# Situation Awareness for Intelligence Analysis and Security Decisions

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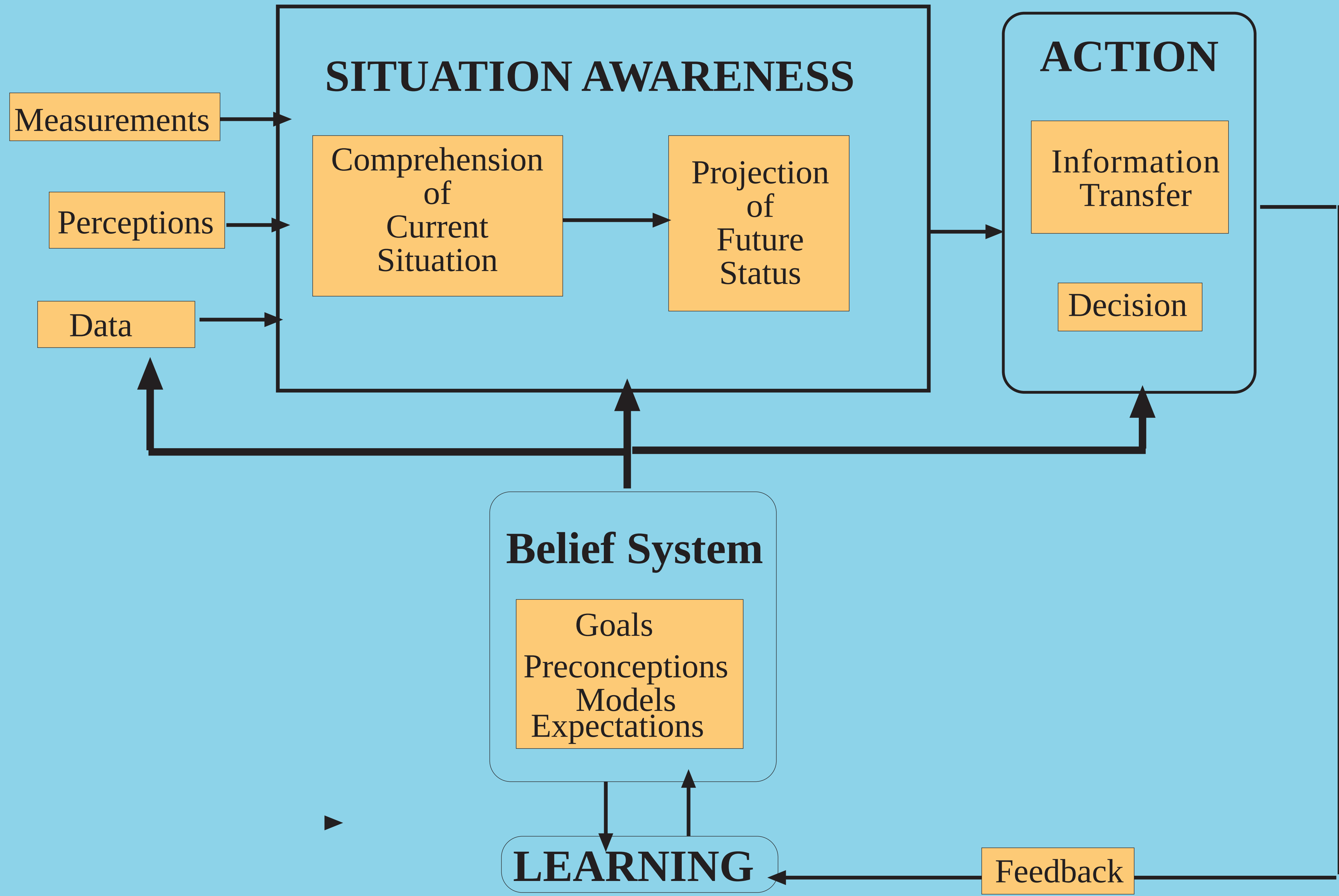

SITUATION AWARENESS
Measurements
Perceptions
Data
Comprehension of Current Situation
Projection of Future Status
ACTION
Information Transfer
Decision
Belief System
Goals
Preconceptions
Models
Expectations
LEARNING
Feedback

David A. Kay, who led the US government's efforts to find evidence of Iraq's illicit weapons programs, reported that the current intelligence systems dealing with weapons of mass destruction are **based on limited information**. He indicated that modern intelligence analysis systems need a way for an analyst to say, **"I don't have enough information to a make a judgment,"** a capacity that he felt the current intelligence systems do not possess. Central to attaining this capability is the **ability to deal with uncertain and imprecise information**

# Perceptions in Intelligence

Realistic decision relevant information is mixture of measurements and perceptions

- The size of the terror group is small
- The leader of xyz seems very angry
- We will be vulnerable for  about fifteen minutes
- Their strategy looks similar to the one they used last time

# Types of Perceptions

- **Attributes of Physical Objects**:
  Speed, Distance, Size, Quantity, Time
- **Emotions and Intent**
  Degree of Anger, Fear, Pain, Injury
- **Concepts**
  Similarity, Possibility, Risk, Value

**Require a formalism**
**to express this kind of information**

# Decision Making Strongly Influenced by Perceptions of Probabilities

- The person walking toward me is **likely** a terrorist.
- The probability that the oil supply will last for two days is **small**.
- Commander X **usually** follows a conservative approach.

