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Received on: 31/01/2017
Accepted on: 20/07/2017

New Strategies for Associative Memories

Abstract- *Associative memory is a neural network used to save collection of input and output data at its layers. Each output data is produced coincide with a given input. It can be useful as an artificial memory in many applications like (military, medical, data security systems, error detection and correction systems …etc.). There are two matters which limit the uses of associative memory; the limited storage capacity, and the error occurred in the reading of output data. A modified strategy is suggested to overcome these limitations by introducing a new algorithm to the design of the associative memory. This method provides a software solution to the problems. The obtained results from the test examples proved that the proposed associative memory net could train and recall unlimited patterns in different sizes efficiently and without any errors.*

Keywords- *Associative memory, intelligent memories, artificial neural network.*

How to cite this article: A.R. Kareem and S.A. Talib, "New Strategies for Associative Memories," *Engineering and Technology Journal*, Vol. 36, Part A, No. 2, pp. ٢٠٧-٢١٢, 2018.

1. Introduction

The information is stored in the human memory as a combination of interconnections among multi neurons [1]. In artificial memory networks such associative memories, all the information are stored as a weight matrix [M] connects the nodes of the input and output layers by which produce an output that coincides to a given input [2]. A general block diagram of the memory is shown in Figure 1. The performing associative mapping between input vector [X] and output vector [Y] is performed based on a weight matrix [M]. Where the design of the network means determining the connection weight matrix [M], or known as encoding [3], it is given by:

$$M = \sum_{i=1} X_i^T \; Y_i \qquad (1)$$

While recall Y_i is achieved by decoding process depending on:

$$Y_i = X_i \, M \qquad (2)$$

Associative memory can be utilizes either in auto-association or in hetero-association applications [4]. The input/output vectors of auto associative memory are similar, as show in Figure 2. While in hetero-associative the information of the input data is different from the information of output, as show in Figure 3.

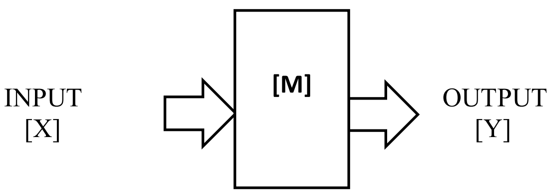

Figure 1: An associative memory

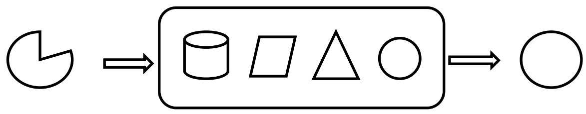

Figure 2: The response of Auto-association

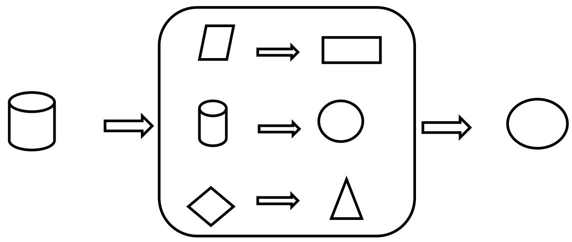

Figure 3: The response of Hetero-association

Bidirectional associative memory (BAM) was introduced in (1988) by Kosko [5]. It is a type of hetero-associative, and it can return another pattern which is potentially of a different size at both of the input and output sides. If these networks well done operated, they will be useful in many applications; such as in data memorization, error detection and correction, and data security. Nevertheless, there are two limitations that are influenced the associative memory's performance, which are: **firstly** the number of patterns that can be saved and exactly recalled is very limited. The weight matrix has (t×r) independent degrees of freedom, where t is the dimension of the input vector (8 for example) and r is the dimension of the output vector (6). This allows the network to be able to store and recall a total of up to min (t, r) independent vector

https://doi.org/10.30684/etj.36.2A.13
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pairs, or min (8,6)=6 in this example. The more conservative heuristic capacity measure is used in a formula [6]:

$$p = \sqrt{\min(t,r)} \quad (3)$$

Secondly the correlation problem occur when an input pattern share several bits with another pattern, so it is impossible to restore the accurate pattern [7]. This error is due to the mathematical correlation of the two operations (1×1=1 &-1×-1 =1), and multiplication any number by zero equal to zero.

