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A Model of Integrated Information Processing Mechanism for Human and Computer Based on Cooperative Functional Modules

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SUMMARY

Combining the human and the computer to form an information processing system, an integrated model is constructed. This paper proposes, as a practical model for such an integrated information processing mechanism, a hierarchical network model composed of cooperative functional modules. As examples of such a model, a cooperative functional module model for the visual pattern recognition and symbolic inference in human problem solving, as well as the cooperative functional module model for the interactive processing of Japanese language are discussed. Then the integrated man-computer functional module model is discussed from the viewpoint of matching/nonmatchings among various component modules.

1. Introduction

With the rapid progress in computer technology, the design problem for the knowledge interface is considered to be important. The treatment of this problem, however, should depend on human information processing in operating the computer. In such a problem, the high-level recognition human mechanisms, such as memory, thinking and language, must be considered. Those objects are entirely new to most engineers, and contain a large number of aspects which are difficult to handle by the traditional engineering approach. Hence, no significant result has been observed which is precise and theoretically transparent, even though such problems have often been discussed.

The author and his colleagues have been studying man-machine relations, especially man-computer information processing mechanisms, for the past decade. They did not aim directly at the design of user-friendly interface, but at modelling mechanisms for high-level human information processing [1]. But the studies are consistent in the sense that the human and the computer are interpreted as a part of the integrated information processing system. The ideas obtained in the course of study can essentially be useful in the design of interfaces which are easy to use.

The first part of this paper proposes a model which describes the human information processing mechanism as a set of cooperative functional modules. An example is presented which is the problem-solving viewed as an information processing model. Until now, such a model has been validated gradually as a conceptual interpretation by studies in neurophysiology for localization of brain functions, and in cognitive psychology and neuropsychology for cognitive information processing. However, if an integrated man-computer information processing mechanism should be considered in such a direction, there must be constructed a precise computational model for the human information processing, based on the idea of functional modules. Little progress has been observed using this approach. The model described in this paper is the first step toward such a goal.

The second purpose of this paper is to discuss the model describing the cooperative information processing of the computer as a set of functional modules. The interactive Japanese processing system is considered as an example. The reason for this is as follows. The interactive process includes a number of functions concerned with the intelligent information processing by computer, such as interpretation and generation of

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sentences, knowledge and inference, generation and transformation of goals, etc. The interactive process includes such aspects and proceeds by the functional cooperation between the system and the user.

Third, this paper considers the cooperative functional module model of the man-computer integrated information processing model based on the result of the forementioned two investigations. The cooperative functional module model for the integrated man-computer information processing mechanism is considered, and the information processing abilities of various component modules and the matching/nonmatching problem among those are discussed. By the matching of the information processing ability is meant that the two modules have the same order of abilities, and by nonmatching is meant other situations (the definition for the information processing ability is to be given later). At the end of this paper, several problems which are not discussed in this paper are described briefly.

2. Functional Module Model for Human Information Processing Mechanism

2.1 Structure of cooperative functional module model

As to the human information processing mechanism, at least the following three levels are considered at present in its description:

(1) neural network level;

(2) cognition function level; and

(3) behavioral level

The author believes that these three levels are not independent; (2) should be placed above (1), and (3) should be placed above (2) in the description. At present, however, there are few studies which attempt to bridge these levels. Consequently, the problem is restricted to the cognitive function in this paper, and a model for the human information processing mechanism is proposed at level (2). The feature of this level is that the object of description is an abstract entity which is the cognitive function. In its description, consequently, it is necessary to introduce the result from a theoretically established field such as the theory of computation.

As the model for the human information processing mechanism at the cognitive function level, a hierarchical network model of the cooperative functional modules is considered. When seen at each level, the model is a network structure of the modules. When seen vertically, the model has a hierarchical structure. It is a dynamic model operated by the cooperation among modules at the same level. The model is illustrated in Fig. 1, where the modules at the top level network can be the cognition, emotion, intention, and Kinethesis/sensory function modules. These modules may be cooperating in their operations at the top level of the human information processing.

At the lower levels of the cognition module, perception, memory, inference and language modules are connected. They form the network at that level and cooperate in their operations. Furthermore, at levels down the perception module, for example, there are visual, auditory, tactile, and other perception modules, which form a network. At levels down the visual perception module, there exist form, motion direction, depth, color and other perception modules, forming a network structure of cooperative modules.

The information processing model shown in Fig. 1, is called the cooperative functional module model of the human information processing. Each module in this model can be considered as one or more computation procedures. The form perception module at a lower level of the visual perception module, for example, is a computational procedure, which receives the visual information input transformed in the pathway from the retina to the visual field through the geniculate body and produces the output as the form of the object.

For the individual modules at levels lower than the visual perception and the kinesthesis/sensory motor function modules, the relation between the neural network, and the cognitive function levels, among three levels [1-3] described previously, is now relatively well understood. For example, the cells in the rear parietal part correspond to the form perception module, and it is indicated that only the form perception is made, independently of the size of the object [2].

