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Fuzzy Sets, the Concept of Height, and the Hedge VERY

P. J. MACVICAR-WHELAN

Abstract—**An experimental and theoretical study of the categorization of human height is reported. Subjects of both sexes whose ages ranged from 6 to 72 were asked to class the height of both men and women using the labels VERY VERY SHORT, VERY SHORT, SHORT, TALL, VERY TALL, and VERY VERY TALL. The experimental results confirm Zadeh's contention about the existence of fuzzy classification (the lack of sharp borders for the classes) but indicate that the hedge VERY causes a shift of the class frontier rather than a steepening of the membership function as proposed by Zadeh. As a result of the experimental studies, a new modeling of the classification process in terms of a family of high- and low-pass filters is proposed. This model, where the filter parameters are related to the parameters of the normal distribution of height, yields a more satisfactory interpretation of the classification then the models of Zadeh and Lakoff.**

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I. INTRODUCTION

Impreciseness and vagueness have a well-established history as concepts worthy of study among philosophers. Some topics of special interest to fuzzy set theory (FST) and its applications have been discussed at length by Goguen [5]. Difficulties resulting from impreciseness in language have been noted by computer scientists [35] as well as linguists [12]. We can quickly appreciate this type of problem by asking ourselves just what is the precise meaning of the phrase "understand English very well."

Interest in such problems among scientists was sparked by Zadeh when he proposed in 1965 the concept of a fuzzy set [37]. Given this background, it is a bit surprising that very little experimental work has been done on such problems, especially by psychophysicists, even as late as the mid-seventies. A relevant study, although not particularly directed to this end, was that of the psychologist Sheppard in 1954 [25]. Unfortunately, this work has escaped much attention. One of the earliest experimental works in the 1970's was that of Kochen and Badre [10], who studied the meaning of the terms greater than, much greater than, and very much greater than five. An active part in the development of fuzzy set theory and its applications is currently under way by psychologists [3], [7], and [23] and by computer scientists and engineers on pattern recognition [27], [8] and control systems [1], [9], and [20]. A bibliography of over 600 articles relevant to fuzzy set theory and its applications has been prepared by Gaines and Kohout [4].

The experimental results were obtained beginning during the summer of 1973 (for more details see [14], [16]). Analysis of these results has resulted in the proposal of a family of linear (limiter) filters, whose parameters are related to those of the normal distributions of the height of men and of women. This family yields a better model of the results than those of Zadeh and Lakoff. Being a one-dimensional variable, human height is a simpler example of a fuzzy set than pattern classification or control-system design.

The main object of the work reported here is to gain a better insight into the nature of a fuzzy set and a better understanding of how the concept of membership function should be applied in practical cases.

II. EXPERIMENTAL STUDIES

A. Choice of Height as the Variable for Study

This correspondence reports on an experimental study of the nature of a fuzzy set that was made in the summer of 1973. At that time the only experimental work available (through private communication) was that of Kochen and Badre [10]. This study contained the disquieting result that 10^6 was considered very much greater than 5 with a confidence level of 0.88 and much greater with a confidence level of only 0.84, so that the natural ordering that one would expect was contradicted by the results.

After consideration of a number of alternatives it was decided that the classification of human height would be a good first choice for the experimental study of a one-dimensional fuzzy variable. Unlike numbers, it is better understood by all segments of the population, it is less of an emotionally charged term than age, it is a one-dimensional variable with known standard distribution parameters $\bar{x}$ and σ, and, finally, it has been discussed at length in the literature of fuzzy sets and of vagueness (see [14]–[16] for more details).

B. Aspects Common to all Three Experimental Methods

The subjects that classified the variable height using one or more of the three methods were all unpaid and of above-average

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intelligence. Since this study was meant to be an initial study of the nature of a fuzzy set, no attempt was made to ensure a representative sample of the population.

All subjects were Americans, so the feet–inches system of measurement was used. An informal atmosphere was maintained to ensure that the subjects understood the task and to elicit clues about how to improve the experimental technique. It was concluded that the subjects were classifying the heights of normal adults and that variations in responses were not due to any special contextual effects. The informal setting of the experiments provided the mechanism to easily correct for possible roles of such factors. This, of course, meant that the amount of dialogue varied from subject to subject. Other aspects of this informality are the fact that the amount of data gathered from each subject varied and the fact that the actual duration of any experimental session was not permitted to exceed the period where the subject was obviously interested in proceeding with the task of data taking. A conscious effort, however, was made to have subjects of both sexes over as large a spread of age and physical height as possible, so that correlation with age, sex, and height might be investigated.