There are several attempts improved the performance of the associative memory and overcome some of its problems, one of these strategies is Modify Bidirectional Associative Memory (MBAM) network [8]. It was suggested to avoid most of the BAM limitation. The patterns are partitioned into a number of vectors with length two, this denotes that the size of this network is constant (i.e., two). Therefore, the network deals with parts of the pattern instead of the whole pattern as one vector. In the bipolar representation, the elements in the vector of each pattern will be either 1 or -1. Because the shortest even length of any vector is two, so the length of vectors was chosen to be two elements. This leads to working with smallest network size regardless of the pattern length, as well as several connections between the two neurons, this architecture permit the ability of avoiding the errors that may be occurred at the output. New restrictions appear with MBAM; the bit number must be even and the input/output patterns have to be the same length. Figure 4 illustrate the structure of MBAM. While kosko expanded the unidirectional auto-associative to bidirectional associative processes [9], by utilizing the correlation matrix given in equation (1), the system able to retrieve the nearest pair given any pair (X,Y), where (X) is the input pattern and (Y) is the output pattern with the help of multidirectional coding and encoding process. However, sometimes the encoding could not ensure that the saved pairs are at local minimum and for this reason results in incorrect recall. Wangs and other's introduced another strategy known as Multiple Training Encoding Strategy (MTES), which achieves the right recall of pattern pairs. This strategy is an enhancement/generalization for Kosko's encoding strategy. Wang's generalized correlation matrix is [9]:

$$M = \sum qi \times xi^t \times yi \quad (4)$$

Where (qi) is showed as the weight of($xi^t \times yi$) and it is a positive real number. It indicates the minimum number of times for utilizing a pattern pair (xi , yi) for training to ensure correct recall of that pair , but it also had a problem , it guarantee to recall only one training pair.

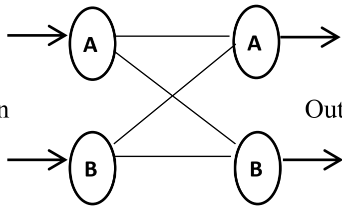

Figure 4: The Modified Bidirectional Associative Memory (MBAM)

2. The Proposed Strategy for AMs

Improving the performance of the AM and overcoming the two main drawbacks of the reading error data and low storage capacity is the goal of the new strategy. All the previous methods which are based on equation 1 or 3 in the encoding process faces some mathematical problems; (1×1) and (-1×-1) have the same result equal to (1), so in the decoding process, this (1) has two probabilities and the obtained result may be goes to the wrong probability. Same thing with respect to (0), it may be obtained with multiplication (0) by any number, so the right number is not always achieved in the decoding side. These problems may be occurred when two input patterns share several bits and the capacity of storage may also be affected, and the mathematical operations in the decoding process are replaced by a software program, which is optimized to solve these problems.

Figure 5 illustrates the encoding process in which the input pattern (X) and the output pattern (Y) are read in binary form (or 0 and 1 form) as a pairs, with t is the number of (X) bits and r is the number of (Y) bits , r is not necessary equal to t. After that (X) and (Y) values must be converted into bipolar form (1=1, 0 = -1), and calculate Sm (summation of Ym bits), and M (connection matrix of equation 1). Then find the power function (Km) which is given by:

$$Km = Xn \times M \quad (5)$$

While the energy function value (Em) is given by:

$$Em = Xn \ M \ Y^t m \quad (6)$$

Km and Em have not to be zero and if zero case is appeared, Y can be regenerated until disappear all the zeros. In the decoding process, the software program can recall all patterns using the procedure illustrated in Figure 6. To recall (Y) patterns, initially can suppose default value for Y vector with all elements equal to positive or negative ones (the two cases are possible) in bit length equal to (r), and calculate (Emd) which is the calculated energy function value (Emd = Km