An example of the network connection at the upper level is the connection between the memory module and the motion module. Bower et al. [3] reported that information is easier to be retrieved if the emotion at that time is similar to the emotion (called mood by Bower et al.) when information is memorized. This suggests that the memory and the emotion are cooperating in their operations. In relation to this fact, it has recently been reported in neurophysiology that brain cortex, especially the pineal body, is concerned with both memory and emotion.

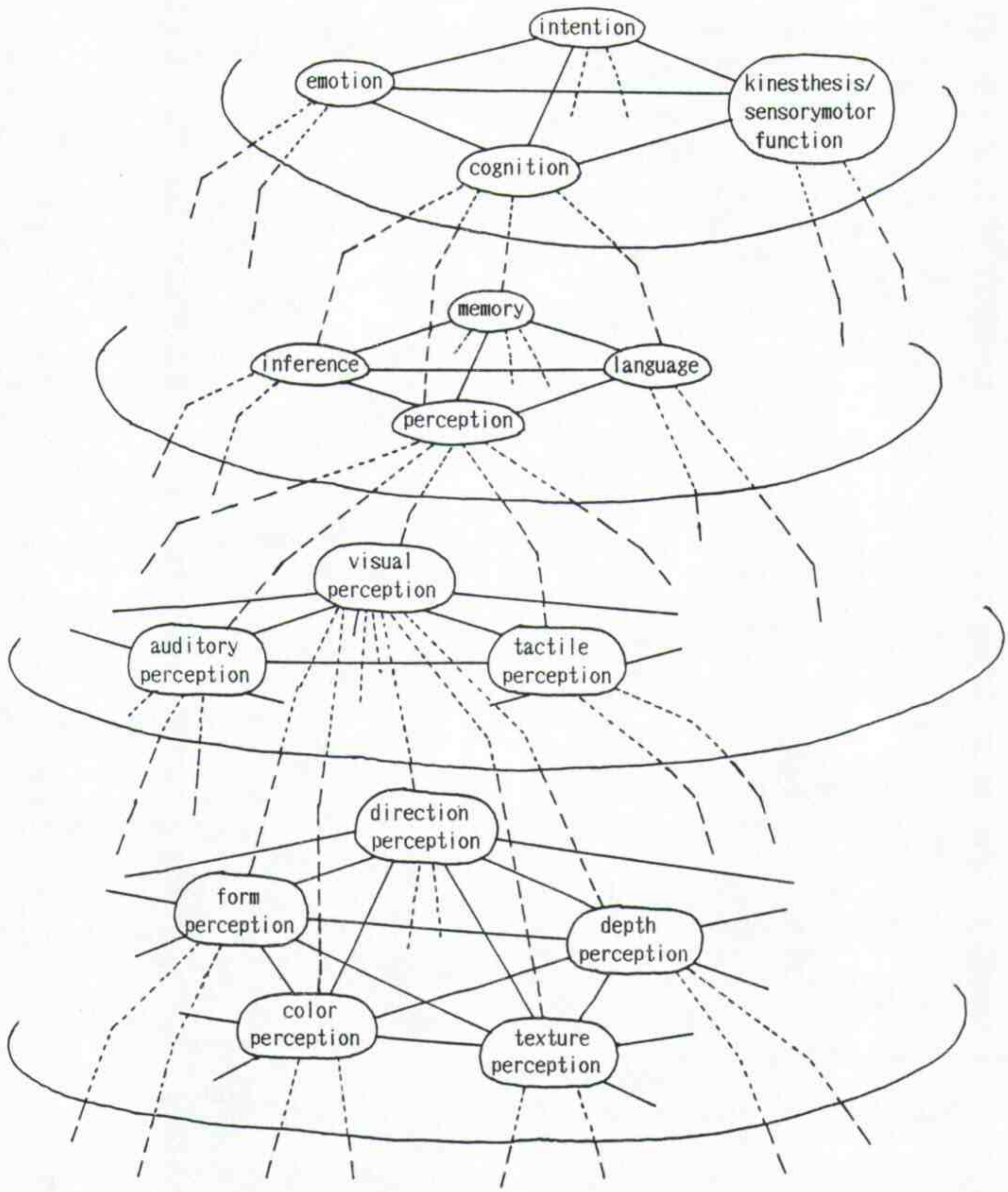


Fig. 1. Cooperative functional module model of human information processing (each node denotes a functional module).

One of the ideas close to the forementioned functional module model is Minsky's theory of "society of mind" [4]. In his theory, a hierarchical network model composed of modules (called agents) is considered. It is a conceptual model with functional division of modules according to various metaphors concerning human information processing. The schema model by Toda [5] is also a cognitive conceptual model for cognition based on various modules and their interactions. Such conceptual models are very important in refining the understanding of human information processing.

