# Visual Mental Imagery Memory Model Based on Weighted Directed Graph

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***Abstract*—Simulation of imagery thinking has important significance for research and development of human intelligent systems. The breakthrough of computer simulation of imagery thinking is the simulation of mental imagery's memory mechanisms. In this study, a visual mental imagery memory model accord with working mechanism of declarative memory has been constructed. The new model has four layers. They are feature layer, hyper column layer, MTL (medial temporal lobe) free neurons layer and imagery concept layer. The design method and function of the model are described in the study. The experiment results demonstrate, the model can extract contour of target effectively and can realize various operation of mental imagery.**

***Index Terms*—imagery thinking, mental imagery, weighted directed graph, declarative memory, memory model, mental imagery cognition**

## I. Introduction

The simulation of human thinking is the research core of artificial intelligence science. It has become one of the hot topics in the 21st century. The research of intelligent system with human thinking will exert a profound influence on national defense, the economy, the education, the culture and so on. It will also accelerate a new industrial revolution with the symbol of information industry. Thinking can be divided into imagery thinking and logical thinking. Nowadays, the research of imagery thinking has been paid more and more attention. The imagery thinking is the thinking carries on mental imagery. Mental imagery is a kind of representation of object or event which does not exist currently. Thinking with mental imagery depends on the storage mode of mental imagery in the brain.

The results of neurophysiology and psychology provide the foundation for the simulation of mental imagery memory mechanism with computer.

Neurophysiology scholars study on the structure of neurons and the interaction among neurons from the aspect of cells and molecules [1]. They ascertained the regions participate in memory of brain and the structure of them; Psychologists mainly experiment on, explain to and model the phenomenon of memory. There are many influential memory models, such as hierarchical network model, spreading activation theory, set-theoretical model, semantic feature-comparison model and human associative memory.

The cognitive scientists had also proposed many mental imagery models. A series of models to verify two kinds of representations theory had been established [2-5]. Ganis, Thompson and Kosslyn had made comparison between the visual buffer's function with different biological brain regions' function, then proposed multi-dimensional sequential theory [4]. Thomas Barkowsky and others had designed architecture for reasoning with mental images [6].

In China, scholars had proposed many theoretical models of visual cognition and reasoning with mental imagery: Yu Bo and others had proposed a new model for image matching based on the structure of the primary visual cortex [7]. Wei Hui, Pan Yun-he, He Xin-gui and others had discussed a new method of mental image represented distributed among neural network, which is a hierarchical model of visual center cortex. They had given a kind of direct knowledge representation mode with the connectivity of graph [8-9]. Li Su, Qi Xiang-lin and others had made deeply studied on the phenomenon of functional column synchronous oscillation [10]. Wang shou-jue and others had made deeply studied on biomimetic pattern recognition. And then they applied the results in the face recognition area [11]. Theory of topological perception proposed by Chen Lin had given a new concept and method to special imagery construction especially [12]. Luo Si-wei and others had proposed sparse code neural network model based on visual system and a computational model of object-based attention using multi-scale analysis and grouping [13-14].

Although the models proposed by the predecessor have made the contribution to the research of visual cognition and reasoning with mental imagery, they either aim at the application research of specific domain or aim at the specific aspect of visual mental imagery operations, and they seldom model every operations of visual mental

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imagery from the aspect of computer.

What deserves to be mentioned is the direct knowledge representation mode proposed by Wei Hui. They considered the connected mode of graph as a kind of direct knowledge representation. Study based on structure not only conforms to human physiological characteristic but also can realize the representation and the association of mental imagery effectively [8]. We consider that although there are many advantages to represent knowledge with connected mode, study based on structure without changing weights is not good at describing the influence of learning intensity to mental imagery forgetting. Connected mode can only be taken for a part of local network in the mental imagery memory system as a tool for imagery storage.