**Need to equip our agents to handle these types of uncertain inputs**

# Modeling Perceptions of Probabilities

- Involve mixture of probabilistic and fuzzy information
- Example: **Time to finish a task**

  Prob(about 1/2 day) is **small**
  Prob(about a day) is **high**
  Prob(Over a day) is **unlikely**
- Probabilities and events are imprecise

**Granular Probability Distributions**

# Fuzzy Logic and Intelligence

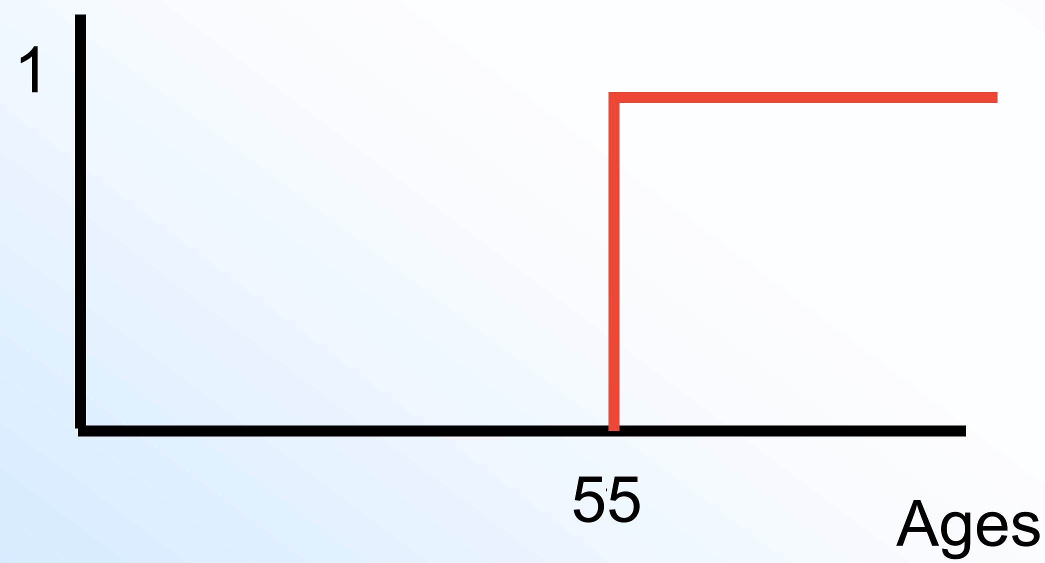
- Intelligence Information
  - Perceptions
  - Linguistic in nature
  - Contains Imprecision and Uncertainty

- Fuzzy Logic can Help
  - Focused on Linguistically Induced Uncertainty
  - Formal Machinery Available

