An Associative Memory Self-Organizing Structured Knowledge Using Fragmentary Information

著者	Nakayama Kenji, Ikehara Keisuke
journal or publication title	IEEE&INNS, Proc. IJCNN'92, Beijing
page range	?53-?58
year	1992-11-01
URL	http://hdl.handle.net/2297/6819

AN ASSOCIATIVE MEMORY SELF-ORGANIZING STRUCTURED KNOWLEDGE USING FRAGMENTARY INFORMATION

Kenji NAKAYAMA **Keisuke IKEHARA**
Dept. of Electrical and Computer Eng., Faculty of Tech., Kanazawa Univ.
2-40-20, Kodatsuno, Kanazawa, 920 JAPAN

ABSTRACT A new associative memory is presented. The purpose of this study is to built an engineering model, which can simulate some parts of human memory system. In order to develop the model, several hypotheses are introduced. They are derived following biological and psychological aspects. The proposed memory system consists of many memory units, which consists of a single input unit and several output neurons. The memory units represent simple and straightforward knowledge. Knowledge is not well structured on neural circuits. Complicated knowledge structure is self-organized in the process of network dynamics. The proposed model can perform the following functions in addition to ordinary association. They include additional learning, self-organizing structured knowledge, forgetting behavior, self-restoration, and other psychological behavior, such as elaborative rehearsal, typicality, priming effects, inference and so on. Simulation of the model was compared with actual psychological experiments. From this comparative evaluation, it is confirmed that the proposed model can perform more flexible associative functions.

I INTRODUCTION

An associative memory is one of hopeful applications of artificial neural networks [1],[2]. The following associative functions can be expected. Related matters are recalled from fragmentary information. Common attributes for several articles are retrieved. Furthermore, more human brain like association processes could be expected [3].

In order to realize these functions, several kinds of approaches have been proposed. They include Associatron [4] and HASP [5], which employ correlation matrices between retrieval keys and matters to be memorized. Memory capacity and noise performance are rather limited. Furthermore, mutually connected neural networks have been applied to this problem. The pieces of knowledge are memorized in the equilibrium states [6],[7]. The model employing asymmetrical weights and variable hysteresis threshold has a large memory capacity and high retrieval rates for noisy stimuli [8]. Another model, employing inhibitory connections in the same cloud, and excitatory connections through core units,.is also useful for retrieving general and specific knowledge [9].

Engineering models, which can simulate more human brain like behavior, are also meaningful in both engineering applications and analyzing mechanism of the human memory system. However, this approach has not been well discussed.

This paper proposes a new associative memory model, which belongs to the second category. Purpose of this model is to simulate the following functions in addition to ordinary associative functions. Additional learning, self-organizing structured knowledge, forgetting behavior, self-restoration, and other psychological behavior of the human memory.

II HYPOTHESES FOR NEW ASSOCIATIVE MEMORY

In order to achieve human brain like associative memories, it is important to take biological and psychological aspects into account. However, most of them have not been cleared. *Therefore*, some hypotheses must be introduced for constructing an engineering model.

2.1 Knowledge Representation

The following hypotheses are employed for neuron level information representation.

(H-1) A single neuron represents a single matter, that is local representation.
(H-2) For a single matter, several neurons are assigned, that is distributed representation.
(H-3) Relations among matters are expressed by connections. Thus, connection weights express strength of the relations.
(H-4) Connection weights are adjusted following experience, that is frequency of the corresponding stimuli.
(H-5) Each neuron has a self-loop in order to hold its state for a while.

2.2 Network Structure and Dynamics

Based on a learning process of human being with fragmentary information, network structure is assumed not to be well organized. Knowledge, represented with neurons and connections, seems to be simple and straightforward. For this reason, the following hypotheses are adopted.

(H-6) A model consists of many memory units, which represent direct relations among matters.

(H-7) Knowledge is automatically structured in network dynamics.

In order to simplify hardware realization and analyzing network dynamics, the following assumption is employed.

(H-8) Propagation of signal from one neuron to the other requires a unit delay.