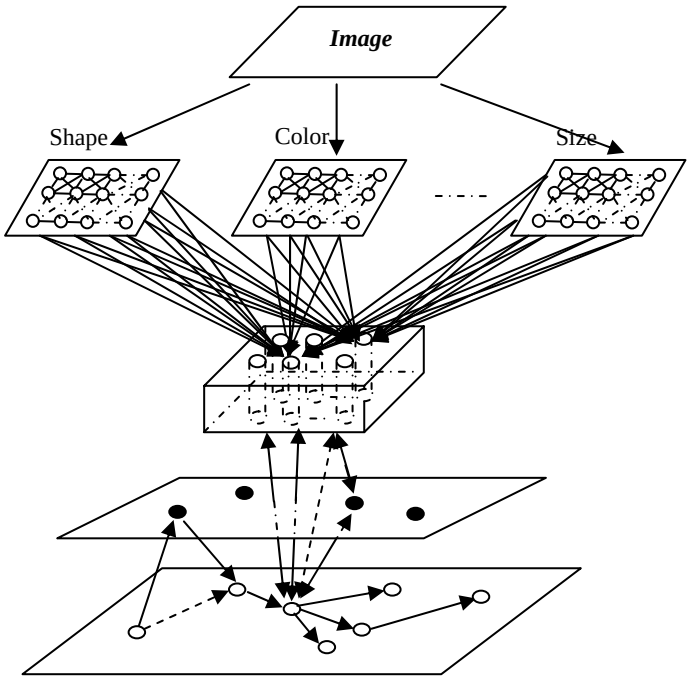
The complexity of human brain decided that it is hard to simulate the whole memory mechanism with one kind of neural network. Psychologists had divided memory into declarative memory and non-declarative memory. Declarative memory is memory for facts, events and the relationship among them. Non-declarative memory is memory for how to perform skill, custom and conditioned reflex and so on. According to the modularity hypothesis, we supposed that each kind of memory has its relative storage pattern network and memory mechanism is the interactive result of many networks with different structure.

On the base of previous work and research results of neurophysiology and psychology, our study aimed to construct a new model which was accord with working mechanism of human imagery declarative memory to model every operations of visual mental imagery from the aspect of computer. The new model called visual mental imagery memory model was constructed with weighted directed graph.

## II. Model Structure And Physiological Basis

The results show that vision is caused by nerve impulsion. After eyes observe a object, the visual information is transmitted to lateral geniculate or epithalamus from nerve cells in retina and finally to primary visual cortex by the form of nerve impulsion.

It is generally accepted that visual information is transmitted separately with its different feature aspects such as the shape, the color, and the size. As shown in Fig. 1, each sub-layer in the first layer of the model reflects different feature aspect of the image.




1) Feature layer. Extract all different features of image with particular rule.

2) Hyper column layer. Encode the codes.

3) MTL free neurons layer. Connect two neurons which are activated at the same time.

4) Imagery concept layer. Realize operations of mental imagery with weighted directed graph.

Fig.1 Mental Imagery Memory Computer Model

There are many functional columns in primary visual cortex. Functional column is a column perpendicular to the cortical surface. It is formed with cells which have same receptive field position and the same physiological function. Each kind of functional columns only withdraws one kind of visual features. Many functional columns with almost the same receptive field but receive different feature compose a hyper column. Hyper column is the functional unit of the visual cortex. These hyper columns not only have the relationship with operations of mental imagery, but also associate with the mental imagery storage. The second layer is hyper column layer. The connections between the first layer and the second layer are total binding. They are synaptic connections. We encode different feature aspects of mental imagery with 0 and 1 in a certain order. Zero represents the excitation of neurons, one represents the inhibition of them. Excitation of a crowd of feature neurons at the same time can excite the excitation of relative functional columns and relative mental imagery concept further. It is the same in turn. Meanwhile, the connections are also neural network connections in the hyper column layer.

The third layer is MTL free neurons layer. Neurophysiologists have already discovered that there is

an important region named MTL (medial temporal lobe) in the whole process of human declarative memory. Its existence makes the short-term memory transform to the long-term memory is possible. In the consolidation process of memory, neurons in MTL and neurons which represent specific object scattered in the neocortex are cooperatively activated together. Although the connections between these neurons in neocortex is weak at first, the connections will stronger and stronger along with repeated activation of MTL until there don't need the intermediary connection of MTL finally. The function of MTL is to connect cerebral cortex where memory information stored, but not to store the memory information itself. The solid round nodes in the third layer represent free neurons in MTL. They can not only connect concept node with the relative neuron group which represent mental imagery concept information, but also can connect one concept node with another concept node. Regardless of which kind of connection, free neurons do not have any meaning.