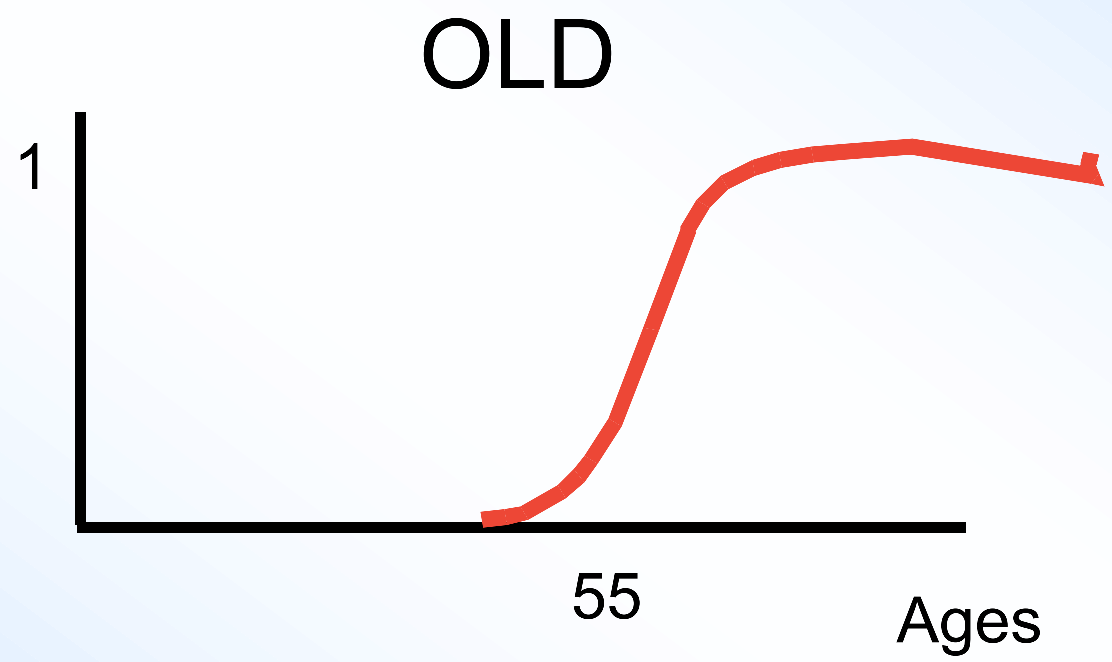
# Key Idea

Representation of the meaning of words can be obtained using **Sets**

OLD



# Fuzzy Sets Provide Sophisticated Representations




Representation of Concepts
in a Manner Closer to Actual Meaning

# Computing with Words

Natural Language Statement

↓

Translation

↓

Processing

↓

Retranslation

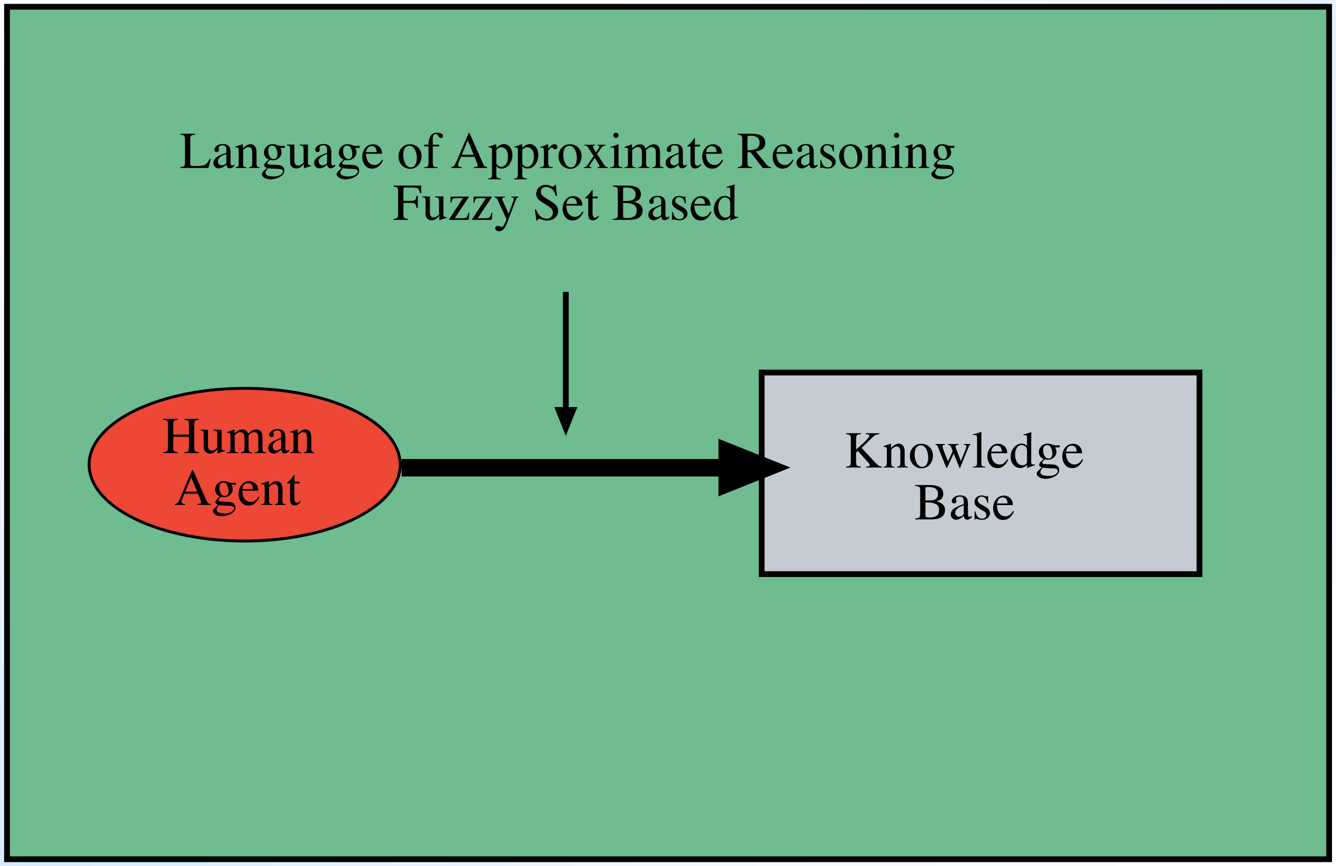
↓

Natural Language Statement

# Features of Computing With Words

- Mechanism for Reasoning with Information Stated in Linguistic Terms
- Semantics Provided Using Fuzzy Sets
- Uses Approximate Reasoning for Knowledge Manipulation

# Building Knowledge Base



# Key concepts

- Linguistic Values
- Approximate Reasoning (AR)
- Fuzzy Arithmetic

# Linguistic Values

## Representation of Linguistic Values for Variables by Fuzzy Sets

**Variable:** V

John's Age

**Universe of Discourse**: X

[0, 100]

**Canonical Statement**:

*John is young*

**Representation in AR formalism**

**V *is* young**

**young** is a linguistic value that can be expressed as a fuzzy subset of X

# Representation of Knowledge Using Fuzzy Logic

- Knowledge expressed using statement **V *is* A**

  A is a fuzzy subset of the domain X of V

- Generalizes idea of constraining value of V

  V lies in the subset B, when B is a crisp subset

- Induces a possibility distribution on X

  A(x) is the possibility that x is the value of V

- Useful when information expressed linguistically

Terrorist was "young" $\Rightarrow$ Age(terrorist) is *young*

# Some Special Cases

- $A = \{x\}$ is equivalent to saying that $V = x$
- $A = X$ is equivalent to saying I don't know
- $Max_X A(x) = 1$: A is normal one solution possible
- $Max_X A(x) < 1$: some conflict with the assumption that V lies in X
- $A = \varnothing$ No possible value in X Complete conflict

# The Entailment Principle

- Basic Inference rule in fuzzy logic

- The principle states:

  From knowledge that <u>V *is* A</u> we can infer <u>V *is* F</u>

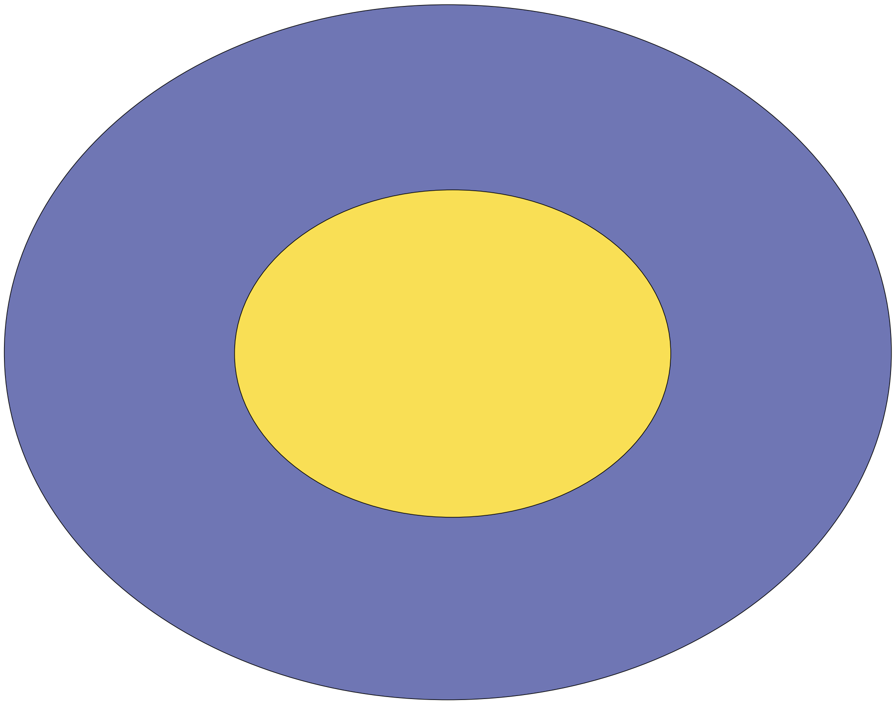
  for any $A \subseteq F$

  ($A \subseteq F$ if $A(x) \leq F(x)$ for all x)

- **Example** Knowing that John's age is between <u>25 and 35</u> allows us to infer that John's age is between <u>10 and 50</u>

