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# A Semantic Information Analysis Method for Man -Machine Hybrid System Based on Possibilistic Restrictions

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***Abstract***— Data, information and meaning are three prime characteristics of any communication scenario. Information is generated by data, and the meaning is extracted from information. Search of a mathematical model to measure meaning of communication has become a discipline of study known as semantic information theory. In his recent paper Zadeh claims that information is equivalent to a restriction and it can be represented as probabilistic and possibilistic restrictions. These restrictions can be modified to represent different aspects of communication (content + meaning) in a hybrid system. In present paper we discuss some vital results from our research on possibilistic modelling of semantic information in a hybrid system. We also present a scheme for information analysis system, with various phases, and define measures of information and meaning based on mode of data set and closeness value of possibility and probability distributions. We shall show that this scheme provides a feasible method to capture both information and meaning in hybrid system.

***Keywords—*** Hybrid systems, Possibility Distribution, Restriction, Semantic Information.

## I. Introduction

Semantic Information theory is a sub-branch of Information Theory which studies the communication of meaning of the message [1]. According to technical definition, the meaning of the message does not have any effect on communication of information [2]. Shannon argues that 'meaning' of the message is entirely dependent on the receiver of the communication. (Part – I - [2]). However, the meaning part becomes essential when we consider various human - human or human - machine systems, where data (information in very basic terms) and its interpretation (semantics) both are vital (Part – II - [2]). Example of such system is economic activity, which is regulated by financial / economic data and its interpretations by economic agents. There are many theories to define and quantify semantic content of information and theoretical changes in mathematical information theory to make it more accommodating for analysis of meaning part. The search of proper theory for measuring "meaning" of communicated message was started within the decade of proposal of Mathematical theory of Communication by Claude E. Shannon. In 1948 W. Weaver (Part – II - [2]), presented the classification of problems of communication viz. technical, semantic and control. The first attempt to modify Shannon's approach was initiated by Bar-Hillel and Carnap and it uses logical probability to measure the semantic information content [3]. In subsequent years this approach was adapted, modified and used to describe how much meaning a message contains. Recent literature pertaining to information theory shows the interest in search of a theory which will enable us to understand information / message or meaning of the communication both [4], [5]. Measuring information through possibility distribution is a prominent theory for the same [6], [7] & [8].

In this paper we shall present a scheme for semantic information analysis in hybrid system based on the measures defined by authors [9], [10]. The paper is organized as follows – in section II, we shall present a brief outline and tenets of possibility theory and its fuzzy set theoretical reformulation by Zadeh. In section III we shall describe the important characteristics of hybrid systems and definition of measures of information. In section IV the phases of analysis system are discussed and lastly in section V we sum up the paper by conclusion and directions of further work.

## II. Possibility Distributions & Restrictions

### A. Possibility Distribution

The concept of Possibility was first proposed by Shackle in 1950 as degree of surprise associated with an event, and further formalized by likes of G. Shafer [11], R. R. Yager

 

[8], [12], Dubois and Prade, [13], [14] and many more. The idea of possibility distribution is closely related to that of a probability distribution; however, they differ in theoretical and conceptual levels.

The possibility distribution is a function $\pi(x)$: $P(X) \rightarrow [0,1]$, with following properties ($P(X)$ being the power set of $X$) –

(i) $\pi(\phi) = 0$, and $\pi(X) = 1$.
(ii) $A \subset B \Rightarrow \pi(A) \leq \pi(B)$.
(iii) For disjoint sets $A$ and $B$, $\pi(A \cup B) = \text{Max}\{\pi(A), \pi(B)\}$.
(iv) When $0 \leq \pi(A) \leq 1$, $A \subset X$ is said to be possibly uncertain.
(v) A possibility distribution is said to be normalized if $\pi(A) = 1$ for at least one $A \subset X$.
(vi) We say that we have complete knowledge of $X$ if $\pi(A) = 1$, and $\pi(B) = 0$, for $A, B \subset X$, $A \neq B$, and we are in complete ignorance of $X$ if for all $A \subset X \Rightarrow \pi(A) = 1$.
(vii) The dual measure of possibility is known as *Necessity* ($\upsilon$), and it is defined as the complement of possibility of complement of $A$, i.e. $\upsilon(A) = 1 - \pi(A^c)$, where $A^c$ is the complement of $A \subset X$.
(viii) For any event $A \subset X \Rightarrow P(A) \leq \pi(A)$, probability of any event is always less than the possibility of that event.

