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A novel model of intelligent design system and its implementation techniques

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ABSTRACT

A novel model of Intelligent Design System (IDS) is put forward. The speciality of the IDS model is that it can imitate designer thinking with mental imagery. The IDS model acquires design knowledge from successful design examples, and produces preliminary design scheme by pattern association. Apart from rules and facts, the knowledge base of IDS model has pattern–type knowledge and numerical methods. The inference engine of IDS model consists of two parts: logical inference engine and pattern–associator. Theoretical basis of the model is explained. Imitation of thinking with mental imagery by Artificial Neural Network techniques is presented. Implementation example shows that the model has the potential to heighten the intelligent level of intelligent design systems nowadays.

1. INTRODUCTION

Design is a special kind of problem solving, which includes a special kind of thought process. This process is called "Synthesis" by Simon [1,2], which involves logical thinking and thinking with mental imagery. The Psychology study concludes that image is the main knowledge type stored in the human brain [3]. An image can be interpreted decomposively by a large amount of abstract knowledge, which is verified by the proverb that a picture is better than a thousand words. The existing models of intelligent design systems (including know-

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ledge–based design systems and / or expert design systems) are generally logic–based, i.e., they mainly imitate logical thinking of designer. Though fuzzy logic and inaccurate inference are used in most traditional intelligent design systems, they can not imitate designer's thinking with mental imagery. Logic–based models of intelligent design systems have the following problems:

a). the bottleneck of knowledge acquisition;

b). some layers gained by decomposition of problem being solved and even the number of the layers may become indefinite; even if when the layers and its numbers are definite, too many layers will result in "combination explosion";

c). the weak ability of the inference engine because of the too simple inference methods and the unflexible control strategy. This is prone to produce problems such as "matching conflict", "combination explosion", "infinite recurrence" etc.

These problems mean that most existing logic–based intelligent design systems can only solve simple and small–scale design problems. In the authors' opinion, the existing logic–based models only concentrate on the farfetched use of logical inference and abstract knowledge, which deviates from the designer's thinking and decision process. The crux of the deviation is the lack of thinking with mental imagery ability that is the main cause producing the above problems.

A better model of Intelligent design system is required to imitate designer's thinking and decision process. In this paper, the imitation of thinking with mental imagery is considered in a novel model of intellignt design system by applying Artificial Neural Network (ANN) and Pattern Recognition (PR) techniques.

2. LOWS OF THINKING IN DESIGN

C. Alexander [4] in his famous work *Notes on the Synthesis of Form* pointed that the final purpose of design is Form. Form is produced by rule–based pattern language operation. Actually, in the process of producing Forms, human brain not only requires analysis and synthesis based on logical thinking, but also requires a kind of image which is the mapping of the objective world. The productionof the image is based upon thinking with mental imagery.

New research on thinking by H. Yin and R. Dai [5] presented that thinking is the processing of information stored in human brain.

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Fig.1 shows the structural model of thinking presented by Yin and Dai [5].

The information stored in human brain is classified in language, sensation and imaging source.