From the authors' viewpoint, however, a common problem of those models is that they are not proposed as computational models, making it difficult to realize a matching with the computer. The models are still insufficient as integrated models for the man-computer information processing mechanism. On the other hand, the models proposed herein can be formulated as a computational model, although the range is still limited. In the following, an example is considered to illustrate the functional module model which is proposed here as a computational model.

2.2 Functional module model for solving series extrapolation problem

As pointed out in the previous subsection, there has been little study on the human information processing mechanism based on the functional module model as a detailed computational model. In the following, a model for the information processing mechanism is described for the problem-solving by the cooperation of the visual pattern recognition modules and the symbolic inference module.

2.2.1 Pattern recognition module and inference module

The visual pattern recognition process of the object has the following features: processing is fast; computation is performed in parallel; and the process is sensitive to the subject structure. On the other hand, the symbolic inference process has the following features: processing is slow; computation is serial at least at the macro-level; and the processing has the robust property that the objects with slightly different structures can be represented by the same symbols. The visual pattern recognition and the symbolic inference with those features may be considered as independent, as the functions of the brain. The cooperation of those two modules, however, is needed at least in solving considerably complex problems, which are of interest to the human activity.

As an hypothesis, a model is considered in which the pattern recognition module and the inference module cooperate to perform an integrated information processing. The module corresponds to the second level from the top in the cooperative model of Fig. 1. Three problems are important in this model: (1) What does the pattern recognition module? (2) What does the inference module? (3) What information is transferred and in what ways between the two modules?

It is assumed that the role of the pattern recognition module is to transform the received external information into symbols. On the other hand, it is assumed that the function of the inference module is to transform the obtained symbols into other symbols following certain rules. Finally, it is assumed that the information is transmitted in the form of symbols, and the two modules work independently, utilizing the information from the other at any time.

2.2.2 Series extrapolation task

To discuss the hypothetical model mentioned in the previous section using an example, a problem-solving task, called series extrapolation task, is considered in the following. The series extrapolation task is the following problem, for example.

"Given a string ax bx cx dx_, determine the letter to be placed in _."

In solving such a problem, the period of the series is usually assumed. The correctness of the assumption is determined by examining the regularity of the letters at the corresponding positions in regard to the period (the position of bold-face letters in **a**x|**b**x|**c**x|**d**x|_ or a**x**|b**x**|c**x**|d**x**|_ in the foregoing example. If the regularity does not apply, the assumption about the period is altered, and the examination is iterated. If the regularity of the series is determined by the test, a rule is generalized to arrive at the solution by extrapolating the series based on the generalized rule.

Thus, to solve the series extrapolation task, a symbolic inference is required, such as hypothesis testing and concept induction. For symbolic inference to work effectively, there must be a process which visually recognizes the pattern in the series. In the forementioned example of ax|bx|cx|dx|_, a pattern should be recognized wherein the same object x is placed at regular intervals. Then it is utilized in the inference.

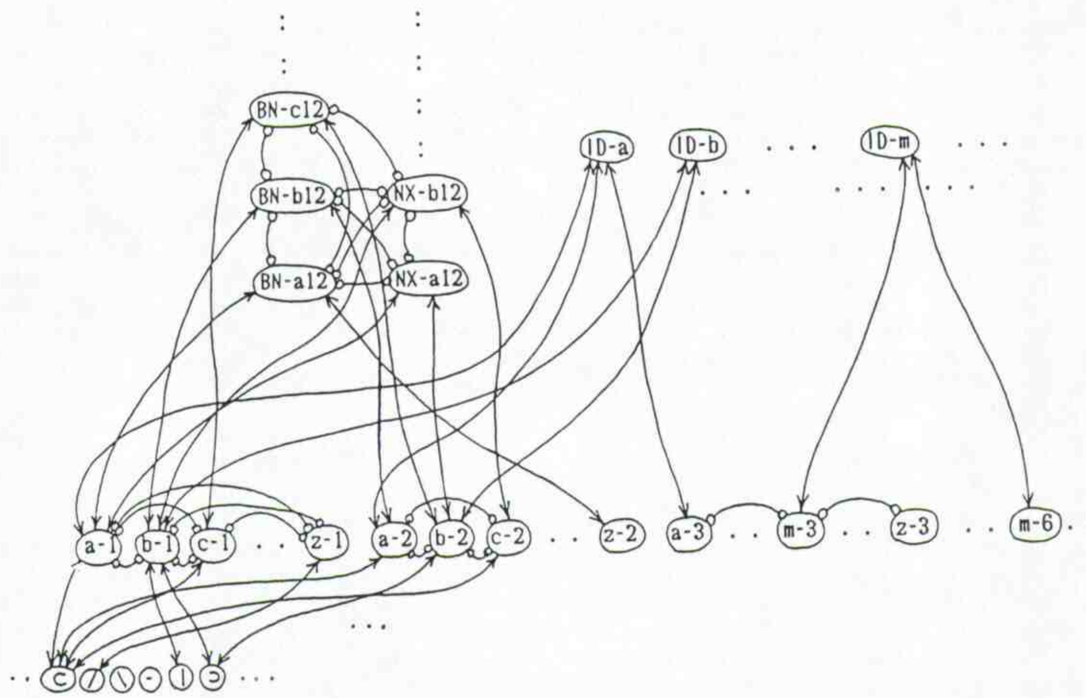
The pattern recognition module symbolizes such a pattern and sends it to the inference module. The inference module makes symbolic inference based on that symbol. The symbol anticipated to be placed at a certain position by the inference is sent to the pattern recognition module. The pattern recognition module utilizes such a predictive information in the control of attention in the recognition and to dissolve the ambiguity in the pattern recognition. Such a cooperative process between modules corresponds to the problem-solving process of the series extrapolation task.