Although we are not sure about the physiological mechanism of memory at present, we all know that the memory is realized by synaptic connection between nerve neurons. The memory is the process of network construction. We described this process with the directed graph. The fourth layer is imagery concept layer. In this layer, we represent the relationship between concepts with the directed graph. Edges in directed graph represent relationship between nodes; Hollow round nodes represent the concepts. This node may be a neuron, may also be a sub-network which describes a concept.

Each hollow node in the concept network is restricted to represent object which has mental imagery information, it no longer expresses the abstract concept because the network is formed based on imagery thinking.

One kind of object may have many individuals with different image, so each concept node in network is connected with many relative neuron groups which represent its mental imagery information. When the number of neuron groups connected with one concept node achieves a certain threshold, these groups will be activated at the same time. System will induce their common characteristic automatically, and will connect a new neuron group which is signed and can represent the common characteristic with the node. Meanwhile, other neuron groups connected with the node are broken off. Information on groups will be cleared. Groups are released to record other information.

## III. Imagery Operation And Relative Mathematics Description

### A. Imagery Extraction

The visual information is divided into many different characteristic aspects: the shape, the color, the size and so on to be transmitted and processed separately after it received by human eyes. And then every aspects of visual information will be assembled together in hyper column. Excitation of a group of characteristic neurons at the same time can excite relative mental imagery concept.

Shape is the most important and indispensable part of the visual information when imagery extraction. Visual information can be processed layer by layer for the receptive field of each kind of nerve cell in the visual pathway has hierarchical characteristic. Sensitivity in direction is the physiological basis of simple cells' edge detection. Simple cells can extract edges of image. Complex cells can extract shape feature information on the basis of output of simple cells through further treatment

We divided shape detection into two steps: edge detection and basic shape detection. Edge detection extracts abundant edge information from natural images; Basic shape detection extracts basic shapes, such as line and circle, from edge information extracted by the first step. More complex shape can be described by the combination of basic shapes.

We use three layers BP neural network to simulate the edge detection process of visual cortex cells in edge detection step. Nine input neurons take the 3×3 Windows scanned image as the input. We set 19 hidden neurons by experience. The output level judges whether there is directional information. Therefore we set a neuron on the output level for it is 0-1 question. We trained the network designed and made simulation experiment using images with noise and images without noise. Experiment results are seen in the fourth part.

Algorithm of basic shape detection step is as follows: Every edge point must be signed with a directional value according to its local edge direction. We signed level, left diagonal, vertical, right diagonal and turning with 0,1,2,3 and 4 respectively. Neighboring edge points with same directional value except points whose value is 4 should be signed on one line. We need to combine line segments with similar direction, complete contour of object some time because we want to get the simplest shape of the object. Suppose the set of line segments we got is *A*, here *A* is $\{a_0, a_1, a_2 \cdots, a_N\}$ and *N* is the number of line segments. Every element in set *A* has attributes such as two endpoints' position and line segment's direction. Line segment pairs which can be combined should satisfy the conditions that the distance between two endpoints from two line segments is smaller than threshold , in other words, two line segments is nearly linked; And the included angle of two line segments is smaller than threshold.

Suppose connection strength of arbitrary line segment pairs is

$$C_{ij} = \begin{cases} w_0 \cdot d_{ij} + w_1 \cdot \theta_{ij} & d_{ij} < T_d, \theta_{ij} < T_\theta \\ 0 & else \end{cases}. \qquad (1)$$

Where,

$d_{ij}$ is the smallest distance between endpoints of line segment $a_i$ and $a_j$,

$\theta_{ij}$ is the included angle of $a_i$ and $a_j$,

$w_0$ is weighted coefficient,

$w_1$ is weighted coefficient,

$T_d$ is the biggest tolerable distance between endpoints of line segments,

$T_\theta$ is the biggest tolerable included angle of line segments.