C. Details of the Three Methods

1) Monotonically Increasing Height: The first experiment on the concept of human height consisted of asking a series of questions of the type: "What percentage confidence do you have that a man x ft y in is tall?"

The response was recorded, the height increased by an inch or so, and the question repeated. This process was continued until values were obtained that ranged from 0 to 100 percent confidence. The experiment was repeated using VERY TALL and VERY VERY TALL in place of TALL and women in place of men.

As is to be expected, the level of confidence rose monotonically as the height increased. To verify whether or not this was due to the manner of questioning, a second experiment was performed similar to the first but with heights chosen more at random.

2) Height Values Chosen at Random: In this experiment the terms MAN or WOMAN as well as the terms TALL or SHORT were chosen more or less at random and combined with a height to yield a question of the same type as in the first experiment.

The data of this experiment were recorded in the form of ordered pairs, the first element being the height and the second member the percentage confidence that the label was applicable to a person of this height.

During the course of the experiment it became obvious that an experimental time of 5–10 min would be best. Care was taken to avoid tiring the subject (who was, after all, unpaid) beyond the point where he was obviously actively interested in the experiment. This accounts for the fact that equal amounts of data were not obtained at all sessions. Method 3) was devised to obtain more data in a shorter period of time without risking boring the subject.

3) Linear Categorization: The experiment consisted of presenting the subject with a strip of paper containing three straight lines along which was a scale of heights in feet and inches, Fig. 1.

It was then explained to the subject that the axis perpendicular to the height axis represented confidence that a person (MAN or WOMAN) of the indicated height and the given property was TALL, VERY TALL, VERY VERY SHORT, etc. The subject was then asked to indicate where on the height axis he/she felt full confidence that one of the labels (VERY VERY SHORT, VERY SHORT, SHORT, TALL, VERY TALL, VERY VERY TALL) occurred, where full confidence that the label did not occur, and how to connect the full confidence of truth to the full confidence of falsity points.

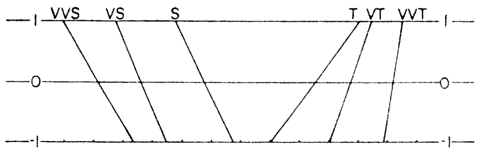

Fig. 1. Example of linear truth function: 1 represents 100 percent confidence that the label is true; 0 represents the neutral point or the 50/50 point; −1 represents 100 percent confidence that the label is false or does not apply; VVS = VERY VERY SHORT; VS = VERY SHORT; S = SHORT; T = TALL; VT = VERY TALL; VVT = VERY VERY TALL; horizontal axis = height given in feet and inches.

While most subjects were satisfied with drawing a straight line between the full confidence points of truth and falsity, some insisted upon a lack of symmetry about the neutral point. No better reason than "It's just the way I feel about it," resulted from questioning about this point. Therefore, the best straight line through the full confidence points and the neutral point was used for data analysis. This lack of symmetry was much smaller than the normal variation in the responses of a subject between one session and another.

D. Experimental Results and Analysis

All the data from the three experiments were reduced to a common denominator by finding the best straight-line fit for the results of the first two experiments. We denote the midpoint of this line between certainty of falsity and certainty of truth by N, the neutral point. The magnitude of the uncertainty about N is characterized by W, the distance from N to a point of certainty. Thus the classification can be characterized by the ordered pair (N, W). The data from all methods is presented in Table I for men and Table II for women. We note that each subject is identified as well as the method used to obtain the given data set.

While one might expect the individual-membership curve to be more likely an S-curve, it should be kept in mind that no subject in the third experiment desired to connect certainty of truth with certainty of falsity by this type of curve. Furthermore, the scatter for the data of any particular curve was greater than any slight S-curve structure that might have occurred at the ends of the curve. Therefore, the simpler straight-line approximation was used rather than trying to fit an S-curve to the data points of the results obtained using Methods 1) and 2). Further details on the responses of a single subject have appeared elsewhere [18].

III. THEORETICAL STUDIES

A. A Partitioning Model: Linear Limiter Filter Family (LLFF)

The classification of human height into the classes VERY VERY SHORT, VERY SHORT, etc., is a special case of the categorization of a one-dimensional variable. If Miller's maximum on the categorization of a perceived variable holds [22], then the partitioning should be into 7 ± 3 groups. While this criterion holds, we must also keep in mind that statements such as "He is roughly 182 or 183 cm tall," are also commonly used. We shall see that classification of human height can be understood in terms of a family of high and low "height pass" filters. As a first step in the development of such a model, we propose the use of the characteristic curves of Method 3). This type of curve is already in widespread use: in communication theory, under the name of ideal limiter with bias [21], for quite some time in psychological modeling [28], and, currently, by the Xerox Company [36], as a simulation operator.