2.2.3 Functional module model

Anzai [6] constructs the computational model using the theory of computational complexity and the production system. He analyzed the experimental data [7] and supported the validity of the forementioned cooperative functional module model.

Based on those preliminary studies, a large-scale cooperative functional module model was constructed for solving the series extrapolation task [8]. The properties of the module described in Sect. 2.1.2 are considered, and the model utilizes the neural network model for the pattern recognition module, and the model based on the set of microinference rules is used as the inference module [9].

The model is a program written by the knowledge representation language OPHELIA [10], constructed for object-oriented computation. The program is implemented at



(a) Module for visual pattern recognition

start

_____ponon<u>m</u>nml_

initial attention

<u>pononm</u>nml_

BN-p12, BN-o23, NX-n34, BN-o45, ID-o and ID-n are activated.

BN-p123 is activated.

ID-n is eliminated since 'n' does not span with equal distance.

Period length is hypothesized as 2 based on ID-o.

attention is moved forward

po<u>nonmn</u>ml_

ID-o is eliminated since 'o' does not span with equal distance.

attention is moved back

<u>ponon</u>mnml_

Period length is hypothesized as 3 based on BN-p123.

attention is moved forward

pon<u>onmnm</u>l_

BN-o456 and BN-n789 are activated.

(BN-o45, ID-n, ID-m or others are not activated because of CPM's prediction)

attention is moved forward

ponon<u>mnml_</u>

Relation is verified.

Extrapolate and find the solution.

(b) Process of series extrapolation problem solving
(Underlines denote the visually attended ranges)

Fig. 2. Process of extrapolating the series ponomnml_ by the cooperative functional module model for series extrapolation problem solving [8].

present on VAX11/750. In this program, each node of the neural network in the pattern recognition module as well as the microinference rule in the inference module are defined as the object in OPHELIA. The communication among nodes or modules is performed in the form of message passing among objects.

In the information processing of the model, the inference module performs the hypothesis testing type inference using the microinference rules. In that case, it controls the attention of the pattern recognition module so that the ambiguity of the recognized pattern is dissolved and the pertinent symbol is generated. On the other hand, the pattern recognition module generates the symbols by propagation of the activation level in the neural network, while controlled by the inference module.

The control of attention in the pattern recognition module corresponds to the eye movement in the human behavior level. In correspondence to the range of attention and the eye movement in the visual system, it is assumed that the number of letters viewed at one time, i.e., the range of gaze, is limited in the model. The range of attention is moved to the left or right by the control of the inference module. The motional aspects of the eye movement, however, are not considered fully in this model. Figure 2 shows the extrapolation process in this model for pononmnml_. In the case of Fig. 2, the range of gaze is limited to five letters, which can be moved horizontally by the inference module.

The forementioned model is a representation within the framework of problem-solving by cooperative functions between the human visual pattern recognition and the inference ability, as was described in Sect. 2.1. The module is considered as a basic one for the information processing mechanism of the user at the interface, from the aspects of the visual perception and the inference.

3. Functional Module Model for Intelligent Information Processing Mechanism of Computer

3.1 Cooperative functional module model for computer information processing

This subsection describes the functional module model for the intelligent information processing of the computer. Typical such a model is the object-oriented computational model, which has already been reported [11]. However, the model deals primarily with problems in computer science and engineering. There has been little study aiming at the construction of the functional module model for the intelligent computer information processing mechanism, aiming at the study of man-computer integrated information processing mechanism.

In the following, the cooperative functional module model for the interactive processing of the natural language is described. The system "Mr. Guide" described as an example, is an intelligent consulting system which provides the tourist information service of Sapporo, Japan through interactive processing of Japanese dialogue. The present version is implemented on the workstations of Sun 2 and 3, as a program of approximately 15,000 steps written by Quintus Prolog and C.