The model sort line segment pairs formed by *A* according to connection strength. The line segment pairs with smallest connection strength $C_{ij}$ are combined each time. A new set is formed by the new line segment with remainder line segments. The direction of the new line segment is calculated according to new endpoints' position. This must be continued until all connection strengths of line segment pairs formed by the set are bigger than threshold sited.

The model extracts shape from set in which the directional values of edge points are 4 with Hough transform and curve fitting.

The processing method of color information is similar to the method of shape. The size feature of object the model recorded is not a concrete digit, but is a general category which is contrasted to other objects' size according to the human physiology characteristic.

Many features of object such as shape, color and size form the representation of it in model. Each representation is corresponding to a mental imagery concept. The mental imagery concept is only a signal which represents one special object in memory. It is connected with semantics in the spoken language system which we learned.

### *B. Mental Imagery Storage*

The main effect caused by study is to decide which nerve connections must be consolidated and which must be removed or modified in the intense competition process of many kinds of brain activity. In the network model, new information is stored by adding new concept nodes and connecting them with old concept node which is stored in network, and also be stored by adding edge between two old concept nodes.

Only a few nerve neurons which are closely related to the process will be activated at the same time when the magnanimous knowledge storied in brain is processing. This causes that we can describe this process by an imagery concept network with limited nodes.

Fig. 2 is the imagery concept network we constructed.

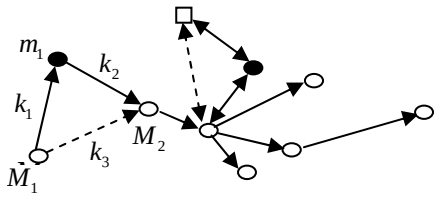



Fig. 2 Imagery Concept Network

The hollow round nodes represent the concepts which have mental imagery in the long-term memory. The solid round nodes represent free neurons in MTL. They do not have any meaning. The hollow square nodes represent the mental imagery information which is corresponding to mental imagery concept. The edges between them are bidirectional arrows for the relationship of concept and mental imagery is one-to-one. The unidirectional arrows only represent the respective relations in the network. For example, we suppose that there are two concept nodes $M_1$ and $M_2$ which represent "the wing" and "the feather" respectively. They had already been stored in the imagery concept network as shown in Fig. 2. When we get the information that there are feathers on wings, $M_1$ and $M_2$ will be activated at the same time. Meanwhile, the construction of the network must be changed to store the new information under certain rules.

The algorithm is as follows:

①Add 1 to the weights of $M_1$ and $M_2$ nodes at first. Make a judgment on whether $M_1$ and $M_2$ nodes are connected. If they are not connected, turn to ②, otherwise turn to ③;

②Add solid round node $m_1$, add a real edge between $m_1$ and $M_1$, and add a real edge between $m_1$ and $M_2$ with certain direction on the basis of the relationship between them. Add virtual edge between $M_1$ and $M_2$. Suppose $k_1$、$k_2$、$k_3$ are weights of edge $M_1m_1$、$m_1M_2$ and $M_1M_2$, $k_1 = k_2 = \theta$, set $k_3$=0, turn to⑧;

③Make a judgment on whether there is a connected path between $M_1$ and $M_2$, and all nodes in this path are hollow nodes and all edges are real edges. If there is, turn to ④, otherwise turn to ⑤;

④Add 1 to the weights of all edges and all nodes in the path above. We can choose a path with random method if there are many paths like that. Turn to ⑧;

⑤There certainly exist a path among $M_1, M_2$ and $m_1$ as shown in Fig. 2. Add 1 to $k_3$. Judge whether $k_3$ is not smaller than $\theta$. If it is not, turn to ⑥, otherwise turn to ⑦;

⑥Delete edge $M_1m_1$ and $m_1M_2$. Release free neuron $m_1$ to participate in other connections. Change edge $M_1M_2$ to real edge. Add $k_3$ to 1, turn to⑧;

⑦Add $k_3$ to 1, turn to⑧;

⑧ End.

