightarrow Literate(x)$$

$Engineer(Ram)$ we can deduce Literate(Ram)

Given Literate(Shyam) we can infer Engineer(Shyam)

by Abduction (Abductive reasoning)

Abduction- deriving conclusions even though they are not more appropriate using implication in reverse

$$\text{Malaria (parasitic infection)} \Rightarrow \text{Hydroxychloroquine}$$

$$Covid19(viral\ \text{infection}) \Leftarrow \text{Hydroxychloroquine}$$

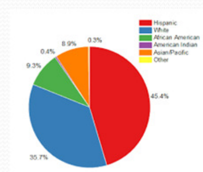
Logics for Non-monotonic reasoning

- **Inheritance:-** " An object inherits **attribute values** from their classes". In a broader way

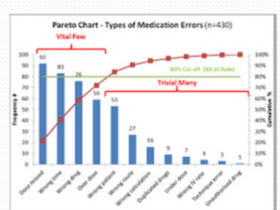
$$\frac{\mathit{BaseBall-Player}(x):\mathrm{height}(x,6)}{\mathrm{height}(x,6)}$$

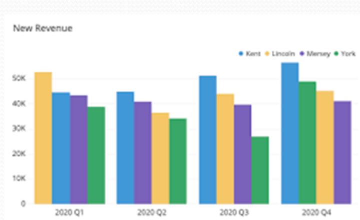
•Closed world assumption
(i.e Reasoning based on **everything you don't know is false**)
e.g. 1 Is there water on planet Mars? **No**
2. If there is no direct flight between Pune to Kanpur in the database; travel agent will say no flight assuming database as complete .

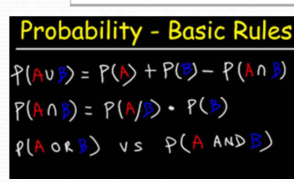
Statistical reasoning



- **Statistical reasoning tools**
  - Fuzzy logic
  - Probability and Bay's theorem







Need of Fuzzy Logic

- Human brain computes with imprecise information. (9.1435+10.1111234=~20)
- Uncertainty is related with most of the information used for computation.
- Precise information is rarely available and not needed for most day to day problem solving
- Some facts involve vague terms like "More", "Better", "Taller" etc.
- Some task can not be performed in a precise manner. e.g classifying Good/bad persons

Use of Fuzzy sets and fuzzy Logic

- To provide a way for representing imprecise things
- To handle uncertain situations other than randomness.
- To capture vagueness in natural languages.

In a domain with n events randomness is

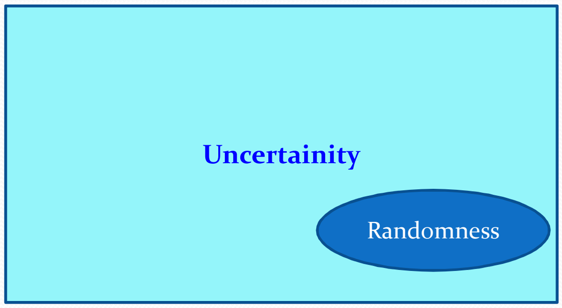
$1. P(E_1) = P(E_2) = \ldots = P(E_n)$

$2. P(E_1) + P(E_2) + \ldots + P(E_n) = 1$

Use probability

Uses of Fuzzy sets and fuzzy Logic

- **Handling uncertainty other than randomness**



What happens ???if

$$1.P(E_1) \neq P(E_2) \neq \ldots \neq P(E_n)$$

$$2.P(E_1) + P(E_2) + \ldots + P(E_n) \neq 1$$

Can not use Probability.
Use Fuzzy Logic

Introduction to Fuzzy sets

- **Set theory; which we have been using was proposed by a German mathematician George Cantor in 1870.**

❑ **Sets with which we are already familiar are termed as crisp set.**

❑ **The membership function of crisp set returns only two values, either 1 or 0.**

1- member $A = \{1,2,3\}$

0- Non meber. $\mu_A(2) = 1$ and $\mu_A(5) = 0$

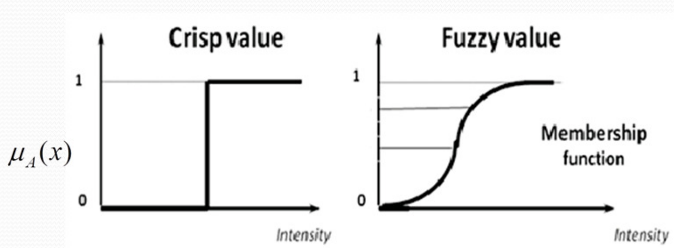
Introduction to Fuzzy sets

- **Fuzzy** means **imprecise/vague/difficult to perceive**
- **Prof. Lotfi Zadeh, 1965, university of California, Berkley, proposed "Fuzzy sets", which are generalization of crisp sets, such that membership function returns values in interval [0,1], including ZERO and ONE.**
  - **1- means a full member**
  - **0-non member**
  - **0< membership < 1 -Partial members**