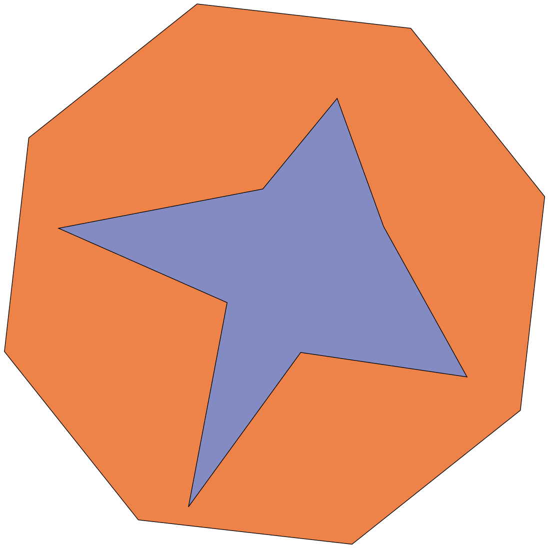
- Related to logic inference $a \Rightarrow a$ or $b$

# DEDUCTION



In yellow circle
must be
in blue circle

# REDUCTION



**In orange saying it is in blue**

°

# REDUCTION

- From **less** precise to **more** precise

- From knowing that John's is between 25 and 35 years old we infer that John's age is 30

- NOT SOUND Can lead to wrong inferences

- Used in human reasoning: Default reasoning

- Pragmatic & Often useful

Mary lives in China $\Rightarrow$ Mary is Chinese

People Use the Imprecision of Language to Balance the Conflicting Objectives of Being Useful and Correct in their Communications and Mental Models of the World

# Specificity and Correctness-Usefulness Clash

- **Less** specific information is less likely to be **useful**

  The expected temperature is between 20 and 100. What should I wear???

- **More** specific information is less likely to be **correct**

  He looks like he weighs 156.3 lbs

# Measuring the Information/Uncertainty in Fuzzy Propositions

- **Specificity** measures the amount of information contained in V *is* A.

- Inversely related uncertainty

- The more specific the more certain

- John is 35
  John is around 35
  John is in his thirties
  John is over 21

***DECREASING Specificity More UNcertainty***

- **Specificity is related to Usefulness**

Knowing our sales will be 2.5 million is more useful then knowing our sales will be between 2 and 3 million

- **IMPRECISION** (Lack of specificity) is often used to assure correctness of Information

**MAJOR TRADEOFF IN INFORMATION PRESENTATION**

**USEFULNESS VERUS CORRECTNESS**

## Definition of Specificity

- The **specificity of V is A** is

$$Sp(A) = A(x^*) - Ave$$

$A(x^*) = Max_X[A(x)]$

$Ave$ = average membership grade in A of all elements except $x^*$

*The difference between the highest membership grade and the average of all the other elements*

# Properties of Specificity Measure

**1.** It lies in unit interval. $0 \leq Sp(A) \leq 1$.

**2.** $Sp(A) = 1$ iff there exists only one element $x^*$ with $A(x^*) = 1$ and all other elements have $A(x) = 0$

**3.** If $A(x) = c$ for all x, then $Sp(A) = 0$.

**4.** If A and B are normal fuzzy subsets and $A \supseteq B$ then $Sp(B) \geq Sp(A)$. Under normality, containment means an increase of specificity.

**Specificity is degree to which V *is* A points to only one element as value of V**

Specificity plays an important role in the development of intelligent information systems. By helping us measure the information content it allows us to compare different information processing algorithms

An important task in security analysis and decision making is the determination of the validity of some conjecture or statement based on known intelligence information

Difficulties arise when the intelligence information contains uncertainty

- **Our plan of attack will work if enemy has less then 5000 defenders**

- **Intelligence tells us that they have between 3000 and 6000 defenders**

- **Will our attack work ?**

- **For Highly Enriched Uranium (HEU) to be used in nuclear weapons the amount of the U–235 isotope must be increased to above 90%**

- **Our intelligence leads us to believe that the highest enrichment the Iranians are capable of is between 84% and 93%**

- **Should our policy be based on the assumption that they are already capable of producing Nuclear Weapons**

## Given <u>V *is* A</u>  Determine Validity of  <u>V *is* B</u>

Situation in which A and B are crisp

Two cases regarding our knowledge of A

**Case 1:** No uncertainty  $A = \{x^*\}$

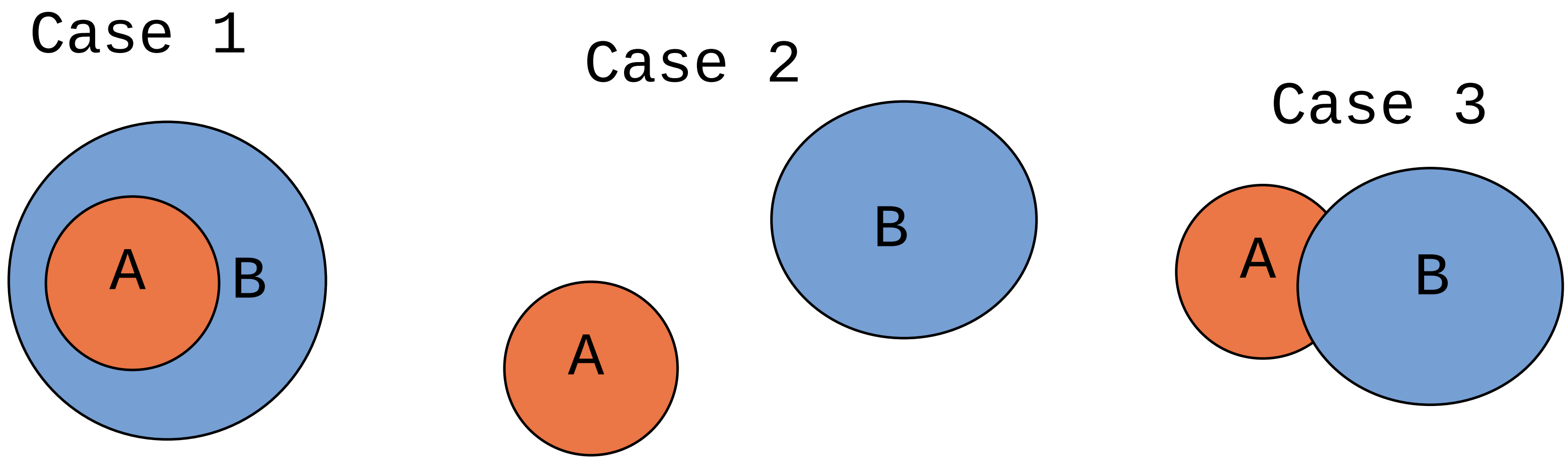
**Answer:** if $x^* \in B$ then the answer is **yes**

if $x^* \notin B$ then the answer is **no**.

