Network-based Hard/Soft Information Fusion:
Soft Information and its Fusion

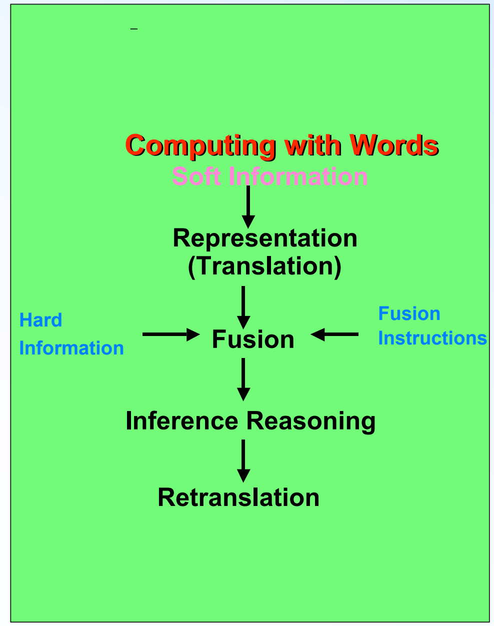
Ronald R. Yager , Iona College
Tel. 212 249 2047, E-Mail: yager@panix.com

Objectives:

- Support development of hard/soft information fusion
- Develop methods for the aggregation of uncertain information
- Provide formalisms for the representation and modeling of soft information

DoD Benefit:

- Better use of available information



Scientific/Technical Approach

- Fuzzy Set Theory
- Monotonic Set Measure
- Dempster Shafer Theory
- Mathematical theory of aggregation
- Computing with Words

Accomplishments

- Poss-Prob Fusion Methods
- Querying Under Uncertainty
- Uncertainty Qualified Expressions
- Set measure Representation

Challenges

- Mixed uncertainty mode fusion
- Complexity of Soft information

Focus of Research
Iona College

Our focus is on the development of new knowledge and fundamental directions and understandings in the process of hard/soft information fusion. This includes the modeling of various types of information as well as the development of technologies for the aggregation and fusion of information

Previous Accomplishments

- Measure Theoretic Paradigm for Uncertainty Modeling
- Fusion and Aggregation of Uncertainty Measures
- Conditioning Approach to Poss-Prob Fusion
- Linguistic Expression of Fusion Rules
- Prioritized Aggregation Operation
- Modeling Doubly Uncertain Constaints
- Decision Making with Uncertain Information
- Quantification of Uncertainty

Publication List
Iona College

Journals

- Yager, R. R., "Set measure directed multi-source information fusion," IEEE Transactions on Fuzzy Systems 19, 1031-1039, 2011.
- Yager, R. R., "Expansible measures of specificity," International Journal of General Systems 41, 247-263, 2012.
- Yager, R. R., "Dempster-Shafer structures with general measures," International Journal of General Systems 41, 395-408, 2012
- Yager, R. R., "Conditional approach to possibility-probability fusion," IEEE Transactions on Fuzzy Systems 20, 46-56, 2012
- Yager, R. R., "On Z-valuations using Zadeh's Z-numbers," International Journal of Intelligent Systems 27, 259-278, 2012
- Yager, R. R., "Entailment principle for measure-based uncertainty," IEEE Transactions on Fuzzy Systems 20, 526-535, 2012.
- Yager, R. R., "Measures of assurance and opportunity in modeling uncertain information," International Journal of Intelligent Systems 27, 776-796, 2012
- Yager, R. R., "Participatory learning of propositional knowledge," IEEE Transactions on Fuzzy Systems 20, 715-727, 2012
- Angelov, P. and Yager, R. R., "A new type of simplified fuzzy rule-based system," International Journal of General Systems 41, 163-186, 2012

Publication List (2)
Iona College

Conferences

- Yager, R. R., "On a view of Zadeh's Z-numbers," Advances in Computational Intelligence- Proceedings of the 14th International Conference on Information Processing and of Uncertanty in Knowledge-Based Systems (IPMU) Part 3, Springer:Berlin, 90-101, 2012
- Yager, R. R. and Petry, F. E., "Using language to influence another's decision," Proceedings of 2nd International Conference on Cross-Cultural Decision Making: Focus 2012 held jointly with AHFE International Conference San Francisco, 7287-7296, 2012