Fuzzy membership function

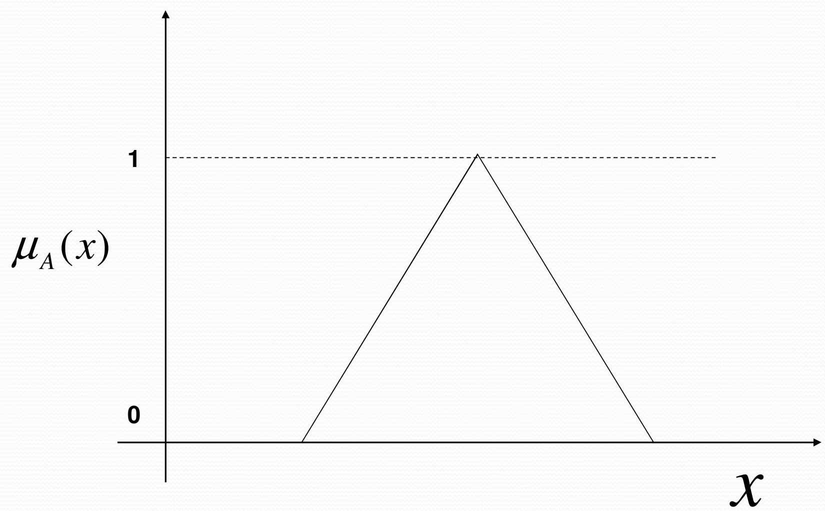
- **A function that takes input x and returns out put as membership grade in [0,1], for x, is called as fuzzy membership function.**

$\mu_A(x)$ **-Read it as " membership of input x in the fuzzy set A"**



https://www.researchgate.net/figure/Difference-between-Crisp-and-Fuzzy-Sets_fig6_311419824

Plot of fuzzy Membership function

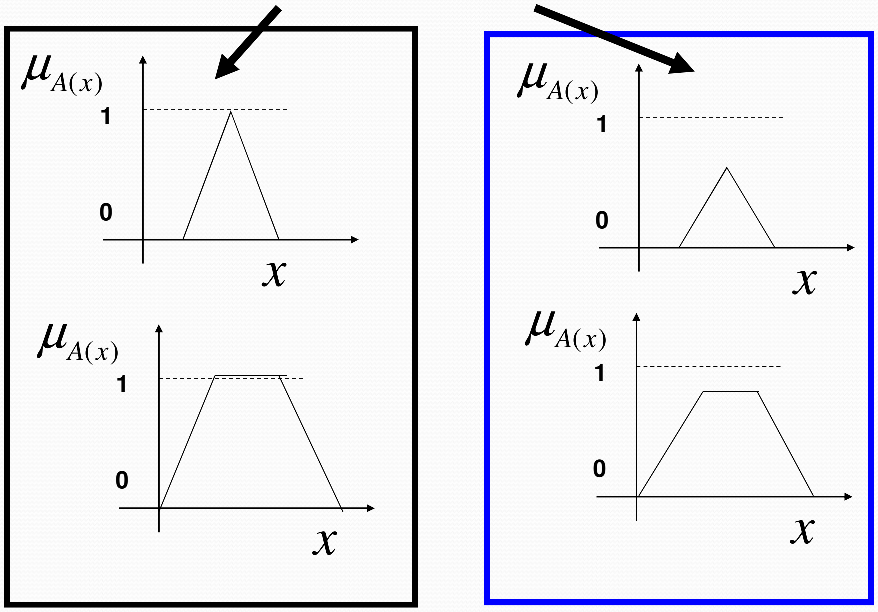


Types of fuzzy sets

- **There are 4 types of fuzzy sets based on the nature of fuzzy membership values.**
  - **Normal fuzzy sets**
  - **Subnormal fuzzy sets**
  - **Convex fuzzy sets**
  - **Non-convex fuzzy sets**

Normal fuzzy set:- **A fuzzy set is called as normal fuzzy set, if at least one of its member has attained highest membership value 1, other wise it is called as subnormal fuzzy set.**

Normal and Subnormal fuzzy sets



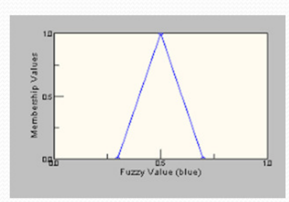
Convex and non-convex fuzzy sets

- **Convex fuzzy set:-** **A fuzzy set is called as convex fuzzy set if the membership values are either monotonically increasing or monotonically decreasing, otherwise it is called as non-convex fuzzy set.**
- **The property of monotonically increasing or decreasing is called convexity.**

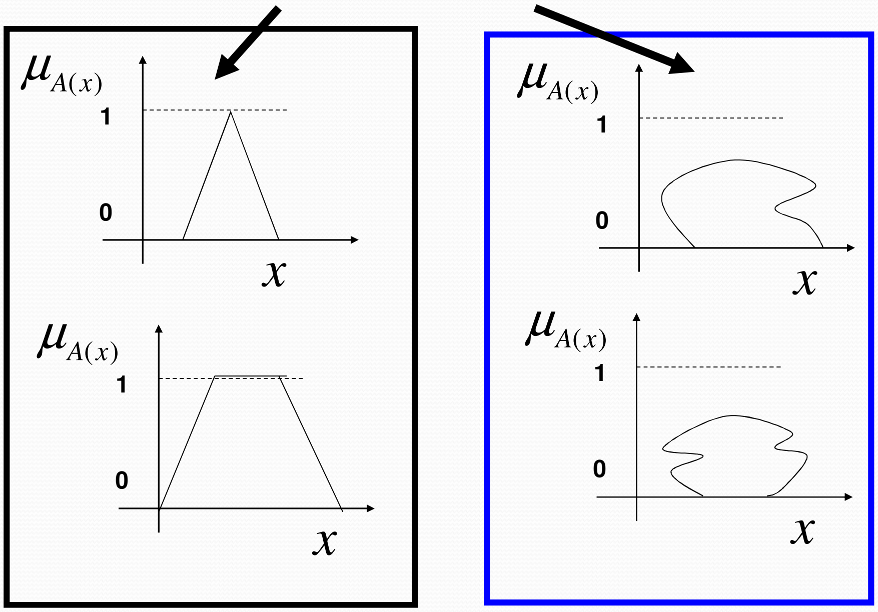
$$f(a\,x_1 + b\,x_2) \le a\,f(x_1) + b\,f(x_2)$$