B. Fuzzy Set Interpretation of Possibility & Concept of Restriction

In 1978 L.A. Zadeh presented the fuzzy set theory treatment of possibility [15], which asserts that in absence of any other information about $X$, except a proposition of type $X$ is $F$, where $F$ is a fuzzy set, the possibility distribution of $X$ is numerically equal to the grade membership function of $X$.

$$X \text{ is } F \Rightarrow \text{Poss}(x = u) = \mu_F(x) \qquad (1)$$

The proposition $X$ is $F$ is known as a possibilistic restriction and the possibility distribution of $X$ is the collection of all possible values of $X$ [15].

A general form of restriction is *X isr R*, where '*X*' and '*R*' are variables and *r* is the restriction type. If *r* is blank (which gives *X is R*) the restriction becomes *possibilistic restriction*. Similarly, for different variations of *R* and *r* we can form various other restrictions. Following table provides an overview of various types of restrictions and examples of information conveyed by the same.

**Table – 1** – Various types of restrictions with examples of information.

| *Type of Restriction* | *Form* | *Example* | *Type of Information* | *Example* |
|---|---|---|---|---|
| *Crisp Restriction* | *X = R* | *X = 3* | *Crisp Information* | *X is an even number.* |
| *Probabilistic Restriction* | *X isp P, where "isp" = Probabilistic restriction and P is a Probability distribution* | *X is normally distributed with mean 0.5.* | *Probabilistic Information* | *Chances of coming "Head" in a toss of fair coin is 1/2* |
| *Possibilistic Restriction* | *X is A, where A is a fuzzy set.* | *X is much less than 3.* | *Possibilistic Information* | *Ram is tall.* |
| *Bi-Modal Restriction* | *(X is A) isp B, a combination of probabilistic and Possibilistic restriction. A and B can both be fuzzy set.* | *The probability of X being less than 3 is very low.* | *Bi-Modal Information* | *Chances that Ram is handsome is very high.* |

C. Information Representation Through Restrictions

The restriction provides a better way to capture information and meaning, because restrictions can be defined mathematically as well as in natural language. We can visualise a restriction as a generalized constraint on the restricted values. In his recent paper Zadeh [16] introduces the information principle which states that "Information = Restriction", i.e. information, communicated in natural language is equivalent to information.

According to Zadeh the information conveyed by restriction" X is A" is equivalent to the possibility distribution denoted by $\Pi = \mu_A$, thus a restriction can be used to denote and measure information. A more restricted restriction represents more information [17] (known as minimum specificity [18]) Human mind has a remarkable ability to convert information in possibilistic restriction and solve problems on the basis of restrictions formed. For example, consider two statements –

(i) Usually it takes half an hour to reach railway station.
(ii) At peak time it takes longer than usual in traffic.

Both these statements are example of information conveyed by possibilistic restriction. Both these restrictions are defined on the variable time with fuzzy limits (usual and longer than usual), and hence the solution will be in terms of time or an interval of time.

 

To imitate this process in machines is difficult due to following reasons -

1. The process of fitting a possibility distribution on a data set is not well formalized as that of a probability distribution [7], [19].
2. The Fitting a restriction on data set is difficult as compare to finding a restriction on data set. (precisiation of restriction) [20].
3. There are no formal methods to form a restriction on data set and precisiate it, especially when data is in continuous observation form [21].
4. Current systems of analysis of information have limited capabilities of handling data of specific types [5], [22].

In view of above problems information representation by restriction has not been used widely despite of being capable of handling vagueness and uncertainty well.

## III. Semantic Information Analysis System based on Data

A. A New Restriction Based System

As it is clear by above discussion that restriction representation of information captures the vagueness and semantic part of information communication very well. This property of restrictions makes it an appropriate tool for representing information in a hybrid system [23], [24], [25]. We first recall a hybrid system which has both human and machine sub-parts. Human part communicates in natural language (verbal) and gestures (nonverbal) and thus generate various types of data. The machine sub-part communicates in data and machine language. Both parts inter-communicate by command – response method in which human part generates data as command and machine sub-part respond with action. Thus, if we can teach machine to read data as restriction and make it enable to analyse information through possibilistic restriction, the inter-communication will be more effective and efficient.

To achieve our goal, we define new measures for a hybrid system. Suppose $X = \{x_1, x_2, \ldots x_n\}$ be the set of observations and let the set of respective frequencies is F = $\{f_1, f_2, \ldots f_n\}$. We denote the sum of frequencies by N = $\Sigma f_j$, and $(x_M, f_M)$ be the mode – model frequency duo which is unique. The ordered pair $(X, F)$ is termed as explanatory database (ED) by Zadeh, [16], [17].