Manuscripts

- Yager, R. R., "Joint cumulative distribution functions for Dempster–Shafer belief structures," Technical Report MII-3204 Machine Intelligence Institute, Iona College, .
- Yager, R. R. and Abbasov, A. M., "On forming joint variables in computing with words," Technical Report MII-3209 Machine Intelligence Institute, Iona College.
- Yager, R. R., "Intelligent aggregation and time series smoothing," Technical Report MII-3210 Machine Intelligence Institute, Iona College

Publication List (3)
Iona College

Articles in Books

- Yager, R. R. and Filev, D. P., "Using Dempster-Shafer structures to provide probabilistic outputs in fuzzy systems modeling," In Combining Experimentation and Theory: A Homage to Abe Mamdani, edited by Trillas, E., Bonissone, P. P., Magdalena, L. and Kacprzyk, J. Springer, Heidelberg, 301-327, 2012
- Yanushkevich, S. N., Stoica, A., Yager, R. R., Boulanov, O. and Shmerko, V. P., "Synthetic biometrics for testing biometric systems and user training," in Industrial Electronics Handbook, edited by Wilamowski, B. M. and Irwin, J. D., CRC Press: Boca Raton, 32.1-32.12, 2011.

Edited Books

- Greco, S., Bouchon-Meunier, B., Coletti, G., Fedrizzi, M., Matarazzo, B. and Yager, R. R., Advances in Computational Intelligence- Proceedings of the 14th International Conference on Information Processing and of Uncertanity in Knowledge-Based Systems (IPMU) Parts 1-4, Springer: Berlin, 2012.

Project Statistics and Summary
Iona College

Students supported:

-# of undergraduate and graduate students 0

-# of post-doc and faculty members 1

-# of degrees awarded (MS, PhD) 0

Publications:

- Journal papers -9
- Conference papers - 2
- Manuscripts -3
- Book and book chapters - 3

Technology Transitions:

- Patents (disclosures) - none

Awards: None

-

Representing and Reasoning with Statements Involving Mixtures of Probabilistic and Soft Linguistic Information

Common Types of Information

- Its likely that Bill's salary is about 200K
- I am pretty sure the number of enemy soldiers is about 300
- Its highly probable reinforcements will arrive by the late afternoon
- That they are headed to the hills near the city is almost certain

Mixture of Probabilistic and Soft Linguistic Information

I am pretty sure the number of enemy soldiers is about 300

Provides information about the variable number of enemy soldiers

Variable: Number of enemy soldiers

Value: about 300

Probability: Pretty Sure

Representation as Z-Valuation

•V is (A, B)

• Z-valuation is indicating that V takes the value A with probability equal B

• A is fuzzy subset of domain X of the variable V

• B is a fuzzy subset of the unit interval

Information as Z- Valuations

Bill's Salary is (about 200k, likely)

Number of soldiers is (about 300, pretty sure)

Arrival of time reinforcements is (late after noon, highly probable)

Modeling Z-Valuations

- Z-valuation V is (A, B) can be viewed as a restriction on V interpreted as Prob(V is A) is B

- From this we can obtain a possibility distribution G, fuzzy subset, over the space $\mathcal{P}$ of probability densities functions on X

Focus of Research
Iona College

If p is some probability density function on X then

$$\text{Prob}_p(V \text{ is } A)) = \int_X A(x)p(x)dx$$

From this we get the possibility of p

$$G(p) = B(\text{Prob}_p(V \text{ is } A)) = B(\int_X A(x)p(x)dx)$$

The information contained in V *is* (A, B) is

a possibility distribution over the space **P**

of probability distributions on V.

Example

The waiting time for a bus is almost certainly no greater than 10 minutes

Represent as Z-valuation: V is (A, B)

Variable V is **waiting time** for bus

A = no greater than 10 minutes

B = almost certain

$A(x) = 1$ for $x \leq 10$ and $A(x) = 0$ for $x > 10$

$B(y) = 1$ if $0.9 \leq y \leq 1$ and $B(y) = 0$ if $0 \leq x < 0.$

Exponential distribution provides a useful formulation for modeling random variables corresponding to waiting times

$$f_{\lambda}(x) = \lambda e^{-\lambda x} \qquad x \geq 0 \text{ and } \lambda \geq 0$$

In this example our underlying space **P** of probability density functions is the class of all exponential distributions. Each distribution is uniquely defined by its parameter $\lambda \geq 0$.

Hence we see our space **P** can be simply represented by the space $\{\lambda \geq 0\}$ with the understanding that each λ corresponds to an exponential distribution.