3.2 Functional module model for natural language interactive process

Consider the interactive processing by computer. It is adequate to consider that the interactive process is performed by the cooperation of several information processing functions. The input information from the user in the interactive process is the linguistic and auditory information such as letter, intonation, pitch and sound intensity, as well as the visual information such as countenance, visual line and gesture. First, the interactive processor system must have the functional modules which process individually those input information data. The existing interactive processing systems, including the one in this paper, however, can handle only a limited number of such information channels.

The output information from the interactive processing system to the user can also be divided into various linguistic-auditory information and visual information as in the case of the input.

The system must also have various internal modules. They are the functional modules to integrate various forms of information and generate higher-level information, as well as the functional modules to determine which part of the higher-level information should be transformed to generate the output information.

Which of these modules should actually be considered depends on the goal of the model constructor, as in the case of the module for human information processing discussed in Sect. 2. In the following, the interactive processing system presented here is discussed as an example of the functional module model of the interactive processing.

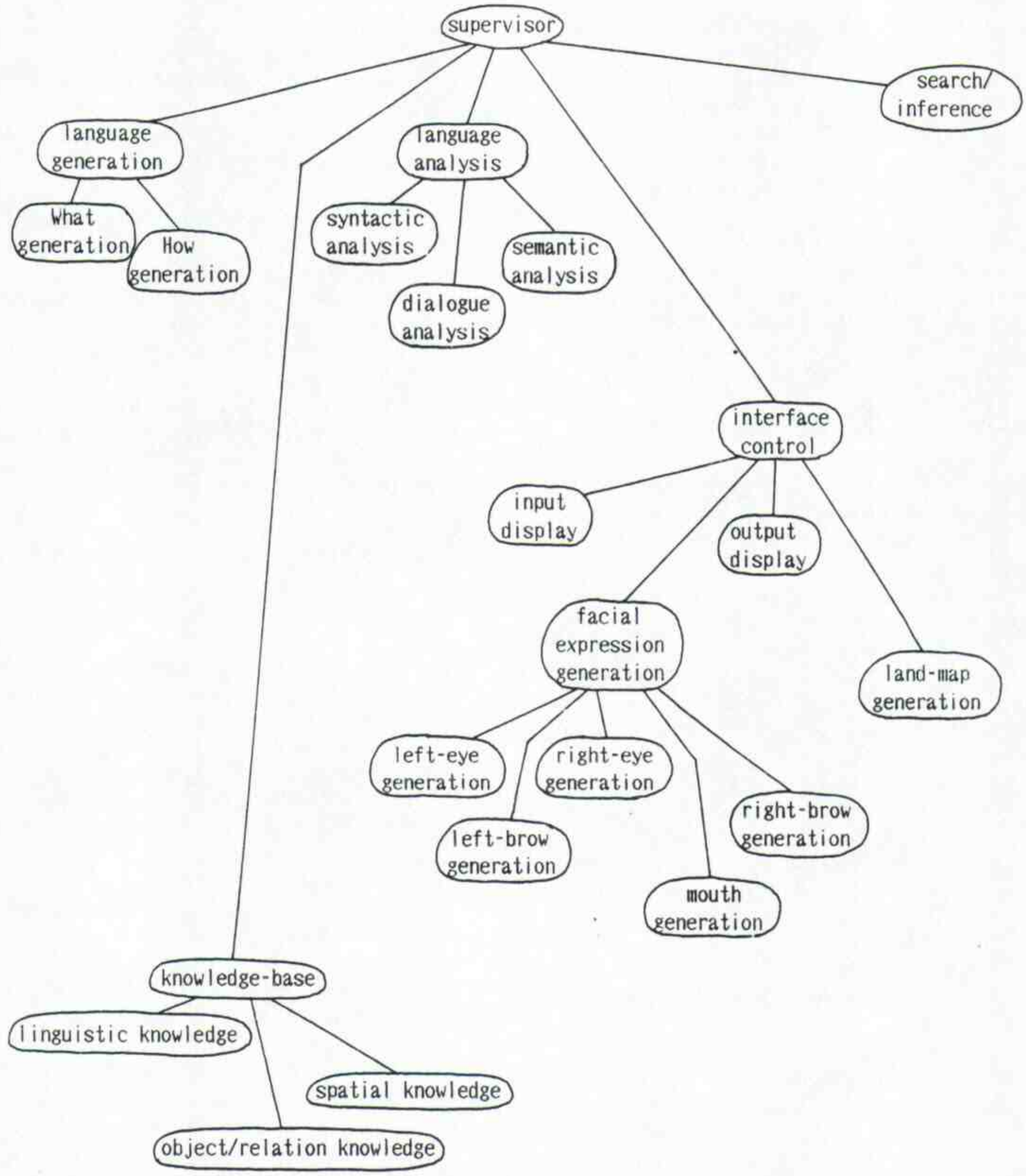


Fig. 3. Cooperative functional module model of Japanese dialog processing by computer [12] (each mode denotes a functional module).