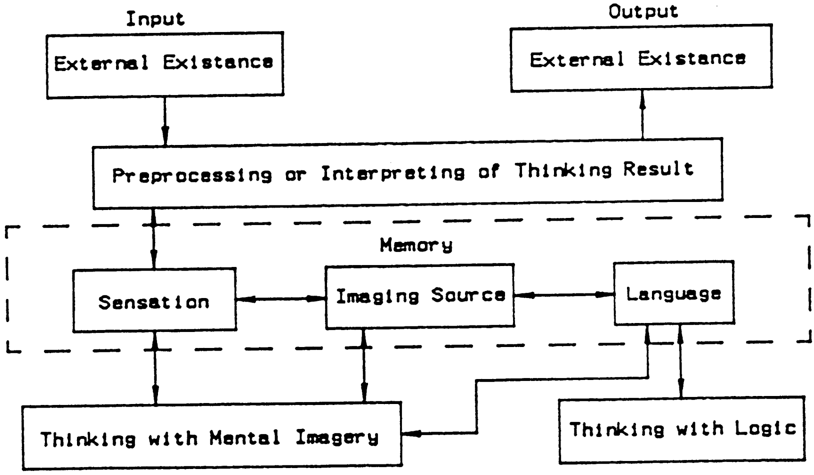

Fig.1 The structural model of thinking

The external existance is mapped to sensation through preprocessing. The preprocessing system represents human's sensation systems such as visual, hearing, taste, smell and touch system. After getting sensation, it is then processed by thinking process, i.e., thinking with logic or thinking with mental imagery. Results of thinking may be represented as sensation stored in memory or interpreted to external existances in order to interchange with the outside.

As is well known, language is the most important information of logical thinking. Here it will not be discussed in detail.

Imaging source is non–language, non–sensation information existing in human brain. For the more, it is the memory of the information which is not transformed from sensation into language. The mapping from sensation to language or from language to sensation involves processing of imaging source.

Pure language operation by rules of language is logical thinking.

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Another sort of operation to sensation, imaging source and language, which is not based on rules of language, is the thinking with mental imagery. Logical thinking is a sort of sequential processing. Thinking with mental imagery is a sort of parallel processing that is synergitic, dynamic, global, indefinite and difficult to express directly.

We generally get an instinctive solution or an assumption to a problem by thinking with mental imagery, then carefully prove the assumption or deeply search the final solution by logical thinking. The two sorts of thinking process can solve problems independently, but usually the two are mutually used. Where we need to make a decision quickly and inaccurately, we use thinking with mental imagery. When we need to prove strictly, we use logical thinking. Only using logical thinking, we can not put forward really new assumptions, and so will not be creative. Only using thinking with mental imagery, we will merely get some superficial or even wrong conclusions.

Thinking in design is a kind of rational thinking [6]. The lows of thinking in design conform to the above expounds.

3. IMITATION OF THINKING WITH MENTAL IMAGERY BASED ON ANN TECHNIQUES

As is known, logical thinking can be imitated by Artificial Intelligence (AI) techniques which are based on symbolic operation. Here, it is unnecessary to discuss about it.

Recently, the rise of ANN study provides an important way of studying and imitating thinking with mental imagery. One of the most influential studies, the parallel Distributed Processing Theory proposed by D. Rumelhart and J. McClelland etc. [7] in 1986, contributed to the exploration of cognitive science.

ANN is capable of adaptive learning, pattern association, and it possesses many features such as robustness and fault tolerance. It is also a large scale adaptive nonlinear dynamic system. The storage and the processing of information are combined into one in ANN systems. The information is stored distributively between the connection of neurons, and is processed by the way of parallel distributed processing.

ANN acquires knowledge from examples through adaptive learning, which frees the knowledge engineer or domain expert from producing large amounts of rules. Knowledge representation is embodied

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in the weight matrix and the topology of the network. Fig.2 shows the model which imitates thinking with mental imagery by means of multilayer feedforward neural network.

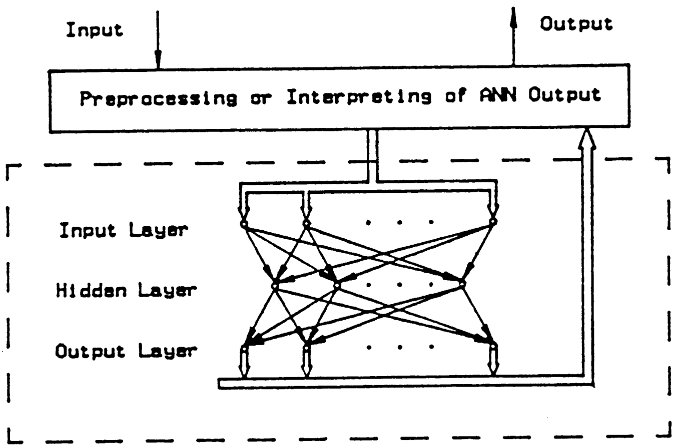

Fig.2 Model of imitating thinking with mental imagery by means of multilayer feedforward neural network