$$\forall a, b \in [0,1] \; and$$

$$\forall x_1, x_2 \in X \,(\text{vector space})$$



Convex and non-convex fuzzy sets



How to define Fuzzy sets?

- **A fuzzy set with finite members having non-zero membership is represented as**

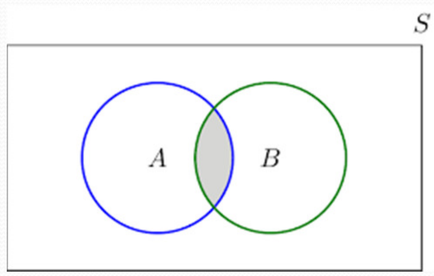
$$A = \left\{ \frac{0.4}{1}, \frac{0.6}{2}, \frac{1}{3} \right\}$$

If there are infinite members having non-zero membership then use a fuzzy membership function to define the fuzzy set as shown below

$$\mu_A(x) = \begin{cases} 1- & \textit{if } \text{condition} \\ 0 < \mu_A(x) < 1 - \text{if conditions} & \\ 0\text{ -} & \text{if conditions} \end{cases}$$

Operations on fuzzy sets

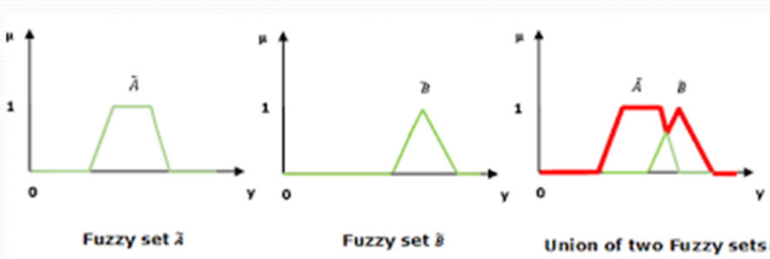
- Following common operations that can be performed on fuzzy sets
  1. Union
  2. Intersection
  3. Compliment



Union of two fuzzy sets

Let **A** and **B** be two fuzzy sets, then their union is defined as

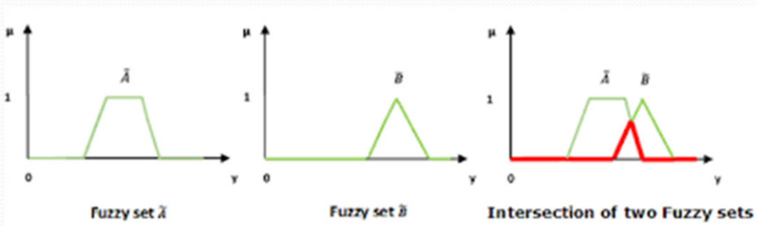
$$\mu_{A \cup B}(x) = \max\ (\mu_{A(x)}, \mu_{B(x)})$$



Intersection of two fuzzy sets

Let A and B be two fuzzy sets, then their intersection is defined as

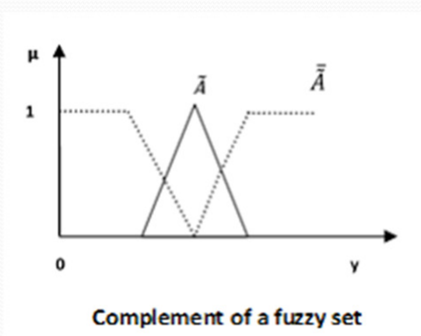
$$\mu_{A \cap B}(x) = \min\ (\mu_{A(x)}, \mu_{B(x)})$$



Compliment of a fuzzy set

Let A be a fuzzy set then its compliment can be defined as

$$\mu_{\bar{A}}(x) = 1 - \mu_{A(x)}$$



Exercise 1 on Fuzzy sets

Consider following fuzzy sets A and B

$$A = \left\{ \frac{0.4}{1}, \frac{0.1}{2}, \frac{0.55}{3}, \frac{0.6}{4}, \frac{.7}{5} \right\} \qquad B = \left\{ \frac{0.5}{4}, \frac{0.6}{5}, \frac{0.7}{6}, \frac{0.7}{7} \right\}$$

1. Compute following things

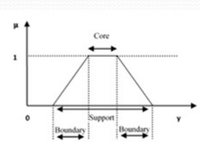
1. Intersection of A and B
2. Union of A and B
3. Compliment of A and B