3.3 Interactive Japanese processing system "Mr. Guide"

The example described in the following is an interactive Japanese processing system which provides the tourist information service in the city of Sapporo. The input information in the interactive processing is the Japanese sentence given by the user through the keyboard. The output information is the Japanese sentence, facial expression and land-map.

At the macro-level, this system is composed of six functional modules shown in Fig. 3, which are supervisor, language analysis, language generation, search/inference, interface control and knowledge-base modules. Among those, the supervisor module works for planning of the interactive operation and the management of the whole operation. These functions are executed by transmitting the instructions and queries to other modules in the form of messages [12].

The language analysis module has lower-level modules, which are syntactic analysis, semantic analysis and dialog analysis modules for the input sentence from the user. Among those, the syntactic analysis module has still lower modules, which are syntactic element analysis and the phrase structure analysis modules [13]. The semantic analysis module transforms the semantic case structure [14] discussed by Toda into modified semantic cases. The dialog analysis module further transforms the result into the common semantic cases, which are used by the supervisor in the interpretation of the user goal.

The language generation module has two lower modules. One is the what-generation module, which determines the semantic case structure (i.e., determines what should be said); the other is the how-generation module, which generates Japanese sentences (how it should be said) [15].

The search/inference module has the inference function, which was specially designed so that the system can efficiently perform the tourist guide. It performs the inference, for example, to search for the route on the map, to determine the route, and to determine the relation between the objects on the map [16].

The interface control module has the following lower level modules. The input display module displays the input sentence from the user. The output display module displays the output sentence generated by the language generation module. There are also provided the land-map generation and the facial expression generation modules. Except for the input display module, those lower-level modules perform not only the display, but also the procedures, including the generation of the graphic data for displaying information and the control of the display window. By the facial expression in this procedure is meant the female facial expression, which corresponds to the present internal state in regard to the system goal for providing information, such as the extent to which the goal has been achieved [16].

The facial expression generation module, for example, receives the instruction as to what expression should be displayed, from the supervisor through the interface control module. It then generates the graphic data for the corresponding facial expression and displays the face based on the result. The facial expression generation module refers to the knowledge-base concerning the shape of the mouth for iroha (Japanese alphabet) 48 characters, and adjusts the shape of the mouth synchronously to the display of the output sentence produced by the language generation module [16]. There is thus provided a cooperation at the level of the facial expression generation and the language generation modules. The facial expression generation module has still lower level modules which deal with facial elements such as (each) eye, (each) eyebrow and mouth. Facial expressions are generated by the cooperation of those lower-level modules.

The land-map generation module also has additional functions other than the simple display of the specified map. It receives the information for the region which is considered in the course of interactive operation from the supervisor through the interface control module. The map restricted to that region is generated dynamically by referring to the coordinate data in the knowledge-base, and the result is displayed [16]. The inference for the region considered in the interaction is made by the supervisor, search/inference and knowledge-base modules.

The modules at the lower level of the interface control module are implemented so that they can be run as parallel processes in the UNIX environment. The knowledge-base module contains the following knowledge. The grammatical and dictionary knowledge for language analysis and generation, the knowledge concerning the coordinate on the map (called location knowledge), and the symbol knowledge such as the names of regions, and landmarks and buildings.

3.4 Man-computer interaction as cooperative information processing

The structure of the functional module described in Sect. 3.3 is based mostly on the hierarchical structure controlled by the supervisor module, as shown in Fig. 3, rather than the cooperation at the same level. In this regard, the modular structure of the proposed system differs considerably from the module structure of the human information processing shown in Fig. 1. In "Mr. Guide," especially, only one supervisor module forms the top level of the hierarchical structure, and no loops exist to control that module. Such a hierarchical structure is a feature, which to some extent, is common to the present computer system.

By contrast, the series extrapolation solving model described in Sect. 2 is a cooperative system, where the mutual control is effected among the modules at the same level. The latter may seem more general from the viewpoint of the cooperative functional module model.

On the other hand, one may argue that "Mr. Guide" is more general in the sense that there is an interaction between the system and the external world (user in this case). In other words, viewing the interactive model between the system and the user as a single system, the system and the user can be regarded as the functional models at the top level, and the interactive operation can be regarded as the integrated man-computer information by their cooperation.

4. Man-Computer Integrated Functional Module Model

4.1 Integrated functional module model

In Sect. 3, the interactive model for man-computer cooperation was discussed as an example. It is suggested that the integrated man-computer system can be modeled by cooperative functional modules. This section generalizes the forementioned idea for the interactive cooperation, and discusses the integrated model for man-computer cooperation, especially from the viewpoint of the information processing abilities of the component modules.

The hierarchical network model of Fig. 4 is considered for the cooperative function model for man-computer cooperation. This model is actually a combination of the models in Figs. 1 and 3. As is shown in Fig. 4, the top level is composed of the user module and the system module, where the two modules control each other.