TABLE I
DATA FOR MEN'S HEIGHT

Subject	Method	Very Very Short N	Very Very Short W	Very Short N	Very Short W	Short N	Short W	Tall N	Tall W	Very Tall N	Very Tall W	Very Very Tall N	Very Very Tall W
F1	I							71.4	2.8	76.0	4.1		
	II							70.6	2.8	71.3	2.0	75.3	5.5
	III	60.5	1.0	64.4	1.0	67.5	1.0	71.5	1.0	74.5	1.0	77.5	1.0
	III	59.2	1.0	61.8	1.2	67.0	2.0	71.5	1.0	77.0	2.0	80.5	2.5
F2	III							71.6	1.0	76.6	1.0		
M3	II							70.6	3.0	73.7	9.3	78.0	12.0
M5	II							71.7	12.2	76.2	7.7	79.2	7.4
F6	II							72.0	12.0	76.2	4.3	78.3	3.0
F8	II							62.6	2.2	66.3	5.2	69.3	3.1
	III	44.4	1.0	46.5	3.0	57.2	4.2	66.3	12.0	68.2	10.6	75.2	6.0
M9	II					64.4	8.0	69.3	2.5	77.1	7.0	80.7	13.0
M11	III	53.2	9.5	55.0	11.0	59.3	7.8	74.0	6.0	78.7	11.0	82.0	8.0
	III	53.0	10.0	54.0	11.7	55.0	11.5	75.2	6.5	78.0	4.0	80.4	7.5
Ave.		54.06	4.50	56.34	5.58	61.73	5.75	70.64	5.00	74.60	5.32	77.85	6.27
σ		6.38	4.80	7.05	5.33	5.29	4.03	3.21	4.37	3.80	3.51	3.57	5.40

Neutral point (N) and width of fuzziness (W). All numbers refer to height in inches.

TABLE II
DATA FOR WOMEN'S HEIGHT

Subject	Method	Very Very Short N	Very Very Short W	Very Short N	Very Short W	Short N	Short W	Tall N	Tall W	Very Tall N	Very Tall W	Very Very Tall N	Very Very Tall W
F1	II							67.0	2.0	72.7	1.7	75.0	6.1
	III	59.5	1.0	60.5	1.0	63.6	1.0	69.4	1.0	71.5	1.0	73.5	1.0
	III	55.0	2.0	57.5	1.0	60.0	2.0	70.4	1.0	74.5	1.0	78.0	2.0
F2	II							66.0	1.0	66.5	1.0		
F6	II							65.8	11.3	63.7	6.8	70.4	• 5.7
F8	II							59.3	3.6	66.2	1.8	69.9	4.1
	III	52.4	5.0	57.2	4.0	52.4	9.0	69.0	6.0	73.2	10.0	76.5	14.5
M11	III	49.0	12.2	54.7	10.1	57.4	5.3	70.6	11.0	73.0	7.1	79.0	11.2
	III	49.5	11.0	51.5	7.0	54.8	11.5	75.0	6.3	76.4	8.8	79.0	9.5
Ave.		53.08	7.04	56.28	4.62	58.74	4.95	68.06	4.90	71.41	4.36	75.16	6.76
σ		4.33	5.20	3.37	3.95	3.29	4.10	4.33	4.04	3.54	3.75	3.63	4.65

Neutral point (N) and width of fuzziness (W). All numbers refer to height in inches.

B. The Filter Function

The filter function, depicted in Fig. 2, can be defined algebraically by

$$F(x, N, W) = \begin{cases} -1, & x \in (-\infty, N-W) \\ -1+(x-N+W)/W, & x \in [N-W, N+W] \\ 1, & x \in (N+W, \infty). \end{cases} \quad (1)$$

We call the function F a high-pass function because all x greater than N (roughly speaking) are passed (have value 1). The negative of this function $-F$ is known as a low-pass function (broken line in Fig. 2). Thus we have a convenient means to naturally incorporate linguistic negation NOT.