2. **Which of the fuzzy set A and B is Normal? Why?**

3. **How can we prove that fuzzy set B is convex?**

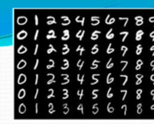
Uses of Fuzzy Membership value

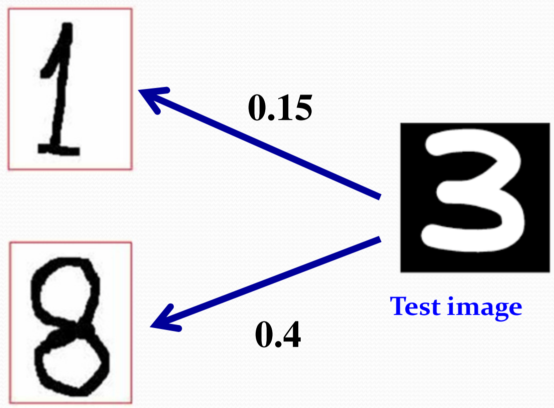
- Are used to **reason** about **similarity** of a test condition with **previously known situations**.
- Can be used to **reason** about **class label** of a test pattern using **previously learned patterns**.
- Washing machine to **decide initial torque** based on weight of cloths.
- Fuzzy **controllers** to take better decisions than crisp controllers.



Features of Membership Function

1. Fuzzy sets for pattern recognition





Fuzzy sets for 1 and 8

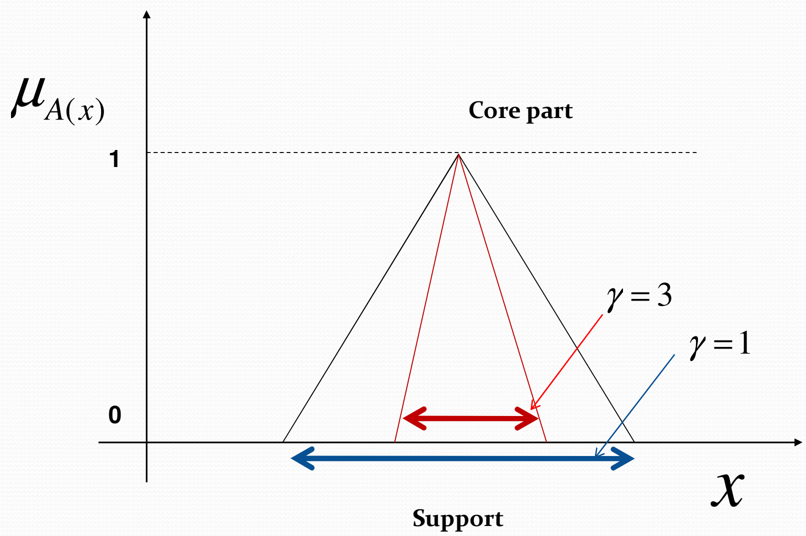
Design a fuzzy set for numbers close to 5

Let A be the fuzzy set & x be a number whose membership is to be calculated

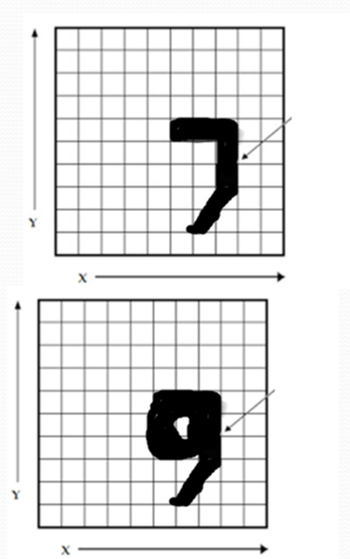
$$\mu_A(x)=\begin{cases} 1 & \text{if } \gamma\left|\dfrac{5}{\max(x,5)}-\dfrac{x}{\max(x,5)}\right|=0 \\ 1-\gamma\left|\dfrac{5}{\max(x,5)}-\dfrac{x}{\max(x,5)}\right| & \text{if } 0<\gamma\left|\dfrac{5}{\max(x,5)}-\dfrac{x}{\max(x,5)}\right|\le 1 \\ 0 & \text{if } \gamma\left|\dfrac{5}{\max(x,5)}-\dfrac{x}{\max(x,5)}\right|>1 \end{cases}$$

$$where,\ \gamma>0-\text{is sensetivity parameter}$$

Role of sensitivity parameter gamma



2. Fuzzy set for HCR matching



$$V_{ref} = (a_1, a_2, ..., a_k)$$

a_i - is the ith feature

$$V_{test} = (b_1, b_2, ..., b_k)$$

Distance d between two images can be computed as

$$d = \sqrt{\sum_{i=1}^{k} (a_i - b_i)^2}$$

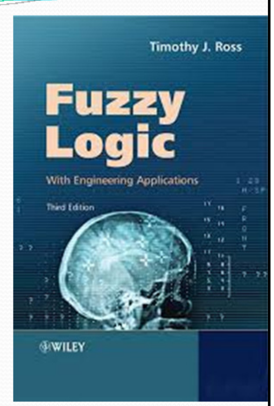
2. Fuzzy set for character matching

-A and B are character patterns to be matched

$$\mu_A(x) = \begin{cases} 1 & if\ \gamma * d(A,B) = 0 \\ 1 - \gamma * d(A,B) & if\ 0 < \gamma * d(A,B) \leq 1 \\ 0 & if\ \gamma * d(A,B) > 1 \end{cases}$$

-d- is the Euclidean distance between features of character A and B

1. Problems on operations on fuzzy sets
2. Problems on fuzzy set design.



Reference Book

- Timothy J. Ross, "*fuzzy logic with engineering applications*" , Wiley publication

Structured Knowledge Representation

- Weak Slot and Filler structures
  - Semantic Nets
  - Frames.
- Strong Slot and Filler structures
  - Conceptual dependency
  - Scripts.