When the situation above occurred, if mental imagery concept has not been stored in imagery concept network, the system will activate relative neuron group which represents its mental imagery information and a new cerebral cortex neuron at the same time. And then, the MTL free neurons will participate in establishing new connection as communicant. The algorithm is similar with above.

Mathematical description of algorithm above is as follows: Suppose weighted directed graph $G$ is $(V,\{E\})$, and the adjacency matrix of it initially is

$$A[i][j]=\begin{cases} w_{ij} & \text{if} < v_i, v_j > \in E \\ w_{ii} & \text{if} \quad v_i \in V \\ \infty & \text{otherwise} \end{cases} . \quad (2)$$

Where, $w_{ij}$ is the weight of edge $< v_i, v_j >$, and $w_{ii}$ is the weight of node $v_i$.

The model will make a judgment on whether node $v_s$ and node $v_t$ in graph are connected if they are activated at the same time. Judgment method is as follows: The model calculates the adjacency matrix of relative undirected graph $A_1$ according to $A$ at first. Then calculate matrix $S$,

$$S=\sum_{k=1}^{m-1} A_1^k . \quad (3)$$

Where $m$ is dimension of matrix $A_1$.

Element $s_{ij}$ in $S$ is the number of connected paths between node $i$ and node $j$. Node $i$ and node $j$ are disconnected when it is zero, connected otherwise. It is proved in reference [15].

The model will extend $m$ dimensional matrix $A$ to $m+1$ dimensional matrix if $v_s$ and $v_t$ are disconnected. Let $a_{mm}$ be zero. Change $a_{st}$ or $a_{ts}$ into zero. Let $a_{sm}=\theta$ and $a_{mt}=\theta$ or $a_{tm}=\theta$ and $a_{ms}=\theta$.

Suppose there is a simple path $\left(v_s=v_{i,0}, v_{i,1}, \cdots, v_{i,m}=v_t\right)$ between node $v_s$ and node $v_t$ if they are connected. Where $< v_{i,j-1}, v_{i,j} > \in E$ and $1 \le j \le m$. Nodes and edges in this path form a subgraph $G'=\left(V', \{E'\}\right)$, then there is a matrix,

$$B[i][j]=\begin{cases} 1 & \text{if} < v_i, v_j > \in E' \text{or} v_i \in V' \\ 0 & \text{otherwise} \end{cases} . \quad (4)$$

Where, $C=A+B$.

Make a judgment on whether there is a $k$ makes that $c_{kk}$ is zero, and $c_{sk}$ is $\theta$ and $c_{kt}$ is $\theta$, or $c_{tk}$ is $\theta$ and $c_{ks}$ is $\theta$ if $c_{st}$ is bigger than $\theta$. If there is, delete all elements of column k and row k in matrix $C$. The matrix remained is the result. Otherwise, the result is $C$ when $v_s$ and $v_t$ are activated at the same time.

### C. Mental Imagery Cognition

Relative mental imagery neuron group which represents its mental imagery information is activated when a hollow round concept node is activated in imagery concept network. Therefore, mental imagery of the concept is constructed in brain. The stimulation of imported image can also activate the relative concept node in imagery concept network. Time spent on searching concept node which is relative to mental imagery neuron group is proportional to the number of nodes stored in network. Deciding the object's category can reduce the time cost. Simultaneously reducing the time cost also needs massive knowledge putting in the knowledge library. If two hollow round nodes of network are activated at the same time, the shortest path connected them will be activated. For example, there are two concept nodes which represent "the duck" and "the feather" respectively. They are connected by node which represents "the wing". If two concepts of "the duck" and "the feather" are given, the node which represents "the wing" will be activated. We will get the information that the duck has wings and the wing has feather. Furthermore, the information that the duck has feather will be obtained.

### D. Mental Imagery Association

If a hollow round concept node in imagery concept network is activated, the next peripheral hollow round concept nodes around it will be activated possibly when mental imagery association is occurred. Which peripheral node will be activated is decided by the activation strategy. We propose an activation strategy called the redundant-weight random method. That is to say, the system should associate the node which is associated recently or associate the node which has the biggest weight on edge with the node activated. We randomly use the two methods above. The system implements "return forbidden mechanism". Therefore, the nodes associated just can't be associated again.