2.3 Unconscious and Conscious Layers

Information processing in the human brain cannot be entirely sensed. Only some part of the processing come to the conscious level. Therefore, we employ the following hypothesis.

(H-9) A model includes unconscious and conscious layers.

2.4 Preprocessors Stimuli

When stimulus "An apple is a red fruit" is given, the following two relations are derived. "Color of an apple is red" and "An apple is a sort of fruit". This kind of primary analysis is assumed to be done before applying them to the memory system.

III STRUCTURE OF NEW ASSOCIATIVE MEMORY

3.1 Block diagram

Based on the hypotheses, a new model for an associative memory has been developed. Figure 1 shows a block diagram. Stimuli are applied to the primary analysis block. Relations among matters are briefly analyzed here. The analyzed relations are entered into a single layer memory block. The outputs of this block are applied to the unconscious layer. Using activation functions, association results are obtained. These results are further transferred to the conscious layer, and at the same time, are fedback to the input of the memory block. Activation functions are also employed in this layer. Its outputs imply association results, which can be actually sensed. These results are also fedback to the input, in order to cause successive associations.

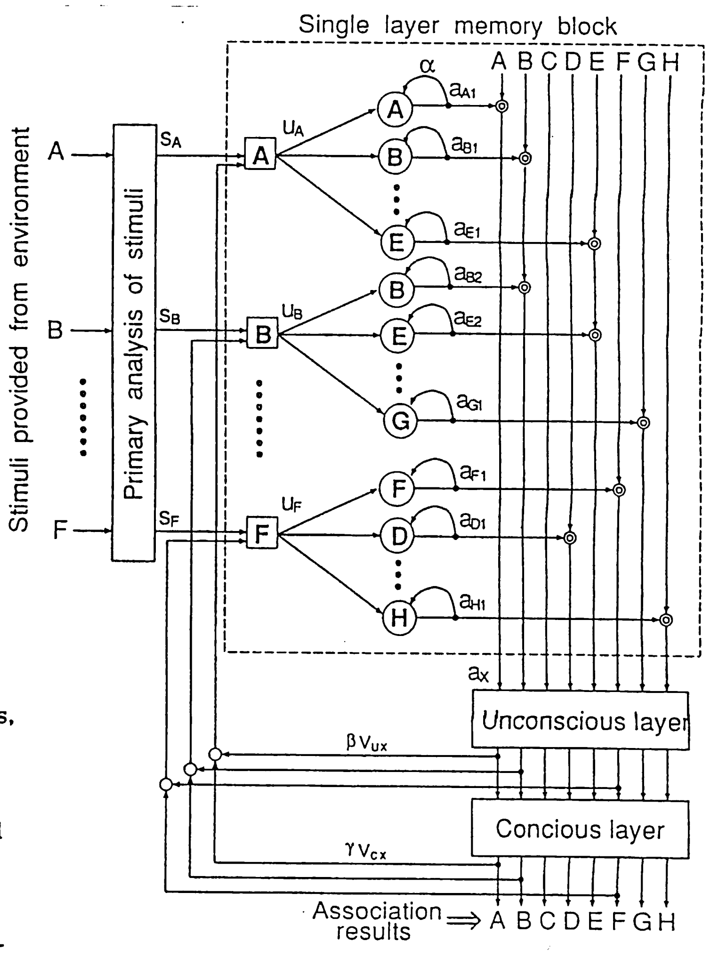

Fig.1 Block diagram of proposed associative memory.

3.2 Single Layer Memory Block

A square indicates an input unit, which receives stimuli from the primary analysis block, the unconscious and conscious layers, and transmit them to neurons denoted with a circle. Alphabet letters indicate corresponding matters. A single unit represents a single matter. Several neurons are assigned to a single matter. A neuron is assigned to the same matter as the input unit. Connections between the squires and the circles represent relations between matters. Therefore, simple and straightforward relations are only memorized in this block. More complicated relations are equivalently generated in network dynamics. Namely, well structured knowledge is self-organized in network dynamics. Each neuron has a self-loop, in order to hold its state for a while. A sub-block, consisting of a single input unit and several neurons connected to it, is called "memory unit". Thus, each memory unit consists of a single retrieval key and its related matters.