A baby dog is called as ____________

What are "*Slot and filler structures*"?

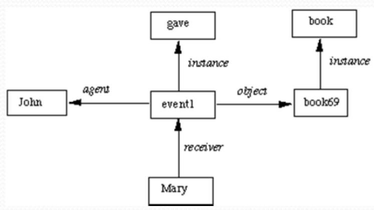
- They provide a way of representing real world facts in a more structured manner than predicate logic (unstructured).
- Used for representing entities and their attributes.
- They supports inheritance along *isa* and *instance* relationship
- Inheritance can be performed more easily than the pure logic.
- They support object orientation.

Weak and strong structures.

- *Weak slot and filler structures:*-

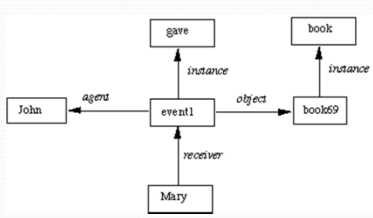
  They do not have straight forward method of reasoning (semantic nets, frames)
- Strong slot and filler structures:-

  They have straight forward method of reasoning (CD, Scripts)



Semantic net

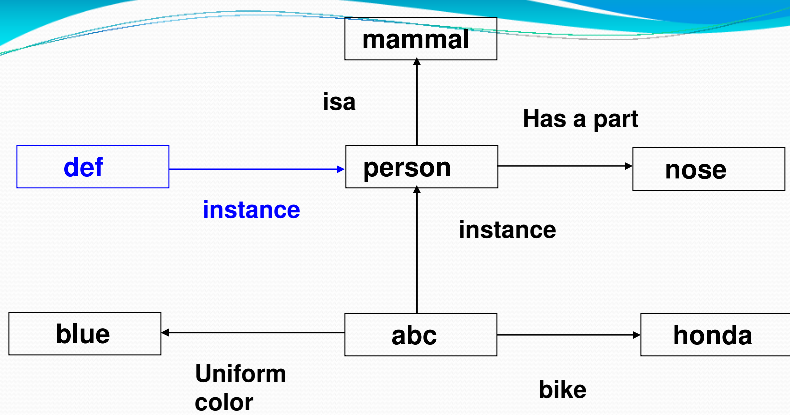
- Basic philosophy- *"Meaning of a concept comes from the way in which it is connected to other concepts".*
- In semantic net knowledge is stored as set of nodes connected to each other by a set of arcs.
- Arcs represents relationship and nodes represents class, subclass or object.



Represent above facts using semantic net.

$$isa(person, mammal)$$
$$insatnce(abc, person)$$
$$haspart(person, nose)$$
$$bike(abc, honda)$$
$$uniformcolor(abc, blue)$$

Binary predicates



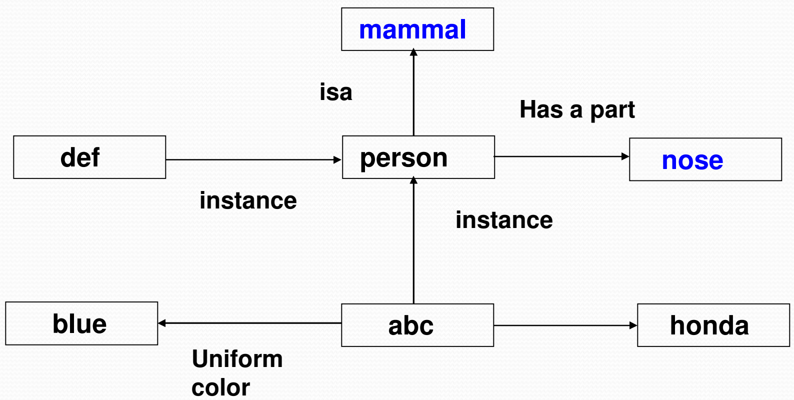
$$haspart(def, nose)$$
$$instance(def, mammal)$$

Can be easily inferred

Intersection search in semantic net

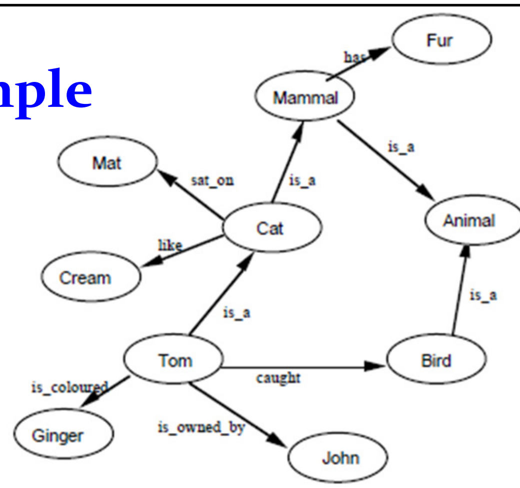
- In semantic net **intersection search** is used to find out relation between any two nodes.

e.g. what is relationship between "mammal" and "nose".