Each of the two forementioned modules has the hierarchical network structure composed of the cooperative functional modules. The user module, for example, has the modular structure as was described in Sect. 2.1. The system module can be considered as having the modular structure described in Sect. 3.3, at the macro-level concerning the linguistic processing and visual display. What is important here is that there are some modules or some lower-level modules which have direct communication channels with the lower-level modules of the user module. For example, the output for the lower-level modules concerning the visual display in the system module, is the input to the visual module at the lower level of the user module.

4.2 Information processing ability of module

This subsection discusses the information processing abilities of the component modules in the integrated functional module model described in the previous subsection. The information processing ability of the module is defined by the kind of processed information, the amount of processing, and the processing speed. By the amount of processing is meant the amount of information processed in unit time, and the processing speed is defined by the time required to convert the input into the output. These definitions and the data discussed in the following are very crude, but are sufficient for making relative the module information processing abilities.

Consider the user module, for example. The information to be processed in the visual module is the multidimensional pattern at some higher level, such as the data at sensation level, direction of motion, form, color, and texture. The amount of processing is of the order of 10^6 bit/s, and the processing speed is of the order of 10 ms. In the linguistic module, the information to be processed is the one-dimensional pattern. The amount of processing is of the order of 10 characters/s, and the processing speed is of the order of 100 ms.

In the system module, on the other hand, when "Mr. Guide" is operated on a computer of the CPU speed of 2 MIPS, the kind of processed information is the two-dimensional bit pattern, the amount of processing is 10^5 bit/s, and the processing speed in the map display module is of the order of 10 s. The language analysis module processes the one-dimensional string with the amount of processing being 100 character/s and the processing speed of 0.5 s.

Thus, the information processing ability of the module corresponding to the human function can be estimated based on the neurophysiology and the cognitive psychology, and that of the module for the computer can be estimated based on the data from computer engineering.

4.3 Matching/nonmatching of information processing abilities

When the information processing abilities of the modules composing the man-computer integrated model are determined, the matching/nonmatching of module abilities can be discussed so that the system as a whole operates satisfactorily. Consider first the user model. To fully utilize the ability of the user model, the lower-level modules should be designed so that they can be run in parallel and independently, as far as possible.

It is known, for example, as a result of psychological experiments, that there exists an interaction between the auditory and vision modules for language. Consequently, there must be an elaboration in receiving the input information from the user so that the input information does not reach in parallel the ear and the eye of the user. As to the vision and the kinesthetic modules, on the other hand, there exists an interaction at lower-level modules related to the eye movement, but the two modules are independent in most other parts. Consequently, it is not a great burden to the sound user, for example, to operate a foot pedal while receiving visual information from the eye, as is seen in the case of playing a piano. When the user is to handle a computer, a