$Y^t m$) and compare it with Em, if Emd ≠ Em then change the first bit of defaulted Ym and compute the Emd again, now if Emd approach from Em that means the change is true, leave it and go to the next bit. Nevertheless, if Emd is go away from Em that means the change is error, return it to the former value and go to the next bit. This procedure is done until the last bit. It can be considered that the pattern is recalled correctly when the two conditions are satisfied (Emd=Em and The bit summation value for default Y equal to Sm). Some optimization steps are added to deal with some cases, if Emd be equal to Em of the previous Y, this is an error case and must be resolved by return the changed bit to the former value, also sometimes Emd is smaller than Em in one step and become larger than it in the next step, this state means that there are an error in the previous bits and the change operation on the previous bits must be repeated, such cases are occurred when the energy function be around the global minimum value or the energy function settling down at a local minimum as shown in Figure 7. The proposed AM find very immune solutions for such problems.

Test Example

This example is solved in three manners, kosko encoding method, multiple training strategy method, and the proposed method.

Consider the three pattern pairs (X1,Y1) , (X2,Y2) , (X3,Y3) given by:

X1= [0 0 0 0 1] **y1=** [0 1 0 1]
X2= [1 0 1 0 1] **y2=** [1 1 0 1]
X3= [0 1 0 1 0] **y3=** [1 1 1 0]

Convert these three binary pattern to bipolar form replacing 0s by -1s:

X1= [-1 -1 -1 -1 1] **y1**= [-1 1 -1 1]
X2= [1 -1 1 -1 1] **y2**= [1 1 -1 1]
X3= [-1 1 -1 1 -1] **y3**= [1 1 1 -1]

I. In Kosko Encoding Eethod

Compute M from equation (1).

$$M = \begin{pmatrix} 1 & -1 & -1 & 1 \\ 1 & -1 & 3 & -3 \\ 1 & -1 & -1 & 1 \\ 1 & -1 & 3 & -3 \\ -1 & 1 & -3 & 3 \end{pmatrix}$$

To recall (Y) patterns:

Y1= x1 × M = [-1 1 -1 1]

Y2= x2 × M = [-1 1 -1 1] ≠ Y2

Y3= x3 × M = [1 -1 1 -1] ≠ Y3

It is clear that Y2 and Y3 patterns not recalled correctly, there is error occurred in the reading of output data.