Another example

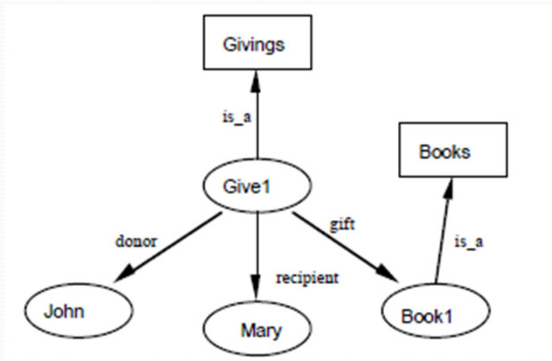
Tom is a cat.
Tom caught a bird.
Tom is owned by John.
Tom is ginger in colour.
Cats like cream.
The cat sat on the mat.
A cat is a mammal.
A bird is an animal.
All mammals are animals.
Mammals have fur.



http://www.eecs.qmul.ac.uk/~mmh/AINotes/AINotes4.pdf

Representing multi-arity predicates in semantic net

gives(John, Mary, Book)



http://www.eecs.qmul.ac.uk/~mmh/AINotes/AINotes4.pdf

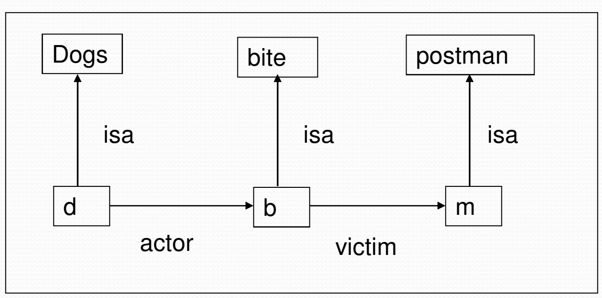
Problem on semantic net

- Represent following fact using semantic net.
- *"Hilbert is a hippo. Like other hippos he eats grass and likes swimming".*

Partitioned Semantic net.

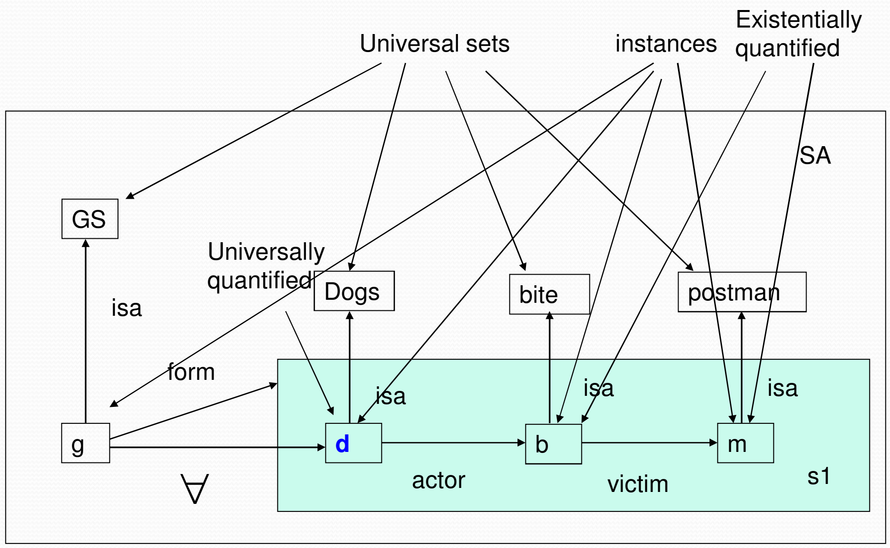
- They are used to represent universally quantified facts.
- In Partitioned Semantic net, each partition corresponds to scope of variable and spaces are hierarchically classified.

Partitioned Semantic net.



Statement "The dog has bitten a postman" can be represented with a semantic net without partition as follows.

Statement "Every dog has bitten a postman" can be represented with a semantic net partition as follows.



Partitioned Semantic net.

GS is a set of *general statements* in this universe.

-Every element of GS has two attributes

1. ***A form*:- which states a relation.**
2. **one or more "*for all*" ∀ connectives,**

   for each universal quantifier.

Advantages and drawbacks of Semantic net.

Advantages

1. They are **explicit** and **easy** to understand
2. They support **default reasoning** in finite time

Drawbacks

1. They are **incomplete** to handle procedural knowledge
2. They are not **temporal** – and thus, can not define sequence and time

Conceptual Dependency (CD)

- **CD** is proposed as a model of **Natural Language Understanding** (NLP) By **Roger Schank**, in **1969** at Stanford university.

-Motto /Aim

-Used to acquire knowledge from natural language input
– "Two sentences identical in meaning, would have a single representation"
-Knowledge representation is independent of language.
- Allow inferences
- Knowledge is represented using conceptual primitives and dependencies

https://en.wikipedia.org/wiki/Conceptual_dependency_theory
https://users.cs.cf.ac.uk/Dave.Marshall/AI2/node69.html

Conceptual Dependency (CD)

Following are the **primitive acts** used in CD

ATRANS -- Transfer of an abstract relationship. *e.g. give*.

PTRANS-- Transfer of the physical location of an object. *e.g. go*.

PROPEL-- Application of a physical force to an object. *e.g. push*.