C. A Filter Family for a Normal Distribution

The obvious first choice for the partitioning of a normal variable by a family of filters is to attempt to find a relation between the filter parameters and the parameters of the distribution $\bar{x}$ and σ. We can expect to find the neutral points of the filters to be a function of both $\bar{x}$ and σ and the spread of uncertainty in classification to be related to σ, since σ plays the role of a scaling factor for values of the variable about $\bar{x}$. We therefore propose a simple relation of the form

$$T\,(\text{LABEL}\,(x)) = \operatorname{sgn} F(x, \bar{x} + n\alpha\sigma, \beta\sigma) \quad (2)$$

where the term LABEL refers to the class name (SMALL, VERY LARGE,

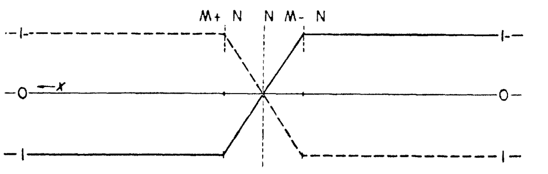

Fig. 2. Graph of function $F(x, N, W)$ (solid line) and function $-F(x, N, W)$ (dashed line): x = independent variable; N = neutral point x; X = range of x (width) between $F = 0$ and $F = 1$ or $F = -1$.

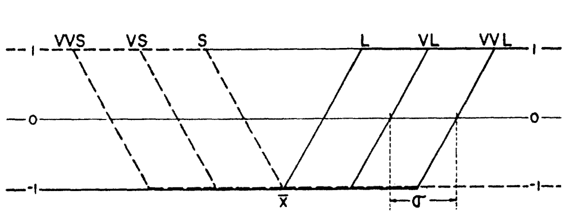

Fig. 3. Filter family using labels LARGE and SMALL: $\bar{x}$ = neutral point of F; σ = shift in neutral point associated with V; 1 = full confidence in truth; 0 = neutral truth value; -1 = full confidence for falsity; VVS = VERY VERY SMALL; VS = VERY SMALL; S = SMALL; L = LARGE; VL = VERY LARGE; VVL = VERY VERY LARGE.

etc.), sgn is + for large (high-pass) and − for small (low-pass), n denotes an integer appropriate to the label (see Fig. 3), and the constants α and β scale the effect of σ. An example of such a family of filters is presented in Fig. 3 for the label set {VERY VERY SMALL, $\cdots$, VERY VERY LARGE} when $\alpha = \beta = 1$.

In terms of this model we hypothesize meanings for the adjectives SMALL and LARGE used with the hedge VERY for a normally distributed variable in the form of (2). Some examples of this are

$$T\,(\text{VERY VERY SMALL }(x)) = -F(x, \bar{x} - 3\alpha\sigma, \beta\sigma)$$

$$T\,(\text{SMALL }(x)) = -F(x, \bar{x} - \alpha\sigma, \beta\sigma)$$

$$T\,(\text{VERY LARGE }(x)) = F(x, \bar{x} + 2\alpha\sigma, \beta\sigma). \quad (3)$$

The term AVERAGE can be modeled by combining a low-pass filter with a high-pass filter to yield a band-pass filter such as

$$T\,(\text{AVERAGE }(x)) = T\,(\text{NOT-SMALL and NOT-LARGE})$$

$$= \min\{F(x, \bar{x} - \alpha\sigma, \beta\sigma), -F(x, \bar{x} + \alpha\sigma, \beta\sigma)\} \quad (4)$$

where we take the operator NOT to have the effect of changing the sign of the filter function and have used Zadeh's proposal for the meaning of intersection of two fuzzy sets.

D. A LLFF for the Partitioning of Human Height

Since human height is known to be a normal distribution, the classification of height is a good application for such a model. Although there is no dearth of data [6], [11], [13], [19], [29], [26], [30], [31], [32], there is no general agreement on the values of $\bar{x}$ and σ for men and women. Average heights quoted vary by up to 10 cm (2 in), and it has been recently determined that a person's height may be 1 cm larger upon arising than upon retiring at night. As working values for $(\bar{h}, \sigma)$ in centimeters we have taken (180.3, 6.4) for men and (165.1, 5.8) for women. We note that $h = 28.4\sigma$ for both ordered pairs.

In Fig. 4 is presented a plot of the average values of the heights corresponding to each of the various labels (data of Tables I and II). The lines correspond to a change in neutral point for each label of 10.9 cm (4.3 in) for men and 9.6 cm (3.8 in) for women. Using these values and the working values for $(\bar{h}, \sigma)$, we obtain the result that $\alpha = 1.7$ is a good value for the normal distribution of both men and women.