Exact information with respect to the value of V leads to precise answers

**Case 2:** There exists some uncertainty about the value of V  (A is not a singleton)

***As noted by Kay this is the typical situation in intelligence analysis***




**Given V is A determine validity of V is B**

- If $A \subseteq B$ then the answer is **Yes**
- If $A \cap B = \emptyset$ then the answer is **No**
- If $A \cap B \neq \emptyset$ & $A \not\subset B$ the answer is **I don't know**

## *Clear answers to questions in the face of uncertain information is not always attainable*

This holds even in the case when B is a singleton. Asking if V = 30 if we only know that V ∈ [25, 40] can't be answered yes or no, the appropriate answer is ***I don't know***

# Measures of Possibility and Certainty

- Fuzzy case needs more sophisticated tools

- Poss[V *is* B / V *is* A] = $Max_X[A(x) \wedge B(x)]$

  Measures degree of intersection between A and B

- Cert[V *is* B/V *is* A] = 1 - Poss[V *is* not B/V *is* A]

  $= 1 - Max_X[A(x) \wedge \overline{B}(x)] = Min_X[\overline{A}(x) \vee B(x)]$

  Measures degree to which A is contained in B

•Possibility and Certainty provide upper and lower bounds (optimistic and pessimistic) to question of whether V *is* B is true given we know that V *is* A

## SOME SPECIAL CASES

- $A = \{x_1\}$, the value of V is exactly known

  Poss[V *is* B/V *is* A] = Cert[V *is* B/V *is* A] = $B(x_1)$

  $B(x_1)$ is the validity of statement V *is* B

- A is a crisp set

  Poss[V *is* B / V *is* A] = $\mathrm{Max}_{x \in A}[B(x)]$

  Cert[V *is* B / V *is* A] = $\mathrm{Min}_{x \in A}[B(x)]$

- Is V equal to some particular value ?? $B = \{x^*\}$

  Poss[V *is* B/ V *is* A] = $A(x^*)$

  Cert[V *is* B / V *is* A] = $1 - \mathrm{Max}_{x \neq x^*}[A(x)]$

When our information, **V *is* A ,** has some uncertainty the answer to a question about the truth of the statement **V *is* B** lies in the interval [L, U] where L is the certainty that V *is* B and U is the possibility that V *is* B

# Decision Making Under Uncertainty

When the decision process requires a more precise determination of the validity of the proposition V *is* B then provided by the interval [L, U] we must provide some means around this difficulty.

Often this involves the inclusion of **subjective** preferences of the responsible decision maker reflecting his **attitudinal character**

## An Example

- Preparing for a party in which we are not sure whether 20 or 500 people are coming

- If we prepare for 500 and only 20 show up then we wasted a lot of money.  If we prepare for 20 and 500 show up we have some embarrassment

- The choice of how many people to prepare for must be based on the subjective preferences of the party giver with respect to being embarrassed or wasting money, **there is no right or wrong**.

**Similar considerations arise in the determination as to whether we should preemptively strike an adversary based on uncertain information with regard to having weapons of mass destruction**

## Hedging on the Information that V *is* A

- Here $\alpha$ is degree of confidence we have in V *is* A,

  V *is* A is $\alpha$ certain

- Translate this hedged knowledge into V *is* F

  $F(x) = Max[A(x), \overline{\alpha}] = A(x) \vee \overline{\alpha}$

- Hedging loosens the constraint on the variable V

- if $\alpha = 1 \Rightarrow$ $F(x) = A(x)$ our unhedged proposition

- If $\alpha = 0$ then $F(x) = 1$ for all x.

Statement V *is* F carries no information

**PROCESSING OF INTELLIGENCE OFTEN INVOLVES**

**THE FUSION OF INFORMATION FROM**

**MULTIPLE SOURCES**

# Intelligent Fusion of Imprecise Information

- Many tasks involve information gathering and subsequent fusion

  Crisis Recognition   Question/Answering

- Information appears as linguistic fragments

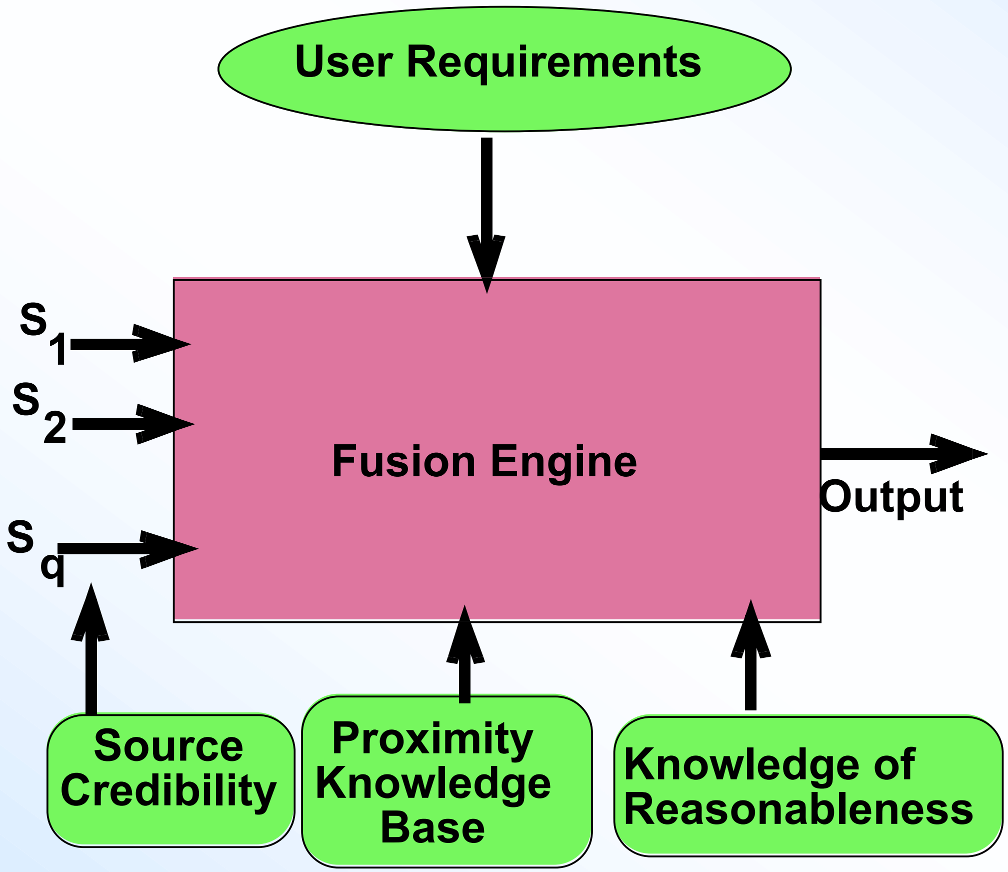
  *Greenspan believes interest rates should increase slowly*