In this case

$$\mathrm{Prob}_{\lambda}(V \text{ is } A) = \int_0^{\infty} A(x) f_{\lambda}(x)\,dx = 1 - e^{-10\lambda}$$

$$G(\lambda) = G(\mathrm{Prob}_{\lambda}(V \text{ is } A)) = B(1 - e^{-10\lambda})$$

Given the definition of B

$G(\lambda) = 1$ if $1 - e^{-10\lambda} \geq 0.9$ $G(\lambda) = 0$ if $1 - e^{-10\lambda} < 0.9$

Solving this we get

$G(\lambda) = 1$ if $\lambda \geq 0.23$

$G(\lambda) = 0$ if $\lambda < 0.23$

G is possibility distribution over exponential distributions with parameter λ such that

$G(\lambda) = 0$ if $\lambda < 0.23$

$G(\lambda) = 1$ if $\lambda \geq 0.23$

Using the Information to Answer Questions

What is the expected waiting time ? E

For exponential probability distributions expected time of occurrence is $1/\lambda$

Expected Waiting Time

$$E = \bigcup_{\lambda \in [0, \infty]} \left\{ \frac{G(\lambda)}{\frac{1}{\lambda}} \right\}$$

Here membership grades are E(t) = 0 if t > 4.35 and E(t) = 1 if t ≤ 4.35.

The expected waiting time is the linguistic value

less the 4.35 minutes.

What is the probability that the waiting time will be greater than fifteen minutes ?

$$\mathrm{Prob}_{\lambda}(V \geq 15) = \int_{15}^{\infty} \lambda e^{-\lambda x} dx = e^{-15\lambda}$$

$$\mathrm{Prob}_{G}(V \geq 15) = \bigcup_{\lambda \in [0,\infty]} \left\{ \frac{G(\lambda)}{\mathrm{Prob}_{G}(V \geq 15)} \right\}$$

$\mathrm{Prob}_G(V \geq 15)$ has the linguistic value of

not more then 0.03

Another question is what is the probability that the waiting will be *short*.

Represent *short* as a fuzzy set S.

$$\mathrm{Prob}_{\lambda}(\text{V is Short}) = \int_0^{\infty} S(x)\lambda e^{-\lambda x}dx$$

$$\mathrm{Prob}_{G}(\text{V is Short}) = \bigcup_{\lambda \geq 023} \left\{ \frac{G(\lambda)}{\mathrm{Prob}_{\lambda}(\text{V is short})} \right\}$$

Fusing Z-Valuations

Assume we have q Z-valuations on the variable V each of the form

$$V \textit{ is } (A_j, B_j) \text{ for } j = 1 \text{ to } q$$

Each of these induces a possibility distribution G_j over the space of all probability distributions **P**

$$G_j(p) = B\left(\int_{-\infty}^{\infty} A_j(x) \cdot p(x)dx\right)$$

One approach to fuse these is to take the conjunction of the q possibility distributions here we get

$$G(p) = Min_j [G_j(p)]$$

Here we are indicating that we must simultaneously accommodate all of the sources of information.

Implicit in this is the assumption that all Z–Valuations are drawn from the same observations

Another assumption is to assume that the Z–valuations were drawn from different observations

For example the observer's are waiting for the bus at different times of the day.

Here our aggregation of the multiple Z–valuations should be different

Assign each V *is* (A_j, B_j) a value w_i corresponding to an idea of their (experience -reliability-expertise -credibility) require that these sum to one

Using the rules of fuzzy arithmetic we then calculate G(p) such that

$$G(P) = \underset{p = w_1 p_1 \oplus w_2 p_2 \oplus \ldots \oplus w_q p_q}{\mathrm{Max}} [G_1(p_1) \wedge G_2(p_2) \wedge \ldots\ldots \wedge G_q(p_q)]$$

Measure Based Approach to the Uncertain Information:

Queries Under Uncertainty

And

Entailment

Definition of a Monotonic Set Measure

A monotonic measure on X is a mapping

$\mu: 2^X \rightarrow [0, 1]$ such that

1) $\mu(\emptyset) = 0$

2) $\mu(X) = 1$ (Normality Condition)

3) $\mu(A) \geq \mu(B)$ if $B \subseteq A$ (Monotonicity)

It associates with subsets of X a number in the unit interval

Modeling Uncertain Information Using a Measure

- Assume V is variable with domain X
- Assume A is subset of X
- μ(A) indicates the **anticipation** of finding the value of V in A

