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# Circular Structure of Conscious Level Processing and Unconscious Level Processing

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## Abstract

Human intelligence has been modeled mainly in two ways: modeling based on central symbol processing, and modeling based on distributed pattern processing. This paper points out limitations of these two approaches, and proposes a hybrid cognitive model of central symbol processing on the conscious level and distributed pattern processing on the unconscious level (C/U model).

The advantages of the C/U model are clarified by explaining the close interaction between the two levels, that is, the circular structure of conscious level processing and unconscious level processing in the knowledge retrieval process. Inductive learning in the model is classified and examined from the viewpoint of conscious and unconscious processing.

## 1 Introduction

Human intelligence has been modeled mainly in two ways: modeling based on central symbol processing (the conventional AI approach), and modeling based on distributed pattern processing (modeling based on network architecture analogous to the neural network) (for example, [1]).

Section 2 clarifies the differences between symbol representation and pattern representation, and points out the limitations of symbol processing and of pattern processing. Section 3 proposes a hybrid cognitive model of central symbol processing on the conscious level and distributed pattern processing on the unconscious level.

## 2 Symbol and Pattern

### 2.1 Differences between Symbol Representation and Pattern Representation

Table 1 shows the differences between symbol representation and pattern representation. There are two kinds of pattern representation: local and distributed. There are three columns: symbol representation, pattern representation (local representation), and pattern representation (distributed representation).

In order to clarify the differences, semantic network is selected for symbol representation. However, the following assertion also holds in other symbol representations: frame, predicate logic, and so on.

The first row shows whether there is one-to-one correspondence between nodes and symbols. Each node in symbol representation and local representation corresponds to a symbol, but each node in distributed representation typically does not correspond to a symbol.

The second row points out whether each node has activity, and whether each link has weight. Symbol representation originally does not have a concept of activity or weight, while pattern representation does.

The third row shows whether there is one-to-one correspondence between links and symbols. Each link in symbol representation corresponds to a symbol, while each link in pattern representation does not.

The bottom row indicates the distinction between central processing and distributed processing. Symbol processing can be either central processing or distributed process-

| | *symbol rep.* | *pattern rep.* | |
|---|---|---|---|
| | | *local rep.* | *distributed rep.* |
| node : symbol | necessarily yes (possibly distributed) | | A no (possibly yes) |
| node : activity link : weight | no (possibly 1/0) | B yes (analog) | |
| link : symbol | yes | no | |
| control | central | C distributed | |

Table 1: Differences between symbol representation and pattern representation

ing (object-oriented programming, for example), while pattern processing necessarily is distributed processing.

### 2.2 Limitations of Symbol Processing

Symbol processing can explain symbolic problem-solving and inference well, but is not sufficient for modeling human intelligence as a whole. Symbol processing is naturally not well suited to perception, recognition, or motor skill. It is difficult to make a correspondence between input/output signals and the concepts that are used by the system.

Boundary A in Table 1 corresponds to this limitation. That is, symbol representation is constrained to have one-to-one correspondence between nodes and symbols [1], and this constraint makes the difficulty in connecting external world and internal representation. Boundary B, that is, whether dynamics of pattern processing is available or not, also relates to this limitation.

Moreover, we suppose that human symbol processing is accompanied by pattern processing on the unconscious level, so pure symbol processing in conventional AI does not fully explain human symbol processing. For example, it is difficult to retrieve contextually appropriate knowledge dynamically.

Boundary B in Table 1 corresponds to this limitation. That is, dynamics (or spreading activation) in distributed pattern processing is suited to contextual retrieval, but symbol representation is not[2].

The bottleneck in knowledge acquisition in building expert systems is a token of the difficulty with purely symbolic modeling.

### 2.3 Limitations of Pattern Processing

Pattern processing can explain automatic sensory and motor skills, and association well. It has the advantages of inherent parallelism, tolerance to faults and noise, and graceful degradation. However, it is not suitable for executing systematic symbol processing: reasoning, planning, and so on.

Boundary C in Table 1 corresponds to this limitation. Although there have been some research attempts (for example [6]) to model human inference based solely on distributed pattern processing, they fail to explain central control by means of distributed pattern processing.

## 3 Hybrid Cognitive Model

Norman et al. proposed a hybrid model of deliberate conscious control and parallel distributed processing [2]. We also suppose that human intelligence is realized by close interaction between central symbol processing on the conscious level and distributed pattern processing on the unconscious level. We proposed the idea of a hybrid cognitive model of conscious/unconscious processing (C/U model) [3, 4].

This section further describes the structure and the function of the model. The circular structure of conscious level processing and unconscious level processing is explained in the knowledge retrieval process. Inductive learning in the model is classified and examined

[1] However, it does not necessarily mean that symbol representation can never be distributed. Symbol representation using microfeatures can be said to be distributed to some extent.