MTRANS-- Transfer of mental information. *e.g. tell*.

MBUILD-- Construct new information from old. *e.g. decide*.

SPEAK -- Utter a sound. *e.g. say*.

https://www.slideshare.net/JismyKJose/conceptual-dependency-70129647

Conceptual Dependency (CD)

Following are the **primitive acts** used in CD

ATTEND-- Focus a sense on a stimulus. e.g. listen, watch.

MOVE-- Movement of a body part by owner. e.g. punch, kick.

GRASP-- Actor grasping an object. e.g. clutch.

INGEST-- Actor ingesting an object. e.g. eat.

EXPEL-- Actor getting rid of an object from body. e.g. Cry.

Conceptual Dependency (CD)

Following are the **Conceptual categories** used in CD

PP-- Real world objects. (picture producers)

ACT-- Real world actions. (any one primitive act)

PA -- Attributes of objects. (picture aiders)

AA -- Attributes of actions. (action aiders)

T-- Times.

LOC-- Locations.

Conceptual Dependency (CD)

Other components used in CD

- **Arrows** indicates direction of dependency ($\rightarrow$)
-**Double arrow** indicate two way link between **actor** and **action** ($\Leftrightarrow$)
  - -**O**- for object case relation
  - -**R**- Recipient case relation
  - - **P**-for past tense
  - -**D**-for destination

Conceptual Dependency (CD)

Following **tense** and **moods** are used in CD

p	Past tense
f	Future tense
t	transition
ts	Start transition
tf	Finish transition
k	continuing
?	interrogative
/	negative
	Absence of any modifier indicates present tense

Rules in Conceptual Dependency (CD)

$$\text{Rule 1}: \text{PP} \Leftrightarrow \text{ACT}$$

Relationship between actor and action . A p/f written on link indicates tense.

$$ex1.\ \text{John ran} \qquad \text{John} \overset{p}{\Leftrightarrow} \text{PTRANS}$$

$$\text{ex2. John will run} \quad \text{John} \overset{f}{\Leftrightarrow} \text{PTRANS}$$

$$\text{Rule 2}: \text{ACT} \leftarrow \text{PP}$$

Relationship between act and PP (object).

$$ex1.\ \text{John pushing bike} \qquad \text{John} \Leftrightarrow \text{PROPEL} \overset{o}{\leftarrow} bike$$

Rules in Conceptual Dependency (CD)

$$\text{Rule 3} : \text{PP} \leftrightarrow \text{PP}$$

Relationship between two PPs (objects)

$ex1.$ John is a doctor   John $\leftrightarrow$ *doctor*

$$\text{Rule 4} : \text{PP} \leftarrow \text{PP}$$

Relationship between two PPs (objects), one provides info to other of 3 types

1. POSS-BY- possession
2. LOC- location
3. CONT- physical containment

-Arrow is towards concept

$ex1.$ John's dog   dog $\xleftarrow{\text{POSS-BY}}$ *John*

2. Train at Pune   Pune $\xleftarrow{\text{LOC}}$ *train*

3. Pen is in the pocket   pocket $\xleftarrow{\text{CONT}}$ *pen*

Rules in Conceptual Dependency (CD)

$$\text{Rule 5} : \text{PP} \Leftrightarrow \text{PA}$$

Relationship between PP (object) and PA (attribute or state of PP)

$ex1.$ John is fat   John $\Leftrightarrow$ *weight*(> 80)

$$\text{Rule 6} : \text{PP} \leftarrow \text{PA}$$

Relationship between PP (object) and PA (attribute of PP)

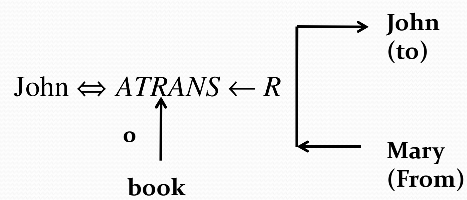
$ex1.$ Smart John   John $\leftarrow$ smart

Rules in Conceptual Dependency (CD)

$$\text{Rule 7: ACT} \leftarrow R \left| \begin{array}{l} \rightarrow PP(to) \\ \\ \leftarrow PP(from) \end{array} \right.$$

Relationship between ACT and source and recipient of the act PP (object) . R indicate recipient case relation

*ex*1. John take the book from mary



https://www.slideshare.net/JismyKJose/conceptual-dependency-70129647

Rules in Conceptual Dependency (CD)

$$\text{Rule 8: PP} \leftarrow \left| \begin{array}{l} \rightarrow PA(to) \\ \\ \leftarrow PA(from) \end{array} \right.$$

Relationship between attributes (PA) of an object (PP)

*ex*1. Tree grows

$$\text{tree} \leftarrow \left| \begin{array}{l} \rightarrow size>c \\ \\ \leftarrow size=c \end{array} \right.$$

Rules in Conceptual Dependency (CD)

$$\text{Rule 9:}\ \begin{array}{c}\Leftrightarrow\{x\}\\ \Uparrow \\ \Leftrightarrow\{y\}\end{array}$$