The Fuzzy Measure has the Capability of modeling in a unified framework many different types of knowledge about the value of a variable

- **Certain Knowledge** $V = x^*$

  $\mu(B) = 1$ if $x^* \in B$ $\mu(B) = 0$ if $x^* \notin B$

- **Probability Distribution**

  $\mu(\{x_j\}) = P_j$ $\Sigma P_j = 1$

  $\mu(A \cup B) = \mu(A) + \mu(B)$ if $A \cap B = \varnothing$

- **Possibility Distribution**

  $\mu(\{x_j\}) = \Pi_j$ $\mathrm{Max}[\Pi_j] = 1$

  $\mu(A \cup B) = \mathrm{Max}(\mu(A), \mu(B))$

DUAL OF MEASURE

- Can associate with any measure a dual.
- If μ is a measure we define its dual as

$$\hat{\mu}(A) = 1 - \mu(\bar{A})$$

Negation of the anticipation of not A

- If μ is a measure its dual is also measure
- The dual of the dual is the original measure

An important use of hard-soft information is answering questions based on intelligence information

Difficulties arise when the intelligence information contains **uncertainty**

- Our plan of attack will work if the enemy has less then 5000 defenders
- Intelligence tells us they have between 3000 and 6000 defenders
- Will our plan of attack work ??

Measures of Assurance and Opportunity

Motivation

- $\mu(A)$ indicates our anticipation of A occurring
- Does $\mu(A) = 1$ assure us that A will occur ??
- Consider the measure $\mu^*(A) = 1$ for all $A \neq \emptyset$
- Here $\mu^*(A) = 1$, however also have $\mu^*(\bar{A}) = 1$
- Here we have just as strong an anticipation

that A will not occur

Measure of Assurance

- *To be assured that A will occur we* have *to anticipate A will occur* **and** *also anticipate that* $\bar{A}$ *will not occur.*
- Our anticipation that $\bar{A}$ will not occur can be measured by 1 - $\mu(\bar{A})$.
- This is the dual of μ, $\hat{\mu}(A)$
- We introduce measure λ called the *assurance* of A defined as $\lambda(A) = \mu(A) \wedge \hat{\mu}(A)$

Focus of Research
Iona College

Measure of Opportunity ψ

- $\psi(A) = \mu(A) \vee \hat{\mu}(A)$
- ψ is a measure
- $\psi(A) \geq \mu(A)$
- . For measures that are duals have

$$\psi_{\mu}(A) = \psi_{\hat{\mu}}(A)$$

.
- $\psi(A)$ is opportunity that value of V lies in A

The measures of assurance and opportunity generalize some fundamental concepts used in uncertainty modeling

Assurance-Opportunity for Special Cases

- **Probability Measure:**

  $\psi(A) = \lambda(A) = \mu(A)$ **Very Special !!!**

- **Possibility Measures**

  Always have $\psi(A) = \mu(A)$ and $\lambda(A) = \hat{\mu}(A)$

ψ is possibility and λ is necessity

- **Dempster-Shafer**

ψ is plausibility and λ is belief

Entailment

- Associate with measure μ the concept of a range R Define $R(A) = [\lambda(A), \psi(A)]$
- If μ_1 and μ_2 have $R_1(A) \subseteq R_2(A)$ for all A say that μ_1 entails μ_2 and denote it as $\mu_1 \mid\!- \mu_2$.
- If $\mu_1 \mid\!- \mu_2$ knowing μ_1 allows inference of μ_2
- Enables measure transformation & coordination

Probability to Possibility Transformation

- V a variable whose domain $X = \{x_1, x_2, \ldots, x_q\}$
- Probability distribution on V such that p_j is probability of x_j
- Assume indexing such that $p_j \geq p_i$ if $j > i$
- Using entailment we can infer possibility distribution Π where

$$\Pi(x_j) = \sum_{k=1}^{j} p_k$$

2012-2013 Research Plans
Iona College

- **Capability Goal:** Advise team on appropriate algorithms for fusion and uncertainty normalization
- **Research Goals**:
  - Modeling Instructions for Fusing Information
  - Providing representation of linguistically expressed Soft Information
  - Continue working on measure based framework for fusion of Information in different uncertain modalities
  - Decisions with Hard-Soft Information
  - Temporal alignment under imprecision
  - Using copulas to join different type variables
  - Adjudicating conflicting information
  - Imprecise Matching

END !!!!!!!

Focus of Research
Iona College