The equations in this block are given in the following. The input unit receives the stimulus $s_x(n)$ and the outputs of the unconscious and conscious layers $v_{ux}(n-1)$ and $v_{cx}(n-1)$, respectively.

$$u_X(n) = s_X(n) + \beta v_{UX}(n-1) + \gamma v_{CX}(n-1) \quad (1)$$

Here, X indicates one of alphabet letters. β and γ are coefficients of the feedback loops, which satisfy $0< \beta, \gamma <1$. $u_X(n)$ is transmitted to the neuron. The input $net_{XK}(n)$ and the output $a_{XK}(n)$ of the neurons are calculated as follows:

$$net_{XK}(n) = w_{YX}u_Y(n) + \alpha a_{XK}(n-1) \quad (2)$$
$$a_{XK}(n) = f_A(net_{XK}(n)) \quad (3)$$

w_{YX} is connection weight from the Y input unit to the X neuron. α is coefficient of the self-loop, which satisfies $0< \alpha <1$.

Σ and Π functions can be used for gathering several $a_{XK}(n)$ at the node ◎.

$$a_X(n) = \sum_K a_{XK}(n-1) \quad (4)$$

$$a_X(n) = \prod_K a_{XK}(n-1) \quad (5)$$

3.3 Unconscious and Conscious Layers

a_X is transformed through a nonlinear function in the unconscious and conscious layers. From the biological analogy, a sort of squashing functions, for instance a logistic function and a threshold function, can be employed.

$$v_{UX}(n) = f_U(a_X(n)) \quad (6)$$
$$v_{CX}(n) = f_C(v_{UX}(n)) \quad (7)$$

In order to recall several articles in reasonable order, variable threshold is employed. Accuracy of association is proportional to the threshold.

IV LEARNING AND ASSOCIATION PROCESSES

In the proposed model, learning and association processes are mutually affected to each other. However, they are somewhat separately described here.

4.1 Learning Process

In the learning process, the connection weights are adjusted through experience. When stimulus "An apple is a red fruit" is given, the following relations are formulated. /Apple/→<Red>, <Fruit>, /Red/→<Apple> and /Fruit/→<Apple>. Symbols /・/ and <・> indicate the input unit and the neuron, respectively. Adjusting weights are classified into two phases.

Phase 1: When the relations do not exist, new connections are generated.

Phase 2: When the connections are already exist, the weights are emphasized.

In both phases, an equation to adjust the connection weight is given by

$$w_{XY}(n) = f_W[\lambda w_{XY}(n-1) + str(n,X,Y)] \quad (8)$$

A function $f_W[]$ is a squashing function. λ is a forgetting factor satisfying $0< \lambda <1$. str (n,X,Y) indicates strength of the stimulus from X to Y articles. str(n,X,Y) is determined by the external and internal stimuli. The latter includes the outputs of the unconscious and conscious layers. If $w_{XY}(n)$ holds large value for a long period, then it is fixed to constant, which never decreases. This means permanent memory.

4.2 Association Process

An association process is described using examples in the following. Suppose the following memory units exist. /Red/→ {<Apple>,<Signal>,<Color>} and /Fruit/→ {<Grape>,<Apple>,<Pear>} . When stimuli /Red/ and /Fruit/ are given, then the Y neuron receives $w_{RY} \cdot u_R$ and $w_{FY} \cdot u_F$. F and R mean "Fruit" and "Red", respectively. If we assume the weights, u_F and u_R are all normalized as unity, and the Σ function is employed at the node ◎, then a_X for "Apple" takes the maximum value, that is a_A=2. A means "Apple". By setting the threshold to be 2, only "Apple" is recalled. This is strict association. If the threshold is chosen to be smaller than 2, vague association can be obtained.

More complicated association process will be described in the next section.

V ASSOCIATIVE FUNCTIONS REALIZED BY NEW MODEL

5.1 Direct Associations

The following ordinary association processes can be done.

(1)Given a single stimulus, related matters are recalled.

(2)Given several stimuli, common matters are recalled.

5.2 Additional Learning

Suppose the following pieces of knowledge are given step by step.