Relationship between one concept

to other that causes it

i.e $\{x\}$ causes $\{y\}$

$$\begin{array}{c}\{x\}\ \text{Bill shot Bob}\\ \Uparrow \\ \{y\}\text{Bobs health is poor}\end{array}$$

https://www.slideshare.net/JismyKJose/conceptual-dependency-70129647

Rules in Conceptual Dependency (CD)

$$\text{Rule 10:}\ \begin{array}{c}\Leftrightarrow\{x\}\\ \downarrow \\ \Leftrightarrow\{y\}\end{array}$$

Relationship between one concept

to other that is happening when one is in progress

i.e $\{y\}$ is happening while $\{x\}$ in progress

$$\begin{array}{c}\{x\}\ \text{while going home}\\ \downarrow \\ \{y\}\text{I saw snake}\end{array}$$

Reference-
https://www.slideshare.net/JismyKJose/conceptual-dependency-70129647

Inferences in Conceptual Dependency (CD)

Inferences can be taken directly from primitive ACT

-Inferences are stored with primitive acts itself e.g

-Action INGEST has following inferences

-- Object is no longer in previous form

-- Actor has less hunger now

-- Physical position of object can be changed and thus PTRANS can be inferred

Conceptual Dependency (CD)

Advantages

-Using primitives need **fewer inference rules** (IR) and IR are **represented** in CD **structure itself**

- Stores knowledge in a **language independent** manner
- Multiple statements using different words having same meaning use **same representation**

Disadvantages

-Difficult to find **correct set of primitives** for a situation

-Knowledge must be decomposed in to low **level primitives**

-Representation of even a **simple sentence** can be **very complex** in CD

http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.73.9307&rep=rep1&type=pdf

Conceptual Dependency (CD)

CD theory is used in MARGIE (Memory, Analysis, Response Generation and Inference in English) system developed for NLP- By Roger Schank, Stanford University , USA, 1973

https://www.ijcai.org/Proceedings/73/Papers/028.pdf

Conditional probability and Bay's theorem

$$P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B)}, \textit{where } P(B) > 0$$

$P(A \mid B)$ – is conditional probability of event A occuring, if event B is true/ already occured

$P(B \mid A)$ – is conditional probability of event B occuring, if event A already occured

$P(A), P(B)$ – are probabilities of event A and B, respectively

A and B must be **different events** and are **dependent** events

Probabilistic reasoning using Bay's theorem

Drug testing for Cannabis user. Cannabis is psycho active drug.

Given data

1. 5% population uses cannabis P(User)=0.05
2. P(Positive | User)=0.9, the actual user of cannabis tested positive i.e *true positive rate is* 90%
3. P(Positive)=0.235

Find the probability that someone is a cannabis user given that they test positive P(User|Positive)

Probabilistic Reasoning using Bay's theorem

$$P(User \mid Positive) = \frac{P(Positive \mid User)P(User)}{P(Positive)}$$

$$P(User \mid Positive) = \frac{P(Positive \mid User)P(User)}{P(Positive)} = \frac{0.9 \times 0.05}{0.235}$$

$$= \frac{0.045}{0.235} = 0.1915 = 19\%$$

https://en.wikipedia.org/wiki/Bayes%27_theorem

Bayesian Networks

- It is one of the approach to reason in Uncertainty using the Probability
- Also termed as Bays Network, Belief network or Decision network.
- It is a graphical model that represents set of variables and conditional dependencies using Directed Acyclic Graph (DAG)
- They are most suited to know the likelihood of probable causes of an event that occurred
- There can be probabilistic relationship between symptoms and disease, given symptoms a disease can be predicted (*probabilistic inference*)

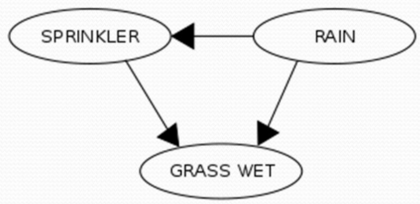
Bayesian Networks

Definition:- *They contain set of nodes representing variables describing observable parameters or hypothesis. Edges represents conditional dependencies.*

- Nodes that are not connected assumed conditionally independent of each other
- Each node is associated with the probability function that takes as input from the nodes parents and provide output that is probability of that variable represented by that node
- For example, if m parent nodes represent m Boolean variables, then the probability function could be represented by a table of 2^m entries, one entry for each of the 2^m possible parent combinations

Bayesian Networks

RAIN	SPRINKLER T	SPRINKLER F
F	0.4	0.6
T	0.01	0.99



RAIN T	RAIN F
0.2	0.8

SPRINKLER	RAIN	GRASS WET T	GRASS WET F
F	F	0.0	1.0
F	T	0.8	0.2
T	F	0.9	0.1
T	T	0.99	0.01

A simple Bayesian network with conditional probability tables

It reasons by using posterior probability of unobserved variable when an evidence of a cause is available

https://en.wikipedia.org/wiki/Bayesian_network#:~:text=A%20Bayesian%20network%20(also%20known,directed%20acyclic%20graph%20(DAG).

Bayesian Networks-Pros and Cons

- Produce accurate and valid results
- Sensitive to prior probabilities
- We need an expert in probability/ great expertise in statistics to define Bayesian Networks, than other approaches.
- Designing them for more variables is a challenging task in machine learning
- BayesiaLab- a s/w for design of Bayesian Networks (bayesia.com)

Reading list

- Justification based truth maintenance system
- Many equivalent ways to write and apply Bays theorem

  https://www.statisticshowto.com/bayes-theorem-problems/

Probability and Bays' theorem