[2] Links in symbol processing can be regarded as having two-valued weight, that is, existence of link means weight 1, and no link means weight 0. Therefore, the essential difference is whether activity and weight are analog-valued or not.

from the viewpoint of conscious and unconscious processing. This section also describes a simulation method that utilizes the characteristics of a parallel logic programming language.

### 3.1 Conscious Level Processing and Unconscious Level Processing

Figure 1 shows the structure and function of the C/U model. The model consists of two closely interactive parts: central symbol processing on the conscious level, and distributed pattern processing on the unconscious level. Both parts are executed in parallel.

On the conscious level, symbols are operated under central control. However, only knowledge which is activated by unconscious level processing can be accessed. It enables efficient execution on the conscious level. For example, people normally are conscious of only one contextually appropriate meaning of a polysemous word, and are not conscious of other meanings of the word. The upward arrow in Figure 1 denotes activation from the unconscious level.

In Figure 1, knowledge on the conscious level is represented in the form of a Prolog program. Conscious level processing can utilize recent memory, which enables backtracking and time sharing. However, recent memory has limited capacity, therefore human backtracking and time sharing is not strict.

On the unconscious level, we assume distributed pattern processing. The functions of this part are processing of input and output signals, that is, perception, recognition, and motor skill, and associative retrieval of contextually appropriate knowledge.

Unconscious level processing goes on receiving activation from the external world, and according to the weights of the connections which reflect the statistical properties of past processing. Conscious processing can fix attention in unconscious processing. It enables efficient and systematic execution of unconscious processing. The downward arrows in Figure 1 denote attention from the conscious level.

On the unconscious level of Figure 1, p, q, and r are nodes, each of which corresponds to a symbol; other hatched nodes do not correspond to symbols individually. In Figure 1, there are nodes which locally correspond to symbols, however, these locally represented nodes can be eliminated by directly connecting symbols on the conscious level to nodes which were connected to eliminated nodes. We can therefore regard the representation as being equivalent to distributed representation.

### 3.2 Circular Structure

This section further explains close interaction between conscious level processing and unconscious level processing, that is, the circular structure of both the processings.

We consider knowledge retrieval process as an example. Williams et al. [8] made experiments on retrieval of names of high school classmates on people who graduated from high school between 4 and 19 years ago. They regarded this kind of retrieval as a kind of problem solving process, which consists of three stages: setting up a context for search, search, and confirmation of the retrieved result. They also showed that these processes occur recursively.

We believe that this kind of knowledge retrieval process is both systematic and associative. It can be modeled as a combination of central symbol processing on the conscious level and distributed pattern (or associative) processing on the unconscious level.

Conscious level processing and unconscious level processing constitute a circular structure. A context for search (or attention) is decided on the conscious level. Then, according to the context, spreading activation occurs on the unconscious level. Then one of the activated knowledge items is retrieved to the conscious level. Then the retrieved knowledge is confirmed and the next context for search is decided on the conscious level.

Retrievals can be either on final objects, on contexts for search, on search strategies, or whatever. These retrievals constitute a multiple circular structure.

### 3.3 Inductive Learning

Inductive learning can be achieved by acquisition of either explicit knowledge (knowledge in symbol representation) or implicit knowledge (knowledge in pattern representation). These two types (explicit inductive learning and implicit inductive learning) should be distinguished in modeling inductive learning.

Both explicit knowledge and implicit knowledge are important in human information processing, so both types of learning are essential to human intelligence.

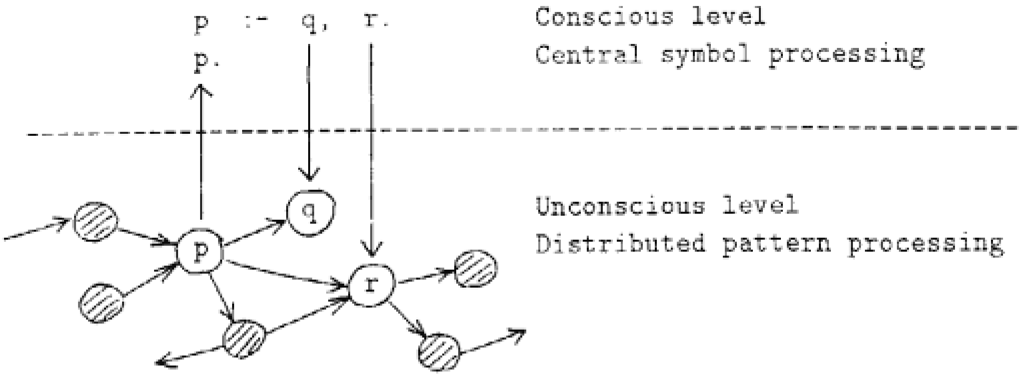


Figure 1: Structure and function of the C/U model

#### 3.3.1 Explicit Inductive Learning

For example, explicit inductive learning includes making explicit rules for classification from given examples, such as making grammar rules for a natural language.