Preprocessing Facility imitates the preprocessing model in Fig.1. The input on the input layer imitates the sensation transfered from external input through preprocessing facility. The output on the output layer imitates the sensation to be interpreted to Forms to interchange with outside. The output of all neurons represent the image of that moment which is a sort of shortterm memory. The weight matrix and the topology of ANN imitate the imaging source which is a sort of longterm memory. The imaging source can represent knowledge which is difficult to express directly, i.e., we can represent very complex knowledge structure by ANN.

The adaptive learning to feedforward neural networks is implemented by learning algorithms such as Back–propagation (BP) method [8] and Learning Rate Matrix (LRM) method [9].

One of the key techniques of ANN–based imitation of thinking with mental imagery is the construction of preprocessing and interpreting of ANN output module. The module must organize examples which can be recognized by ANN, and interpret ANN output to Forms which can interchange with outside. The design of the module

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is problem dependent, and PR techniques are always used to code the input and the output data. Only if the network has learned successfully, it would be able to do pattern association.

4. THE INTELLIGENT DESIGN SYSTEM (IDS) MODEL

The combination of logical thinking and thinking with mental imagery is an inevitable tendency of thinking imitation.

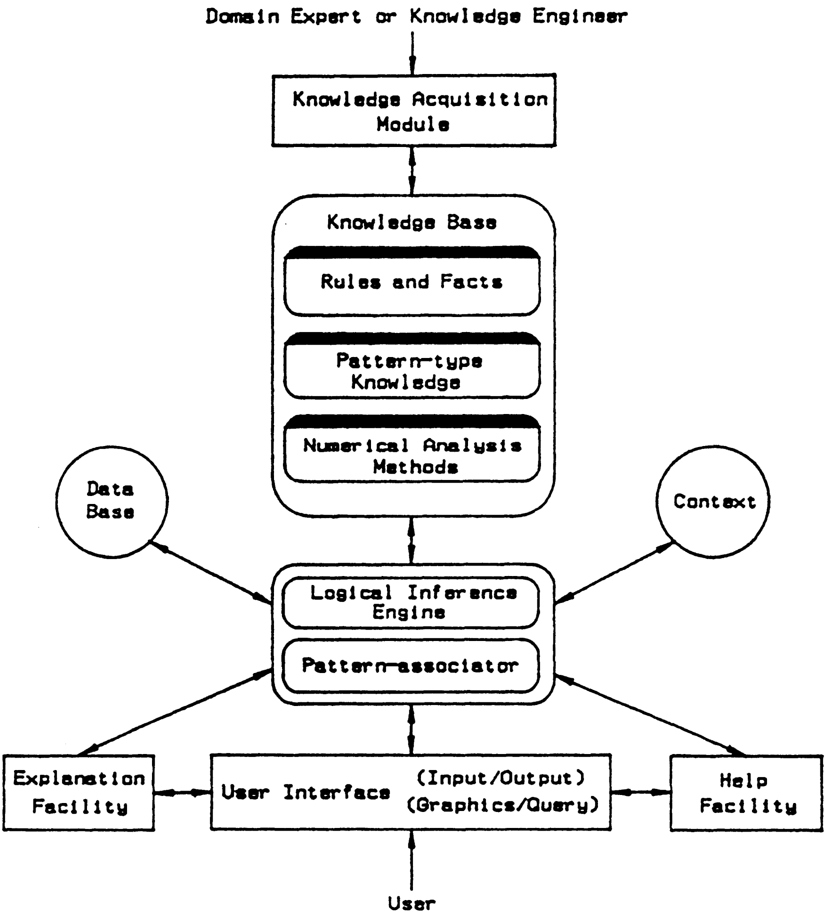

Fig.3 The frame of IDS

The novel Intelligent Design System model named IDS is shown in Fig.3. The IDS model has all modulus that traditional Expert Design System (EDS) has, but the content and the organization of inference engine, knowledge base and knowledge acquisition module of IDS are different from EDS's.