- Fuzzy Methods allows representation and manipulation of these linguistic fragments

# Some Issues for Intelligent Fusion of Information

- Information Extraction
- Information Representation
- Inclusion  of Commonsense Knowledge
- Problem Specific Fusion Rules
- Combining of Different Modalities
- Managing conflicts in  imprecise information

# Multi-Source Fusion



# Multi-Source Information Fusion

- V *is* $A_i$, for i = 1 to q, information supplied by different sources

- Fused value **V *is* D** $(D = \cap_i A_i)$

$$D(x) = Min_i[A_i(x)]$$

- **Fundamental Properties of Fusion Process.**

For all x, $D(x) \leq A_i(x)$ that is $D \subseteq A_i$

If $D = \bigcap_{i=1}^{q} A_i$ and $E = D \cap A_{q+1}$ then $E \subseteq D$

Increasing # of sources Reduces fused subset size

- Objective in using multiple sources is to

  Increase the information / Decrease uncertainty

- We desire to increase the specificity

- If D is normal then $Sp(D) \geq Sp(A_i)$ for any i

  We have we have gained information

- If $Max_x D(x) \leq 1$, some of sources are conflicting

  Fusion of sources resulted in more confusion

  Our specificity has decreased

# Fusing Conflicting Information

- Do not to use all the information

- Select which information to use and fuse

- Requires adjudicating between information supplied by the different sources

- Adjudication requires inclusion of additional "subjective" knowledge from the person ultimately responsible for fusing the information

# Features of Suggested Fusion Process

- Makes use of a credibility/confidence measure

- It is in this credibility measure the additional knowledge is included

- Involves tradeoff between selecting subsets of sources that are not conflicting while still providing credible fusion

- Let $P_i$ denote V *is* $A_i$

  $\mathsf{P} = \{P_1, ..., P_q\}$

- Associate with $\mathsf{P}$ a measure $\mu: 2^{\mathsf{P}} \rightarrow [0, 1]$

  (credibility measure)

- For each subset B of $\mathsf{P}$, $\mu(B)$ is credibility of using as our fused value the fusion of the data in B.

- Properties of $\mu$: **1**. $\mu(\varnothing) = 0$, **2**. $\mu(\mathsf{P}) = 1$ and

  **3**. $\mu$ is monotonic, if $B_1 \subset B_2$ then $\mu(B_2) \geq \mu(B_1)$

**OUR OBJECTIVE IS TO FIND THE SUBSET OF** $\mathcal{P}$

**WITH THE MOST INFORMATIVE AND CREDIBLE**

**FUSION**

- Assume B is a subset of P
- Let $D_B$ be the fusion of the knowledge in B
- $$D_B = \bigcap_{P_i \in B} A_i,$$
- Using B leads to the statement V *is* $D_B$
- Any statement obtained by using only the information in B only has a credibility of $\mu(B)$

- Determination of the **Quality** of the knowledge obtained using B is based on two criteria

- Criteria One: Knowledge provided using B is informative This measured as $Sp(D_B)$

- Criteria Two: B is a credible subset of P
  This measured as $\mu(B)$

- $Qual(B) = Sp(D_B)\ \mu(B)$

- Find B* such that Qual(B*) is the largest

- **Output of fusion process**
  **V *is* $D_{B^*}$ with confidence $\mu(B^*)$**

- We shall refer to this process as Qual-Fuse
- We let Qual-Fuse($P$, $\mu$) =B*
- If no conflict in $P$

  then $D_P$ is normal

  Qual–Fuse($P$, $\mu$) = $P$

  Fusion output: V is $D_P$ with confidence 1

# Man-Machine Communications

Computerized information fusion systems manipulate mathematical representations of information. The result of this fusion process is generally information that is in some formal mathematical structure (fuzzy set/ probability distribution etc).

Human decision makers and other users of information fusion systems prefer information expressed in natural language like statements