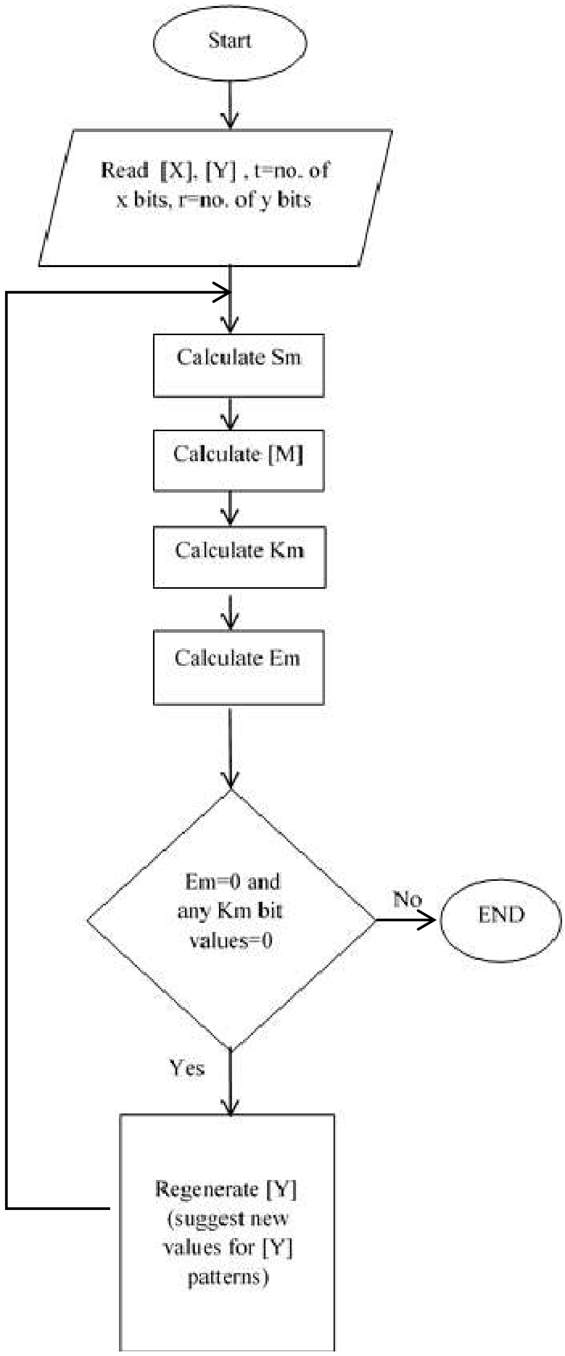

Figure 5: Encoding Process Flowchart

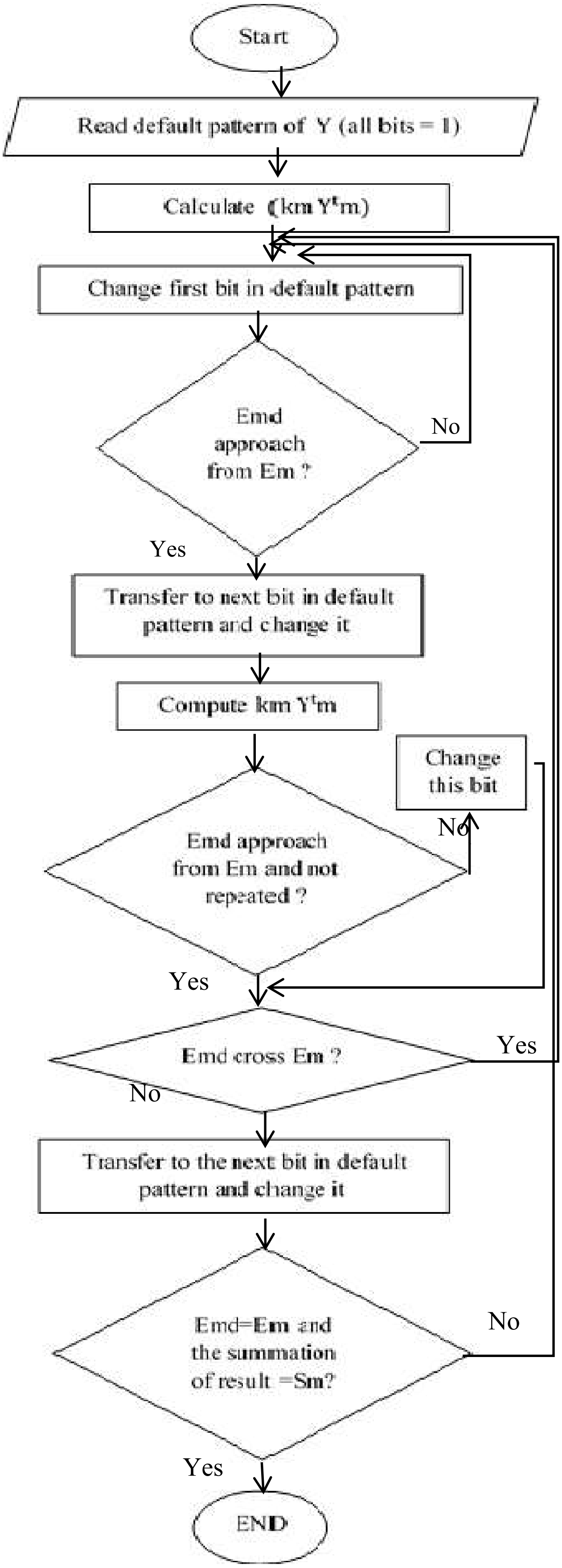

Figure 6: Decoding Process Flowchart

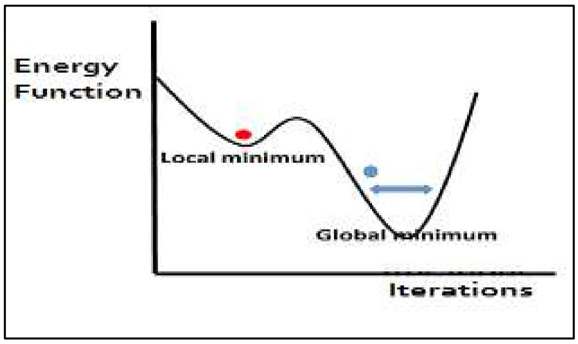

Figure 7: Energy function missing the global minimum

II. In Multiple Training Strategy Method

Compute [M] from equation (3), in which adding (q-1) into the situation that occur error in it. Choose q=2 and the augmented correlation matrix M becomes:

$$M = (X1^t \times Y1) + 2\,(X2^t \times Y2) + (X3^t \times Y3) \quad (7)$$

$$M = \begin{pmatrix} 2 & 0 & -2 & 2 \\ 0 & -2 & 4 & -4 \\ 2 & 0 & -2 & 2 \\ 0 & -2 & 4 & -4 \\ 0 & 2 & -4 & 4 \end{pmatrix}$$

Y1= [-1 1 -1 1]
Y2= [1 1 -1 1]
Y3= [-1 -1 1 -1] $\neq$ Y3

In the above method Y3 pattern not recalled correctly, there is error occurred in the reading of output data, the correlation matrix M needs to be further augmented by multiple training of (X3 , Y3) , and the augmented correlation matrix M becomes:

$$M = X1^t \times Y1) + 2(X2^t \times Y2) + 2(X3^t \times Y3) \quad (8)$$

$$M = \begin{pmatrix} 1 & -1 & -3 & 3 \\ 1 & -1 & 5 & -5 \\ 1 & -1 & -3 & 3 \\ 1 & -1 & 5 & -5 \\ -1 & 1 & -5 & 5 \end{pmatrix}$$

Y1= [-1 1 -1 1]
Y2= [-1 1 -1 1] $\neq$ Y2