(1)An apple has round shape and red color.

(2)An apple tastes sweet.

(3)An apple is a sort of fruits.

Then the following memory units are generated or are emphasized.

(1)/Apple/→ {··,<Round>,<Red>,··} ,/Round/→ {··,<Apple>,··} ,/Red/→ {··,<Apple>,··}

(2)/Apple/→ {··,<Round>,<Red>,<Sweet>,··} ,/Sweet/→ {··,<Apple>,··}

(3)/Apple/→ {··,<Round>,<Red>,<Sweet>,<Fruit>,··} ,/Fruit/→ {··,<Apple>,··}

Each process can be individually and additionally done in the proposed model.

5.3 Self-Organizing Structured Knowledge

As described in the previous section, the memory units represent simple and straightforward relations. However, in the association process, the proposed model can respond to the stimuli as if having well structured knowledge. Knowledge is structured in the process of network dynamics. Furthermore, as described in the learning process, new connections can be generated using internal stimuli through the feedback loops. These processes can make it possible to self-organizing structured knowledge.

5.4 Self-Restoration

The proposed model always has reciprocal relations in different memory units. For example, if the relation /Apple/→<Red> exists, then its reciprocal relation /Red/→<Apple> always exits. Therefore, even if the neuron for <Red> connected to /Apple/ dies, a new neuron can be generated using the relation /Red/→<Apple>. Namely, if <Apple> is retrieved from /Red/ in some other association, then its reciprocal relation is generated. In another word, information is memorized in multiplexed mode. This make self-restoration possible.

5.5 Psychological Functions

(1) Elaborative Rehearsal

For example, a list including "ball, lake, bat, glove, fishing, spikes" is shown. After a while, it is requested to answer the articles in the list. If a person is familiar with "baseball", then "ball, bat, glove, spikes" are recalled faster that the other.

This behavior can be realized by the proposed model as follows: First, the articles in the list are applied to the model as stimuli. From these stimuli, <Baseball> is associated as a most common article of the stimuli. <Baseball> is fedback to the input units. In the next step, the input units receive both /List/ and /Baseball/ as stimuli. The stimulus /Baseball/ strengthen the related articles. As a result, the above articles can be recalled faster than the other articles.

(2) Typicality

Suppose the following two questions are given. "Is a penguin classified into a category of bird?" and "Is a sparrow classified into a category of bird?". It can be expected that everybody will respond "yes" to the second question faster than to the first question. Because a sparrow has many properties, which are typical to bird, compared with a penguin.

This psychological aspect can be simulated using the proposed model. Table 1 shows examples of the pieces of knowledge. From this table, when /Sparrow/ and /Bird/ are given as stimuli, many attributes can be activated compared with using stimuli /Penguin/ and /Bird/.

Table 1 Examples of memory units.

Input units	neurons
/Bird/	<wing> <bill> <fly> <high nest> <oviparity>
/Sparrow/	<wing> <bill> <fly> <high nest> <oviparity>
/Penguin/	<wing> <bill> <not fly> <low nest> <oviparity>

(3) Priming Effects

From psychological experiments, the preceding stimuli affect the association results caused by the succeeding stimuli. In our model, the results associated by the preceding stimuli can be activated for a while through the feedback loops, and are used as internal stimuli. Therefore, they can affect the succeeding association process.

(4) Inference

Suppose a person does not know the taste of a fruit "A". However, its attributes are similar to those of an orange. In this case, the person tends to imagine its taste may be "sweet".

The inference process simulated by the proposed model is as follows: Suppose <Yellow>, <Round>, <Middle size>, <Fruit> are associated from /A/. They are fedback to the input units. These attributes are also connected to <Orange>. Therefore, at the next step, <Orange> is activated. This result is further fedback to the input units. From /Taste/ and /Orange/, the taste of orange, that is <Sweet> is associated.

VI SIMULATION AND PSYCHOLOGICAL EXPERIMENTS

Simulation using the proposed model has been compared with psychological experiments. A person was assigned to be examined. This subject did not know the purpose of the experiment.