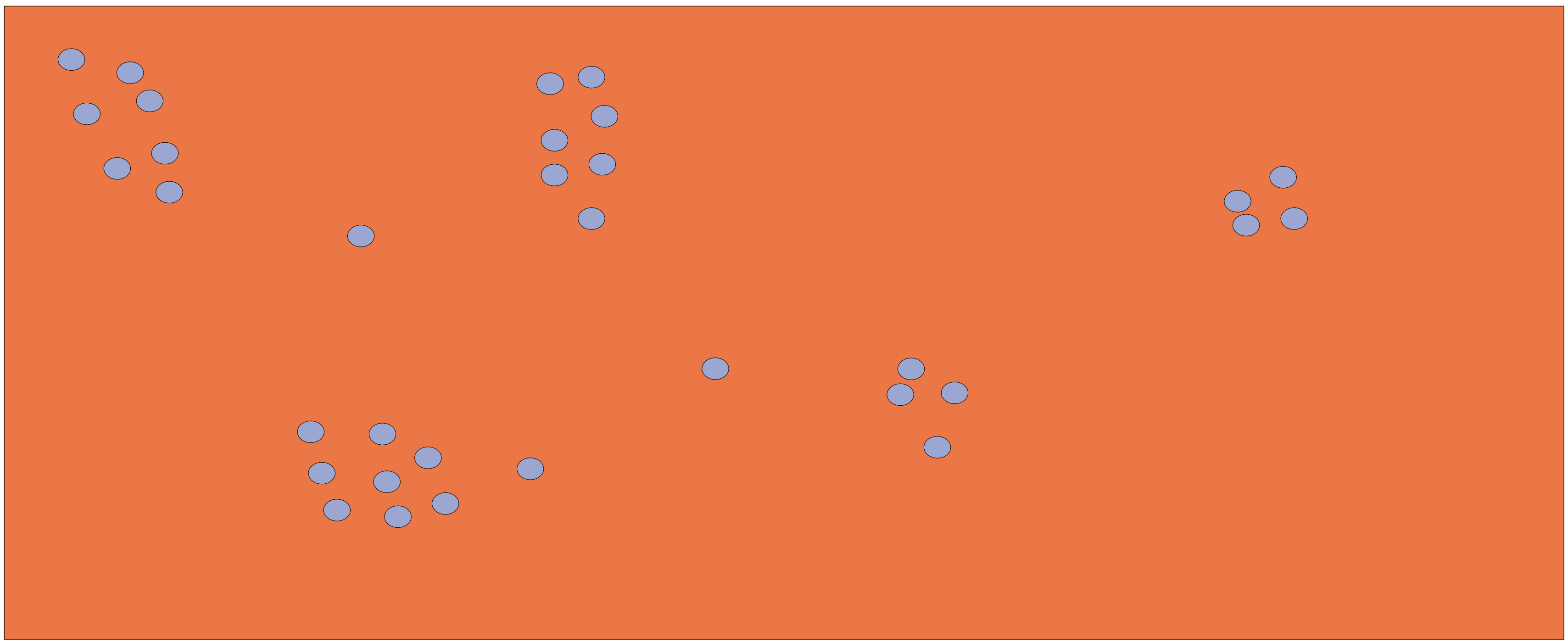
# RETRANSLATION

Process of converting the formal mathematical representations resulting from information fusion into natural language like statements understandable to the human user

# Disinformation Dissemination

- At times we have an agenda when expressing the fused value
- Convey a particular perception
- Denability/Accountability
- Imbed true value in larger granular that gives desired perception without being false

In some situations, the presentation of a single fused value may not be sufficient or appropriate. This is particularly the case when we have clusters of strongly conflicting source data



# Multiple Fused Values from Multi-Source Data

- Generation of multiple fusions from $(P, \mu)$.

- For notational convenience in the following we shall find it convenient to denote the fuzzy subsets $A_j$ as $A_j^1$, thus $P_j$ corresponds to the observation $V$ *is* $A_j^1$

## Basic Procedural Algorithm

**1**. Initialize our system with P, μ and set i = 1.

**2**. Apply Qual-Fuse(P, μ) this returns $B_1$

**3**. Revise each $P_j$ to V *is* $A_j^2$ where $A_j^2 = A_j^1 - D_{B_1}$

We recall $A_j^1 - D_{B_1} = A_j^1 \cap \overline{D}_{B_1}$

**4**. Set i = 2

**5.** Let P = [$P_1$, ..., $P_1$] with $P_j$ such that V *is* $A_j^i$

**6.** Apply Qual-Fuse(P, μ) this returns $B_i$

**7.** More fusions desired? No-stop, Yes - continue

**8.** Set i = i + 1

**9.** Calculate $A_j^i = A_j^{i-1} - D_{B_{i-1}}$

**10**. Go to step 5

Final result of this process is a collection of fused values of the form

V *is* $D_{B_1}$ with credibility $\mu(B_1)$

V *is* $D_{B_2}$ with credibility $\mu(B_2)$

V *is* $D_{B_k}$ with credibility $\mu(B_k)$

# INFORMATION FROM RELATIONS

- John is a **little more then twice** as old as Mary

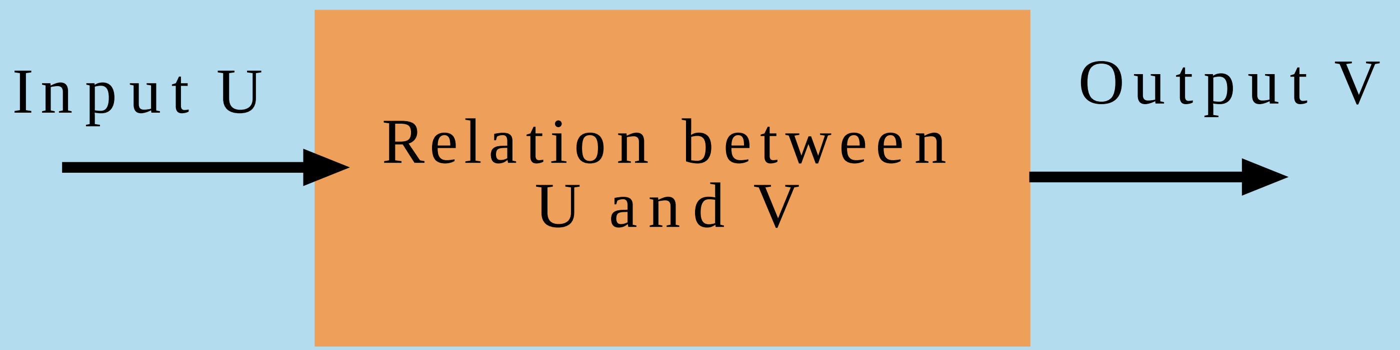
  Mary is **about 15** years old

  How old is John ?

- If the exchange rate is increased by **more then 2 0 %** then our sales will decrease by **about a quarter**

It is anticipated the increase will **be about 18%**

What will happen to our sales ??




A Kind of Information Fusion Problem

# FUSING DATA AND RELATIONS

- U is a variable with domain X
- V is a variable with domain Y
- RELATION (U, V) *is* R

  R is fuzzy subset on $X \times Y$

  R(x, y) compatibility of U = x and V = y
- Data U *is* A
- Fused Value V *is* B

  $B(y) = Max_x[Min(A(x), R(x, y))]$

**AN IMPORTANT PROBLEM IN COMPUTATIONAL INTELLIGENCE AND KNOWLEDGE ENGINEERING IS THE ISSUE OF THE PRESENTATION OF DIFFERENT KINDS OF RELATIONS IN A MANNER THAT ALLOWS COMPUTER MANIPULATION**

# SOME TYPES OF RELATIONS

- **Implication:** If U is G then V is H

  $$R(x, y) = \overline{G}(x) \vee H(y)$$

- **Fuzzy Model**

(U is $A_1$ and V is $B_1$) or (U is $A_2$ and V is $B_2$) or .......

$$R(x, y) = \mathrm{Max}_j[A_j(x) \wedge B_j(y)$$

- **Mathematical** "V is about twice U"

  R(x, y) = Degree y satisfies being about twice x

# PROTOFORMS

- If U is G then V is H

  U is A

>>> V is B where $B(y) = Poss(\text{not } G/A) \vee H(y)$

- ($U$ is $A_1$ and $V$ is $B_1$) or ($U$ is $A_2$ and $V$ is $B_2$) or ....