### E. Mental Imagery Forgetting

If the connection of two concept nodes has not activated in a certain time, the weight on the edge must be decreased for a degree. When the weight is lower than the threshold, the connection between two concept nodes will be broken off. Meanwhile the relationship of them will be forgotten.

We set weights on hollow round concept nodes also. If the concept node has not activated in a certain time, the weight of it must be decreased for a degree. When the weight is lower than the threshold, the information on the node will be cleared, and all connections with the node will be broken off. The node represent the neuron will be released to wait for participating in next process of mental imagery record.

Define forgetting matrix is

$$T[i][j]=\begin{cases} T_{ij}(t) & \text{if} < v_i, v_j > \in E \text{or} v_i \in V \\ 0 & \text{otherwise} \end{cases} . \quad (5)$$

Here, $T_{ij}(t)$ is changed with time. It will be added to 1 if the relative edge or node is not activated in a certain time.

Calculate results of forgetting on a regular schedule:

$$A=A-T=\begin{cases} w_{ij}-T_{ij}(t) & \text{if} w_{ij}-T_{ij}(t)>0 \\ w_{ii}-T_{ii}(t) & \text{if} i=j \\ \infty & \text{otherwise} \end{cases} . \quad (6)$$

Make a judgment that if the node has been forgotten. Define

$$S[i][j]=\begin{cases} 1 & \text{if} i=j \\ \infty & \text{if} i=j=k \\ 0 & \text{otherwise} \end{cases} . \quad (7)$$

If the value of diagonal $a_{kk}$ in matrix $A$ is not a positive number, the node has been forgotten and the forgetting result is $A \bullet S$, otherwise it is $A$.

## IV. EXPERIMENTAL RESULTS

The training set of BP neural network is a Lenna image with 100×100 pixels in the part of edge detection for the demonstration. Take the edges extracted by sobel as supervisory learning signal. Set the biggest training times is 1000. Data in training process are as shown in Tab. 1.

Tab.1 Training Process Data of BP Network

| Training Times | Error | Training Times | Error |
|---|---|---|---|
| 0 | 4.74761 | 550 | 0.0223019 |
| 50 | 0.0391042 | 600 | 0.0221144 |
| 100 | 0.0314246 | 650 | 0.0218433 |
| 150 | 0.0281959 | 700 | 0.0216827 |
| 200 | 0.026307 | 750 | 0.0215714 |
| 250 | 0.0250886 | 800 | 0.0214989 |
| 300 | 0.0242323 | 850 | 0.0214113 |
| 350 | 0.0236163 | 900 | 0.0213031 |
| 400 | 0.0232005 | 950 | 0.0212343 |
| 450 | 0.0227962 | 1000 | 0.0211621 |
| 500 | 0.0225129 | | |

We extracted edges from feather image and lenna image interfered by white noise whose variance is 10 with the network we designed and many classical edge detection algorithms. Fig. 3 shows Experimental results.

Experimental results demonstrate that Canny and LOG algorithms may obtain a good detection effect, except LOG algorithm always obtain pseudo-edges meanwhile when the image detected is an image with no noise. LOG algorithm obtaining pseudo-edges may relate to its detection method with zero-crossing. Quality of detection with traditional algorithms is declined obviously and LOG algorithm obtains more pseudo-edges operator when the image detected is interfered by noise. However Canny algorithm's effect is very well. We made simulation experiment on images with noise and images without noise with the network we designed. Experiment results demonstrate that the BP network we designed can not only extract useful edges effectively but also accord with visual physiological characteristics better when compared with traditional algorithms.