6.1 Investigation of Fundamental Memories

Objects to be associated are limited to "fruits" and "vegetables". Fundamental memories of the subject are investigated as follows:

Step 1: Ask the subject to give names of fruits and vegetables.

Step 2: Ask the subject to give attributes of the fruits and vegetables given in Step 1.

Step 3: Given the attributes obtained in Step 2, ask the subject to retrieve names of fruits and vegetables.

Table 2 shows examples of this investigation.

Table 2 Examples of investigation for fundamental memories.

Stimulus	Step	Responses of Subject
fruit	1	mandarin orange , apple , strawberry , pear , banana , grape , pineapple , peach , orange , watermelon
vegitable	1	radish , carrot , potato , welsh onion , onion , pumpkin , broccoli , celery , cabbage , white rape , paceli
apple	2	to peel off , red , sweet , round , winter , Aomori*
pear	2	sweet , moisture , easy to peel off , round ,autumn , Tottori *
radish	2	Oden**, Oroshi**, relish , legs , white , leaf , pungent , long , Nerima*, Sakurajima*
pumpkin	2	Nimono**, winter solstice , pumpkin pie , red been solid skin , green , round , flatlike , sweet , big , winter
red	3	Ferrali , signal , drunker , carrot
leaf	3	tree , fallen leaves , dead leaves , Sasa-sushi
pungent	3	radish , onion , welsh onion , a kind of taste

• Name of place •• Japanese foods

6.2 Construction of Associative Memory

The memory units in the single layer memory block are constructed using data obtained in the previous section. The connection weights are determined as follows:

(1) Articles and attributes, which are directly associated from the given stimuli in all steps, have connection weight=1.

(2) Attributes, which are associated after their category, such as "color", "shape", "size" and so on, are specified in Step 2, have connection weights=0.4～0.6.

(3) In Step 3, if the corresponding articles are not recalled from the attributes, obtained in Step 2, then connections from these attributes to the articles have weights=0.4～0.6.

6.3 Simulation and Psychological Experiments

(1) Association from a Single Stimulus

Table 3 shows association results in both simulation and psychological experiment. The matters with a underline are associated in both ways.

(2) Association from Several Stimuli

Table 4 shows association results in both methods.

(3) Priming Effects

Psychological experiment were carried out as follows: First, /Orange/, /Pear/ and /Pineapple/ are given as stimuli, and the subject is asked to give attributes associated from them. After that, the subject is asked to give names of fruits and vegetables except for orange, pear and pineapple. As a result, the subject responds "Apple" → "Banana" → "Grape" →"Persimmon"→"Loquat"→"Fig"→・・.

Table 3 Association results from a single stimulus.

Stimulus	Responses of subject	Result of simulation
seed	watermelon , strawberry , tamato	grape , watermelon
Aomori*	apple	apple
apple	red , round , to peel off , Aomori* , Fuji** , pie , computer	to peel off , red , sweet
pear	Tottori*, 20th century** , moisture autumun , easy to peel off	sweet , moisture , easy to peel off
strawberry	small , red , milk , harvest , ice cream , cake	red , small , seed
radish	Oroshi*** , Oden*** , Nerima* , Sakurajima* , relish , katuramuki***	Oroshi*** , Oden*** , relish , leaf , katuramuki*** , legs , white
yellow	mandarin orange	mandarin orange

Underlines show that responses are same.
• Name of place •• Fruits ••• Japanese foods

In simulation, the same preceding stimuli were applied. Figure 2 shows activation level for related attributes. These attributes are fedback to the input units as stimuli. At the next step, /Fruit/ was given as the external stimuli. Figure 3 shows activation level of related fruits. These results are mostly consistent with the above results.

Ⅶ CONCLUSIONS

This paper presents a new associative memory. This model consists of many memory units, which represent simple and straightforward knowledge. Complicated knowledge structure can be self-organized through the network dynamics. Comparisons between simulation of the model and actual psychological experiments have demonstrated efficiency of the new model.

Table 4 Association results from several stimuli.