  U is A

>>> V is B where $B(y) = Max_j[Poss(A/A_j) \wedge B_j(y)]$

# Multiple Relations

- Many cases knowledge expressed using multiple relations between U and V

- (U, V) is $R_j$ for j = 1 to m

- We must combine relations

- (U, V) is $R_1$ and (U, V) is $R_2$ and .......

- (U, V) is R

$$R(x, y) = Min_j[R_j(x, y)]$$

# TYPICAL AND DEFAULT KNOWLEDGE

- **Default Knowledge:**

  **Typically** V is B

  Representation: If **V is B is possible** then V is B

- **Typically** If U is A then V is B

  If U is A and **V is B is possible** then V is B

- Requires the determination of Poss(V is B/V is F) where F is what we already know about V

- Introduces priority considerations

## FUSING PROBABILISTIC AND FUZZY INFORMATION

- Data: V *is* A    A is fuzzy set on X
  Probability distribution **P** on X

- Induces a probability distribution $\tilde{P}$ on X

- View as conditional probability distribution on X

- $$\text{Prob}(x/A,\ P) = \frac{P(A \text{ and } \{x\})}{P(A)}$$

- $$\tilde{P}(x) = \frac{A(x)\ P(x)}{\sum_j A(x_j)\ P(x_j)}$$

# FUZZY RELATIONS AND PROBABILISTIC INFORMATION

- Knowledge Fuzzy Relation
  (U, V) is R

- Data Probability distribution **P** on U

- Induces probability distribution with $\widehat{P}$ on V

- $$\widehat{P(y)} = \frac{\sum_{j} P(x_j)\ R(x_j, y)}{\sum_{i} \sum_{j} P(x_j)\ R(x_j, y_i)}$$

# Question Answering Systems

- Information available in knowledge base
- Formulates knowledge not in KB
- Reasoning Capability
- Requires Representation of Knowledge
- Approximate Reasoning & Fuzzy Sets
- Knowledge Trees

# Knowledge Base

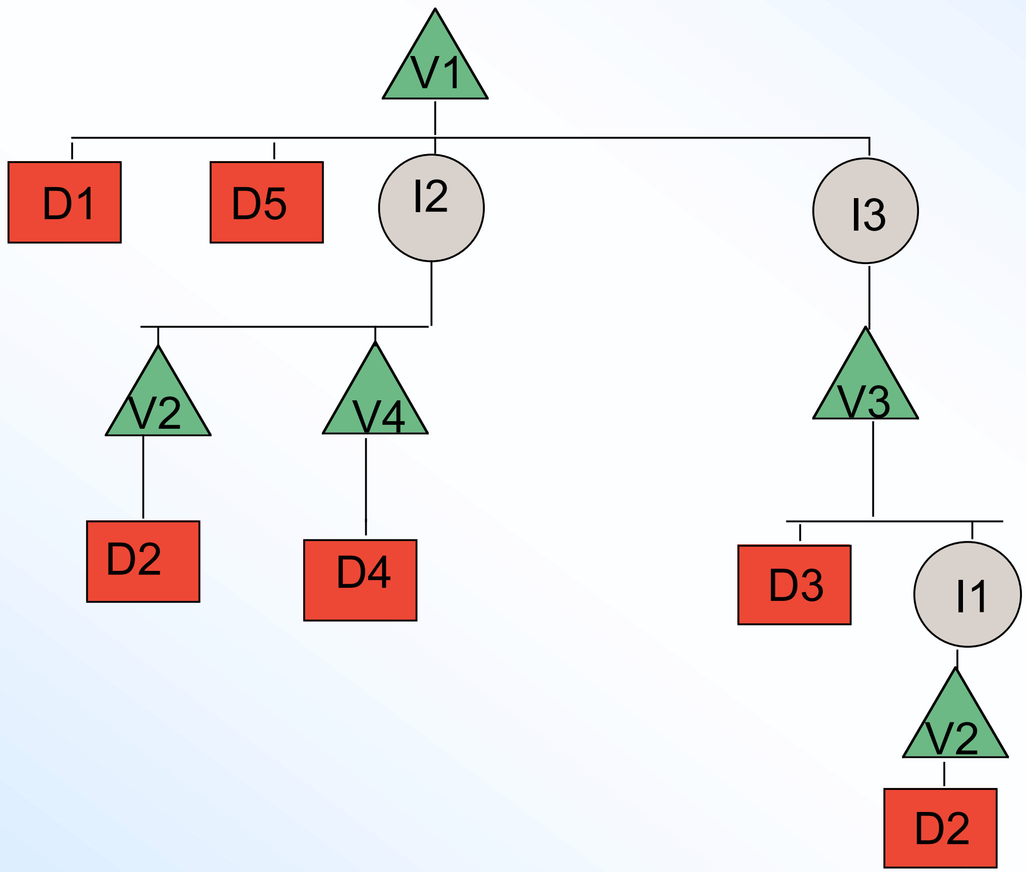
- Data Propositions
- D1: V1 *is* A1 D2: V2 *is* A2
- D3: V3 *is* A3 D4: V4 *is* A4
- D5: V1 *is* B1

- Implicational Propositions
- I1: If V2 *is* C2 then V3 *is* C3
- I2: If V2 *is* D2 and V4 *is* D4 then V1 *is* D1
- I3: If V3 *is* E3 then V1 *is* E1

# Question Answering with Knowledge Trees

- Question: What is the value of V1 ??
- Mobilize relevant knowledge using knowledge trees
- Determine answer using AR

# KNOWLEDGE TREE



# Features of Knowledge Trees

- Mobilizes Task Relevant Information
- Uses protoforms for local reasoning
- Points out directions to search out new information