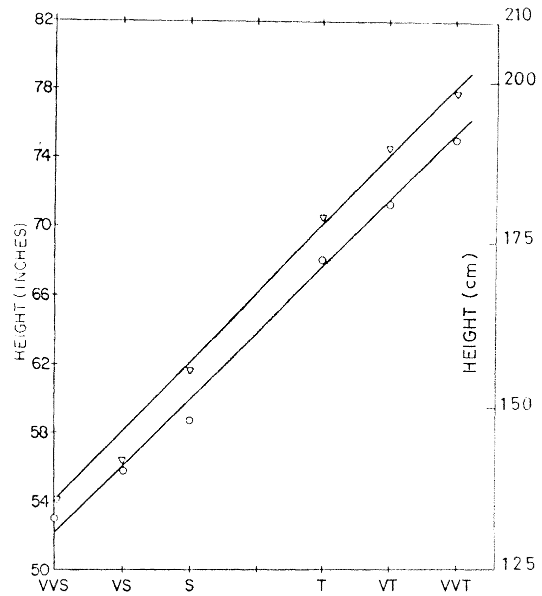

Fig. 4. Average values for neutral points of terms descriptive of height of men and women: VVS = VERY VERY SHORT; VS = VERY SHORT; S = SHORT; T = TALL; VT = VERY TALL; VVT = VERY VERY TALL; ○ = women; △ = men.

IV. Discussion of Results and Model

Although the number of subjects and the amount of data are small, one can still draw useful conclusions about the nature of the partition of a one-dimensional variable into fuzzy classes. Zadeh's major contention that the frontier between classes is not sharp but fuzzy is corroborated, but the nature of the frontier is more complicated than is suggested by the membership functions proposed by Zadeh. While confidence about belonging or not belonging to a class does not change abruptly, the confidence curve (membership curve) is not fixed (with respect to both location and range of values over which membership is uncertain) for the data of a single subject as well as for the data of a group of subjects. The nature of this variation did not seem too dependent upon the experimental method. More detailed discussion of the experimental results for a single subject can be found in [18].

The role of the hedge VERY is that of a shifting operation, as suggested by Lakoff [12], and not a steepening of the membership function, as suggested by Zadeh [38]. A shift is consistent with other usage: classification of the electromagnetic spectrum [33], [2], [34], classification of numbers [10], and classification of time, walking distance, and weekly income [25]. Whether the shift is by an additive constant or a multiplication factor depends upon the range of values of the variable. A shift by a factor of two seems more appropriate for psychological variables such as the musical scale, and a shift by a factor of ten seems more appropriate for numbers compared to a given number[1] and for physical variables such as the electromagnetic frequency spectrum. Further work in this area should help establish the validity of writing semantic equations such as

FAR = LARGE DISTANCE

VERY VERY YOUNG WOMAN = WOMAN OF VERY VERY SMALL AGE (5)

Sheppard's work indicates that RATHER is combined with VERY

[1] As a result of this conjecture the author and Carl Bennink (a psychology senior experienced in testing) asked a class of about 60 astronomy students to indicate the categorization labels (VERY MUCH SMALLER, MUCH SMALLER, SMALLER, LARGER, MUCH LARGER, VERY MUCH LARGER) than (1, 10, 100). The results were not conclusive, and this is attributed to some pitfalls of psychological testing. It is hoped to repeat the experiment under better controlled conditions.

in British usage in a way that is not common in American usage (see [16] for more details). He, consequently, provides an example of differences between countries that are commonly considered to use the same language—a result that is of interest to those working on machine translation of languages.

A discussion of how the results of this experiment relate to published work on the applications of fuzzy set theory, especially to control theory, has appeared in [17]. The main points of the results reported above are to stress that further experimental work is necessary to clarify the nature of fuzzy classification and that the nature of FST is not as simple as was first believed. Thus applications based upon the tentative proposals of Zadeh about set membership and morphisms of fuzzy sets should be viewed with caution.

V. Summary and Conclusions

Both experimental results on the classification of human height and a theoretical modeling of this classification process have been presented. Zadeh's contention about the fuzziness of the boundaries of linguistic sets has been corroborated. No evidence was found to support the usage of an S-curve to represent the confidence level of heights belonging to a given class, so that the degree of confidence for any height belonging to a given class could be adequately approximated by a linear limiter function. Variations in the position of the confidence curve as well as its width for any class indicate that even for a single individual the confidence curve cannot be simply equated to Zadeh's fuzzy set membership function. Variations for the data of a single subject and among the different subjects are as great as any differences that can be attributed to the different methods of obtaining experimental data. Furthermore, any differences due to age, height, or sex of the subjects were small compared to the data variations.

The hedge VERY should be assigned the role of a shifting operator, as was proposed by Lakoff, rather than that of steepening the slope of the membership function, as was proposed by Zadeh. More experimental work is needed to enable one to speak with confidence about the nature of fuzzy sets and operations on these sets (such as union and intersection) and to establish a firm foundation for a practical fuzzy logic. The linear limiter function family provides a simple modeling of the classification of a one-dimensional variable. The family's parameters can be related (at least in the case of human height) to the mean and standard deviation of a normal distribution in a simple direct way.

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