Associative Memory System Using Fuzzy Sets

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Abstract

An associative memory (AM) system using fuzzy sets is presented in this paper. Vectors to be stored in the AM are transformed into fuzzy sets. Fuzzy rules are constructed from the fuzzified vectors to associate vector when a stimulus vector is input to the AM system. Computational experiments are carried out to evaluate performance of the AM system. The experiments show that the AM system is responsive to feature of the stimulus vectors. In addition, the AM system performs more than 95% correct association rate until 20% of the binary valued elements of the stored vectors are flipped randomly from either zero or one.

1. Introduction

An associative memory (AM) stores information in a whole area of a memory system, unlike a standard computer memory system where information corresponds to a specific address (Kohonen, 1972 and 1987). This distributive memory system makes AM tolerant to noisy and/or partial input, and it is most attractive features for applying the AM to real-world problems.

As we intend to apply the AM systems to real-world problems such as pattern recognition, data mining, image processing, and so on, relevant available information involves imprecision, uncertainty, and partial truth. We are looking for a design method of the AM system which is tolerant to the problems related to the real-world. Zadeh introduced soft computing (SC) to exploit the tolerance for imprecision, uncertainty, and partial truth, and approximation to achieve tractability, robustness, low solution cost and better rapport of reality (Zadeh, 1997).

In this paper, we will present a design method of an AM system using fuzzy sets. In the AM systems, the imprecision, the uncertainty, and the partial truth of the given information are included into membership functions of fuzzy sets, and fuzzified information is stored in the AM system. The paper is organized as follows. Procedures to form fuzzy stimulus and response vectors are described in section 2. In section 3, association rules to associate a stimulus vector with response vector is introduced. In section 4, the performance of the AM system is evaluated by computational experiments.

2. Transforming stimulus and response vectors into fuzzy sets

We assume that elements of vectors are binary values as either zero or one. We transform stimulus vectors to be stored in the AM system into fuzzy set based on the following idea: when we observe an element of the binary valued as zero, we cannot negate the possibility that the observed value is one by an uncertainty and/or imprecision related to the real-world problems. The converse is also true. This transformation enables us information processing while maintaining the possibility of the binary value which is not observed.

A binary value of an element of stimulus vector is transformed into the fuzzy set as

$$\tilde{A}_i^j = \sum_{l=0}^{L-1} \mu_{\tilde{A}_i^j}(x_l)/x_l \quad (j = 0,1,2,...,p)$$

where $\mu_{\tilde{A}_i^j}(x_l)$ is the membership function and $x_l(l = 0,1,2,..., L-1)$ is a discrete value between 0.0 and 1.0 (Mizumoto, 1989).

$\mu_{\tilde{A}_i^j}(x_l)$ is determined as follows: if the value of the A_i^j is zero, a grade of membership function is 1.0 at $x_l = 0.0$ and decreases linearly along the hypotenuse of the right-angled triangle until the grade becomes zero at $x_l = x_\alpha$. On the other hand, if the A_i^j is one, the grade of the membership function is 1.0 at $x_l = 1.0$ and decreases linearly along the hypotenuse of the right-angled triangle until the grade becomes zero at $x_l = x_\beta$.

The elements of the response vector to be stored in the AM system are transformed into fuzzy sets according to the following idea. We assume that if an element at a location occurs as either zero or one at a low rate of frequency for all stimulus vectors stored in the AM system, the value of the element at that location is essential. Conversely, if an element at a location occurs as either zero or one at a high rate of frequency, the value of the element at that location is not essential. The fewer the occurring frequency of the value of the element, the more essential. A right-angled triangle is used to form the membership function which is right-angle triangle formed. We determined shape of the triangle as follows. If the element of the response vector is essential, uncertainty of the membership function is small. On the other hand, the element is not essential, uncertainty of the membership function is large. The more essential the element of the response vector, the larger the membership function. Therefore, the length of the base of the triangle is given as

$$length = \frac{n'}{n}$$

where n' is the occurring frequency of the element at a location as either zero or one. n is the number of stimulus vectors stored in the AM system. The height of the triangle is also given as $1/n'$.

3. Association Rules

Association rules consists of an exciting rule and inhibiting rule. The association rule generates fuzzy output vector when a stimulus input vector is given to the AM system. The exciting rule gives a large grade of membership function in the area around 1.0 of the element of the fuzzy output vector, when an element of an incoming vector is almost the same as the element of the stored vector in the AM system. On the other hand, the inhibiting rule gives a large grade of membership function in the area around 0.0 of the element of the fuzzy output vector, when an element of input vector is different from element of the stored vectors.

We made the exciting AM rule using Cartesian product between each element of stimulus and response vectors to be stored in the AM. To make an inhibiting rule, element of each stimulus and response vectors stored in the AM system is flipped either zero or one or vice versa. The inhibiting AM rule is made from these flipped stimulus and response vectors by the same procedures to make exciting AM rules.

When a stimulus vector is input to the AM system, the AM rules generate n fuzzy vectors, respectively. The membership function of each element of the output vector is composed by max-min operation. If the present vector is close to one of the stored vector, the grade of membership function of the elements of the output vector will be larger in the area around 1.0 than the area around 0.0. Converse is also true.

The membership functions of all elements of the output vectors are summed and normalized to produce averaged output vector. Then, we compute a centroid of averaged membership function which gives the similarity between the presented vector and vectors stored in the AM system. The AM system chooses the largest centroid out of n centroids each of which gives the similarity between the presented vector and n stored vectors. The vector showing the largest centriod is associated with the input vector.

4. Performance of the AM system

Performance of the AM system was evaluated by computational experiments. Alphabetical characters consists of 64 elements are prepared for the experiments. These characters are stored in the AM system as stimulus vectors.

Since C, O, and G are very similar patterns when they are represented in 64 size, it is difficult to distiguish pattern C from O and it is also difficult to distiguish pattern C from G. We flipped one elemet of C which is part of elements composing the pattern O. Since the rate of ocurring frequency of the element is low, the element is an essential element of the pattern O. The AM system associates vector pattern O, however the AM with correlation matrix method (CMM) associates pattern C. We also flipped two elements of patern C which are essential elements to represent pattern G. The AM system associates pattern G, but the AM with CMM associates pattern C. The same experiment is carried out using similar pattern O, G, and Q. The AM system associated correct pattern when a part of essential elements are flipped. In the similar pattern such as P and R, the AM system associated correct pattern. These experiments show that the AM system is robust when the essential elements are flipped. We speculate that this robustness is advantage to use the AM system for real-world problems.

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