The inference engine of IDS model consists of two parts. The logical inference engine is almost the same as EDS's. The pattern–associator can associate more detailed information from some incomplete, uncertain or even ambiguous feature information. It completes the coding of the key parameters of design requirements and environment of design entity, and the decoding of ANN's output. In terms of the given design requirements and the environment of design entity, pattern–associator can produce an initial design scheme very quickly in the form of an outlined drawing.

The knowledge base of IDS model consists of three parts. The first part is rules and facts. The third part which is utilized to analyze intermediate results or to reach final result is numerical methods. The second part is pattern–type knowledge that supports pattern–associator to make association. The pattern–type knowledge is stored as weight and threshold value and the topology of ANN.

The knowledge acquisition module has the new ability that can learn from examples. That is, the acquisition of pattern–type knowledge is based upon examples which generally are the mapping from the key parameters of design requirement and environment of design entity to the outlined drawing of existing successful designs. These examples must be first coded by pattern–associator, and then learned by ANN. After weight matrices are acquired by adaptive learning, the sensitivity of weight must be analyzed [10]. If the sensitivity is too large, measures must be taken to decrease it [11], otherwise, adaptive learning will be restarted with new ANN topology. Weight matrices with low sensitivity and the corresponding ANN topologies will be stored as pattern–type knowledge.

The initial design scheme produced by pattern association can be modified interactively by the designer and evaluated by using rules and logical inference. The evaluations propose the direction of modification and the system will modify the design scheme under the interaction of the designers. An intelligent interface is also needed to connect IDS with numerical methods.

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5. IMPLEMENTATION EXAMPLE

According to the IDS model, a Structural Design Intelligent System named SDIS used for configurational design of wing box structure of an airplane is developed [12].

Pattern−type knowledge is first learned by ANN−1 and ANN−2 which are three−layer feedforward nets with Sigmoid activation function. ANN−1 has the topology of 9 input neurons, 20 hidden neurons and 4 output neurons. ANN−2 has the topology of 4 input neurons, 36 hidden neurons and 24 output neurons. The learned patterns of 20 existing configurational designs of Fighter's swept wing structure are expressed as follows:

$$[X_p, Y_p], (p = 1, 2, ...20)$$

where, X_p is the pth input vector of ANN−1, Y_p is the pth output vector of ANN−1 and ANN−2.

X_p is gained by normalization of aspect−ratio, taper−ratio, root chord length, average relative depth of airfoil, swept angle, load factor, maximum cruise speed, installation of landing gear, and relative location between wing and fuselage. Y_p is divided into Y'_p and Y''_p. Y'_p, the output vector of ANN−1 and also the input vector of ANN−2, is the code of the type of structural configuration. Y''_p, the output of ANN−2, is the Freemann code [13] of geometric layout of structural components.

On the other hand, SDIS has 165 rules about technological design, structural stability, aeroelastic influence, cost of manufacture, weight of structure and force transmission for airplane wing design.

Giving the Fighter's theoretical outline and flight performence in computerized form, we have got a very satisfying structural configuration by SDIS. SDIS has also been evaluated and used by tens of experts and designers, which proves that SDIS is practical and efficient.

6. CONCLUSIONS

By the implementation of SDIS, we draw that IDS model has the following advantages:

a). Through introducing pattern−type knowledge, the number of rules are greatly reduced, which heightens the inference speed and effectively avoids the combination explosion problem.

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b). The learning of pattern–type knowledge is implemented by the learning of ANN, which can free the knowledge engineer or domain expert from producing a large amount of production rules.

c). With small quantity of internal and external storage resources of computer used, the IDS model can provide designer strong pattern association ability, for the information is distributively stored in ANN.

d). Because the pattern–type knowledge is learned previously, the pattern association is completed very quickly. This is the reason that SDIS produces a new design scheme very quickly.

So, the IDS model has the potential to heighten the intelligent level of intelligent design system nowadays.

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