Y3= [1 -1 1 -1] $\neq$ Y3

Multiple training strategy method guarantee to recall only one training pair, and after applying its algorithm on the situation that has error in reading the output data, it still has this errors in the same situations.

III. The proposed new strategy for AM algorithm

Depending on the encoding algorithm given in figure (5):

t = 5 , r = 4

S1= 0 , S2= 2 , S3= 2

Calculate M from equation (1):

$$M = \begin{pmatrix} 1 & -1 & -1 & 1 \\ 1 & -1 & 3 & -3 \\ 1 & -1 & -1 & 1 \\ 1 & -1 & 3 & -3 \\ -1 & 1 & -3 & 3 \end{pmatrix}$$

Calculating Km from equation (4) gives:

K1= [-5 5 -7 7] , K2= [-1 1 -11 11] , K3= [1 -1 11 -11] and Em from equation (5) gives:

E1= 24, E2= 22 , E3=22

For decoding process:

To recall Y1, initially let Y1= [1 1 1 1], E1=24 , S1= 0

$K1Y1^t$ = 0< 24 (main value)

$K1\ Y1^t$ = 10 < 24 (approach from 24)

$K1Y1^t$ = 0 error (away from 24)

$K1Y1^t$ = = 24 = energy function and S1=0 , so Y1=[-1 1 -1 1]

To find Y2 let Y2=[1 1 1 1] , E2 =22, S2 = 2

$K2\ Y2^t$ = 0 < 22 (main value)

$K2\ Y2^t$ = 2 < 22 (approach from 22)

$K2\ Y2^t$ = 0 error (go away from 22)

$K2\ Y2^t$ = 24 big error (cross E2 value), there are error in the previous bits.