Stimulus	Responses of subject	Result of simulation
seed , summer	watermelon , tomato	watermelon , tomato
autumn , moisture	pear	pear
winter , vegitables	punpkin , potato , sweet potato , white rape	radish , pumpkin , white rape sweet potato
rabbit , round	no association	no association
white,round,sweet	no association	onion
red,round,Aomori*	apple	apple
round,sweet,autumn	pear , grape	pear
apple , pear , cabbage mandalin orange	food	sweet , round
apple , pear , cabbage , mandalin orange , shape	round	round

Underlines show that responses are same.
* Name of place

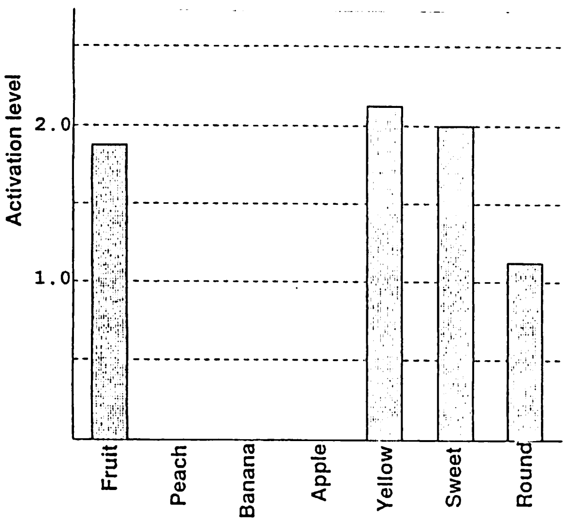

Fig.2 Activation level for attributes associated from /Orange/, /Pear/ and /Pineapple/.

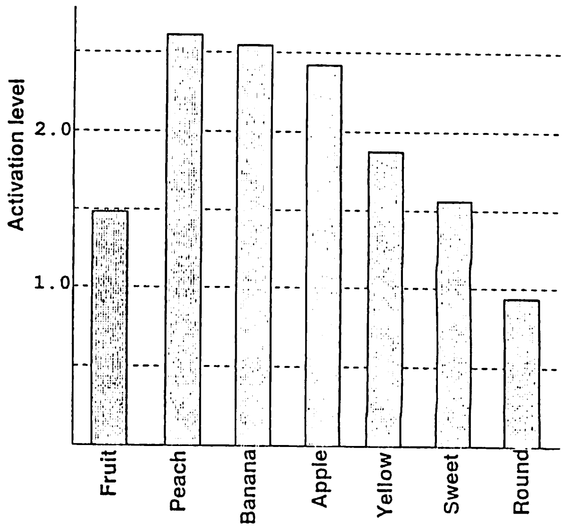

Fig.3 Activation level for fruits associated under affection of preceding stimuli.

REFERENCES

[1]T.Kohonen,"Self-Organization and Associative Memory", 3rd ed., Springer-Verlag, 1989.

[2]D.E.Rumelhart, J.L.McClelland and The PDP Research Group,"Parallel Distributed Processing", The MIT Press, 1986.

[3]R.L.Klatzky,"Human Memory-Structures and Processes", 2nd ed., W.H.Freeman and Company, 1980.

[4]K.Nakano,"Associatron-A model of associative memory", IEEE Trans. on S.M.C., vol.SMC-2, no.3, pp.381-388, July 1972.

[5]Y.Hirai,"A model of human associative processor (HASP)", IEEE Trans on SMC, vol.SMC-13, no.5, pp.851-857, 1983.

[6]J.J.Hopfield,"Neural networks and physical systems with emergent collective computational abilities", Proc. Natl. Acad. Sci. USA 79, pp.2554-2558, 1982.

[7]K.Nakayama and M.Tonomura,"A stochastic associative memory using mutually connected neural network", Proc. ISITA'90, Hawaii, pp.639-642, 1990.

[8]K.Nakayama and N.Mitsutani,"An adaptive hysteresis threshold method for an associative memory using mutually connected neural network", Proc. IJCNN'91, Seattle, vol. Ⅱ, p.A-914, 1991.

[9]J.L.McClelland,"Retrieving general and specific knowledge form stored knowledge of specifics", Proc. Third Annual Conf. Cognitive Science Society, 1981.