We define natural probability measure $P : (X, F) \to [0, 1]$, by

$$P\left(x_j\right) = \frac{f_j}{N} \qquad (2)$$

We also define natural possibility distribution $\pi_M : (X, F) \to [0, 1]$, by –

$$\pi_M\left(x_j\right) = \frac{f_j}{f_M} \qquad (3)$$

The measure defined by equation (2) is the classical definition of probability. This measure is also used as a controller of the system. Similarly, the measure defined by equation (3) is a normalized possibility distribution under following sufficient conditions –

1) The mode of the distribution $x_m$ is unique.
2) The mode frequency $f_m$ is much higher than any other frequencies $f_j$ (i .e. $f_j << f_m$) .(For proof see [9]).

The *closeness value* is defined by –

$$\sum_{i=1}^{n} \pi_M\left(x_i\right) - \sum_{i=1}^{n} P\left(x_i\right) = \frac{\bar{N}}{f_M} \qquad (4)$$

And the *elemental closeness value* is defined by –

$$\pi_M\left(x_i\right) - P\left(x_i\right) = \left(\frac{\bar{N}}{N\, f_M}\right) f_i \qquad (5)$$

Where $\bar{N}$ is sum of frequencies excluding $f_M$.

In above equation (3) we have used mode-frequency to define possibility (for other existing methods see [24]), because it is the highest frequency in the distribution, thus the observation set is restricted by the mode. Also, mode is the most probable (highest probability) and highest possible frequency in any sample. One more important observation is that in both equations (4) and (5), the RHS is positive, hence we conclude that $P(x_j) \leq \pi_M(x_j)$, which is true according to Zadeh, termed as *'Any event which is probable, it is possible also'* (property (viii) in section II A).

## IV. Phases of Analysis System

Thus, based on above measures the information analysis system progresses through following steps or phases – We start with a hybrid system (for example automated vehicle), with basic inference rules and basic knowledge base (KB) with memory capabilities.

1) Initiation Phase - For a given problem, various decision variables are listed $\{x_1, x_2, \ldots\}$, which constitutes the observation set X. The variables can be multi-dimensional or multi-attributed. This phase is also a learning phase for system.

2) Confirmation Phase - For each decision variable the frequencies are measured. In this phase the minimum number of observations n is also confirmed, hence an explanatory database is formed (X, F). The control aspects of equation (2) is used at this stage as we take the minimum number n – observations for which $\sum_{i=1}^{n} P\left(x_i\right) = 1$.

 

3) Analysis Phase - In this phase we define and evaluate measures defined by equations (2), (3) (4) & (5) for ED. If the sufficient conditions of unique and higher mode frequency are not met, we can break (X, F) in disjoint subsets in which the conditions are satisfied, again subject to control condition. The system can progress through time and newer observations can be added and old observations can be removed.

4) Decision Phase - In this phase the closeness criteria defined by equations (4) & (5) are used to follow minimum difference condition (Precisiation of restriction). Together with minimum specificity (min. closeness value) the decisions can be made. The modal frequency dominates the course of action or decision. The steps are repeated until the desired result is obtained. If the sample has to be adjusted for newer frequencies then the Principle of minimum specificity and control condition dictate the selection of newer observations to add (see [10]).

This system mimics the human process of decision making without relying on data sufficiency and complete knowledge. Only requirement is the accuracy of observations. The above process tries to resolve the difficulty of fitting possibility distribution when data is given or data set is insufficient, since mode is most possible and probable observation, it is a natural choice to restrict the observation set. Together with probability and possibility measure based on mode can be used as a novel measure of information in a hybrid system.

## V. Conclusion and Future Scope

In above discussion it is shown that restrictions are useful tool to represent and measure information. Not only they capture meaning but also the essential fuzzy nature of natural language. In this paper we have defined measures of information on the basis of mode of a given data set. This measure follows a normalized possibility distribution [9], [26] under the conditions of unique and relatively high modal frequency. We have also defined a difference measure for possibility and probability for complete observation set and for individual elements which work as the decision criterion for the model. An overview of information processing system is also presented with different phases of the system, initiation, confirmation, analysis and decision. In further research we shall extend this approach on multi – mode frequency database. Further we will develop applications in Artificial Intelligence, Machine learning and Economics.

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