Return from beginning:

$K2\ Y2^t$ = 22 = E2, and S2= 2, so Y2=[1 1 -1 1]

To find Y3 let Y3= [1 1 1 1], E3 =22 , S3 = 2

$K3Y3^t$ = 0 < 22 (main value)

$K3Y3^t$ = -2 error (go away from 22)

$K3Y3^t$ = 2 < 22 (approach from 22)

$K3Y3^t$ = -20 error(go away from 22)

$K3Y3^t$ = 24 big error (due to 24 cross 22 value), this means that there are error in the previous bits

Return from beginning:

$$K3Y3^t = [1\ -1\ \ 1\ 1\ -1\ 1] \begin{bmatrix} -1 \\ -1 \\ 1 \\ -1 \end{bmatrix} = 22 = E3$$

But the summation of bits = -2 ≠ S3

$$K3\ Y3^t = [\ 1\ -1\ \ 1\ -1\ 1] \begin{bmatrix} 1 \\ 1 \\ 1 \\ -1 \end{bmatrix} = 22 = E3$$

And the summation of bits = 2= S3

So Y3= [1 1 1 -1].

The example above proves the efficiency of the proposed method where it can recall all pairs correctly, also it has the ability of storing pairs with different length, which is make the AM very useful in security applications as well as in computers manufacturing by reducing the word length traveled on the transmission lines and so on. Figure 8 illustrate the comparison in decoding process between efficiency and time consumption in seconds for kosko, multiple training, proposed new strategy for AM methods. In Kosko encoding method the convergence ratio is increase from 0 to 40% in 2s while in multiple training method the convergence ratio is increase from 0 to 60% in 3s. Nevertheless, in proposed new strategy for AM the convergence ratio is increased from 0 to 100% in 4s. It is clear that although the new strategy consumes one second more than the other strategies to reach the correct code, but it can reach 100% efficiency, while in spite of Kosko and multiple training methods are faster than the proposed new strategy but they don't reach the required efficiency.

This is happened due to the number of new suggestion values for Y to satisfy the condition that all Emd and Km values not equal to zero. In some cases, there is no need for these suggestions which make the process be very faster.

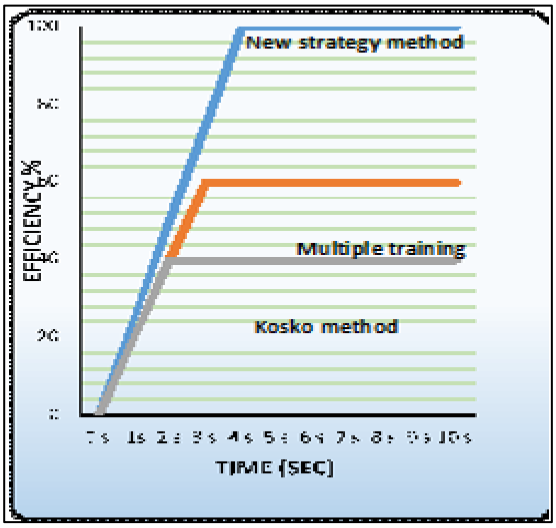

Figure 8: The differences among kosko, multiply, training, proposed new strategy for AM methods in convergences ratio and time consumption

Conclusion

To upgrade the efficiency of the association tasks of the AM and overcoming its main drawbacks, a modified method or strategy in the design of the net is proposed and tested. A new algorithm is suggested for the encoding and decoding of the AM. The tests validate the net and proved its ability to encode and decode all input/output pairs correctly regardless if the data in the pairs have the same length or not, as well as its capability to store pairs without any limitations on its storage capacity. The modified design gives the robustness of the network to be used in many applications.

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