Explicit inductive learning has been studied in conventional AI with little success, because it is very difficult to extract appropriate features for making explicit rules in purely symbolic processing.

In the C/U model, explicit inductive learning can be modeled using the circular structure of knowledge retrieval process, which is described in the previous section. The objects of retrieval are the features necessary for making explicit rules which classify given examples. They are retrieved efficiently utilizing multiple circular structure of the conscious level processing and the unconscious level processing. The rules which contain the retrieved features are constructed and tested on the conscious level.

#### 3.3.2 Implicit Inductive Learning

For example, implicit inductive learning includes acquisition of one's native language, acquisition of natural concepts, and so on. The correspondence between symbols on the conscious level and patterns on the unconscious level is acquired by implicit inductive learning, too.

Implicit inductive learning has been studied in the neural network approach (or connectionism). The problems with this approach are the necessity for a huge network and for a long learning time.

In the C/U model, attention from the conscious level enables efficient learning on the unconscious level.

#### 3.3.3 Transfer to Unconscious Level Processing through Experience

Distributed pattern processing on the unconscious level is much faster than central symbol processing on the conscious level. However, learning through experience is necessary for pattern processing on the unconscious level.

The following is a model of transfer from conscious level processing to unconscious level processing through experience. At first, there is no implicit knowledge for a task. If explicit knowledge for the task is presented, the task can be done on the conscious level. Learning on the unconscious level progresses as the task is repeated using the explicit knowledge. The learning is accelerated by attention from the conscious level, and the attention can be decided using the explicit knowledge. After implicit knowledge is learned, the task can be done automatically on the unconscious level.

### 3.4 Simulation in a Parallel Logic Programming Language

This section describes a simulation method that utilizes the characteristics of a parallel logic programming language, Guarded Horn Clauses (GHC) [7].

In GHC, two programming styles can be used: process-oriented programming and message-oriented programming. In process-oriented programming, processes are called successively and they are normally not suspended. In message-oriented programming, processes are usually suspended and the message flow is noticed.

Process-oriented programming is fit for describing central symbol processing on the conscious level. Although message-oriented programming is originally fit for distributed symbol processing, it can be used for simulating distributed pattern processing.

A template of the program which simulates the C/U model is shown below. In GHC, we follow the syntactic convention that begins variables with uppercase letters. In the following templates of programs, most arguments are omitted for simplicity.

```
mental_processes( ):- true|
  symbol_processing( ),
  pattern_processing( ).
```

This clause says that symbol processing on the conscious level and pattern processing on the unconscious level are executed in AND-parallel.

A template of clauses which represent symbol processing is as follows:

```
head( ):- State1=active|
  goal11( ),...,goal1n( ).     (1)
head( ):- State2=active|
  goal21( ),...,goal2m( ).     (2)
...                            ...
```

State1 and State2 are variables which denote the activity of each clause, (1) and (2). Instantiation of each variable by pattern processing means that each clause becomes active. If the variable is not instantiated, execution of the guard goal is suspended.

An example of clauses which represent pattern processing in the C/U model is partly shown below. A node in the network is represented by a process in program, and spreading activation is represented by interprocess communication.

```
process(In1,In2,Out1,Read,Activity):-
  In1=[fire|Tail]|
  calculate(Activity,NewActivity),
  set_Out1_if_necessary( ),
  process(Tail,In2,Out1,Read,NewActivity).
process(In1,In2,Out1,Read,Activity):-
  Read=[State1|Tail],
  Activity>=threshold|
  State1=active,
  process(In1,In2,Out1,Tail,Activity).
...
```

The process programmed here has two input streams, In1 and In2, and one output stream, Out1, for interprocess communication. The process has a corresponding clause, (1), for the symbol processing shown above. The activity of the process can be read through a stream, Read. The first clause of the program means that if the In1 stream is instantiated, that is, if the process which is connected through In1 fires, then NewActivity is calculated, and so on. The second clause shows that if a message comes through the Read stream, and the process is active, then variable State1 in the message is instantiated. Variable State1 is used for judging the activity of clause (1) as shown above.

## 4 Conclusions

We proposed a hybrid cognitive model of central symbol processing on the conscious level and distributed pattern processing on the unconscious level (C/U model). We clarified the advantages of the model by explaining the circular structure between the two levels, and by explaining inductive learning in the model. We are planning to make simulation programs of middle size in some example problems.

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