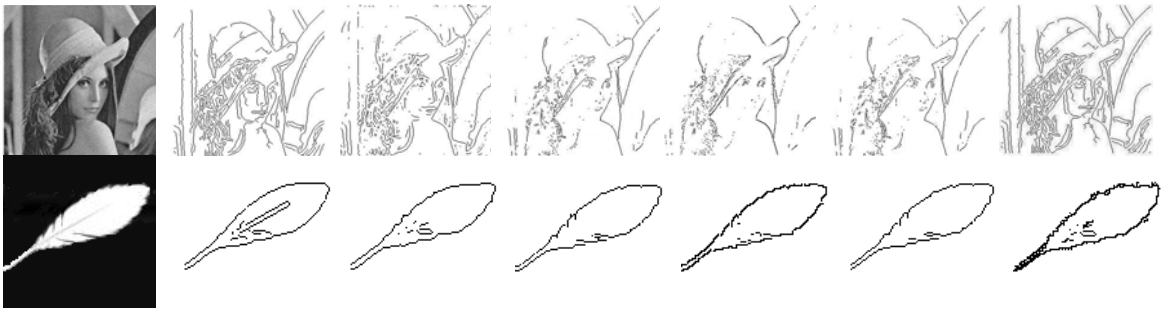



Fig. 3 Experiment Result Images

We detected basic shape from result images of edges detection network with the method stated in article. Experiment Result Images are as shown in Fig. 4. Experiment results demonstrate that it can extract the simplest shape of the object effectively with the method proposed in part of Imagery Extraction.


Fig. 4 Experiment Result Images

Our study realized the imagery concept network with the object-oriented language--C++ which can expand attribute interfaces for concept nodes. We used Visual C++6.0 to realize the development of the program, with SQL Server 2000 as database.

We showed the data stored in the database on the form of network present on running interface and set the demonstration position of every node for the demonstration because code is complex. We trained imagery concept network at first, set $\theta$ is 10. When the network had been trained to the extent, the network is as shown in Fig. 5.

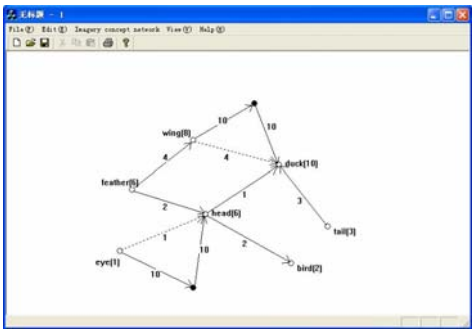



Fig. 5 Network Structure after Trained

The name of node is only the sign which relates to the semantics in the brain, so we present it with words is only for understanding. Number in brackets behind the nodes' name represents the weight of node in the current state. The solid nodes represent the free neurons in MTL. They act as intermediary nodes only and have nothing meaning, so they have no names and no weights.

When the system gains the mental imageries of "the duck" and "the feather", imagery concept nodes which are relative to them are activated. The "the wing" node which connected them together and the relative edges are also activated. Weights of relative nodes and relative edges are all added to 1. The weight of virtual edge between "the wing" and "the duck" nodes is 5 by now. The structure of the network is not changed because the

weight isn't bigger than $\theta$. The operation result of network is as shown in Fig. 6. Nodes and edges which had been activated are highlighted demonstrated. The experimental results indicated that we can realize simple reasoning with the model we constructed.

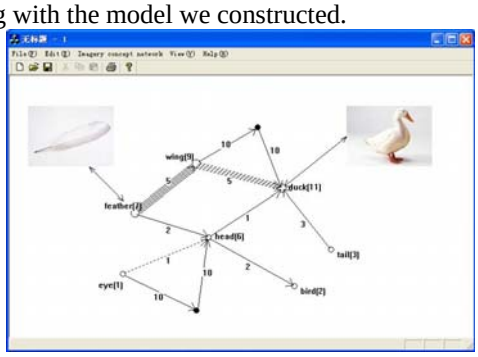



Fig. 6 Operation Result of Imagery Concept Network

## V. Conclusion

The breakthrough of computer simulation of imagery thinking is the simulation of mental imagery's memory mechanisms. In this study, a visual mental imagery memory computer model accord with working mechanism of declarative memory has been constructed. Only a simple reasoning model according to specific aspect of memory and in certain knowledge category can be constructed by now for the complexity of imagery thinking. How to construct more complex imagery thinking model needs further research. The design method and function of the model are described in the study. The experiment results demonstrate, the model can extract contour of target effectively and can realize various operation of mental imagery.

## Acknowledgment

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