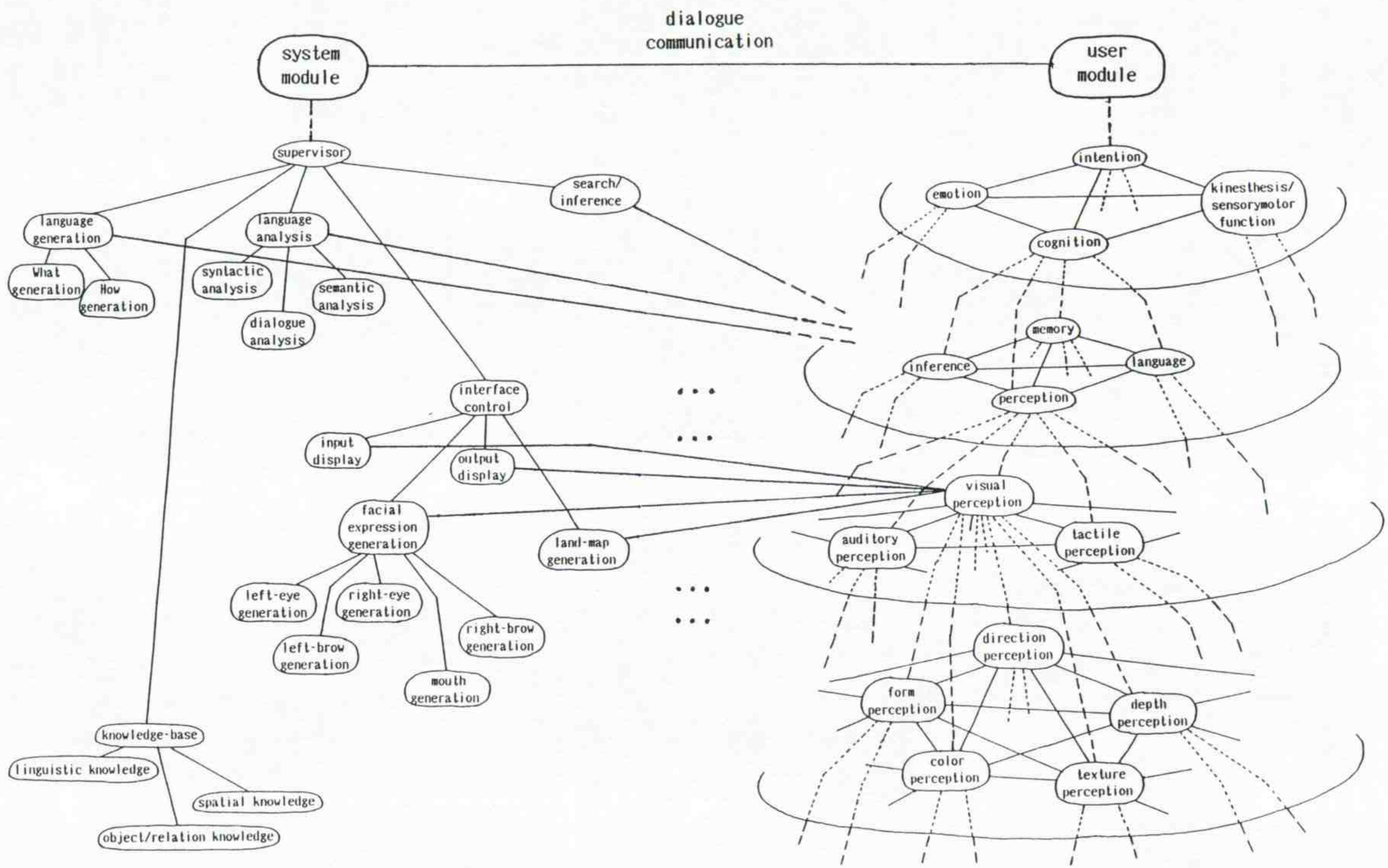


Fig. 4. Integrated functional module model of human and computer.

method may be devised whereby the user operates a pedal by his or her foot.

Such an idea concerning the abilities of the user modules can be applied to the design of the interface for users with various functional impairments. The idea can also be applied to the design of the interface, where the measure is not the efficiency for the user to just speed up the information processing, but to handle the environment with sufficient easiness. Thus, the ability assignment among lower-level modules in the user module can be analyzed as an intermodule matching problem of the module abilities.

For the ability of the system module, on the other hand, one can discuss the matching of abilities to improve the efficiency of the overall computer system. This corresponds to the problem of process synchronization in parallel processing from the viewpoint of computer science. The problem as to which modules should be operated in parallel, for example, concerns directly the computational efficiency of the system. In contrast to the case of the user module, however, the efficiency of the system module depends on the architecture in operating the module, as well as the computational efficiency of the algorithm of the component modules. It should be noted that those factors change rapidly with the development of technology.

Next, we discuss the matching/nonmatching between the user module and the system module. One of the features of the integrated man-computer model discussed up to this point in this paper is that the relation between those modules can be handled in the same way as the relation between modules at lower-level of those modules. Applying this idea, the efficiency of the integrated system of the user and the system depends similarly on the relation between abilities of the lower-level modules. Consider, for example, the information transmission path from the system to the user. The information processing amount and the processing speed of the visual display module, which is at the lower-level of the system module, should be equal to or larger than those of the visual module, which is the lower-level module of the user module. Similar situations apply to the language display module and the language module.

As to the information transmission path from the user to the system, on the other hand, the following situation must be considered. Assume that the processing speed of the user module as a whole is of the order of 0.1 s (it is estimated that the time a human operator can wait before the computer without being irritated, is of the order of 0.1 s). Then the processing speed of the system module as a whole should be 0.1 s or less.

The foregoing example is the case of nonmatching, where the system module should have a higher ability than that of the user module. A similar reasoning applies to many other functions such as inference. Especially, the extent to which the ability of each module in the system should be made higher, can be determined by analyzing the extent of nonmatching to the user module.

5. Conclusions

This paper proposed a hierarchical network model composed of cooperative functional modules as a model for the integrated man-computer information processing mechanism. Discussions are made for the functional module model for the visual pattern recognition and symbolic inference in problem-solving as well as the functional module model for interactive Japanese language processing. The integrated model is also discussed.

Note that such modeling can also be made using certain kinds of automata and networks. In this sense, one might argue that the idea is not new as a theory at the abstract level. As was suggested by examples in this paper, however, the man-computer interface is a problem composed of a large number of complex functions, from a neural network to the behavior model. For such a problem, if one starts from simple definitions and tries to apply a simple abstract model, it will take a long time until a practically useful result is obtained. Otherwise, we should directly face the complexity included in the man-computer interface, and construct a model including that complexity.

The idea underlying this study in the man-computer information processing is to find a model which can represent the information processing mechanism as a real problem in the interaction with the external environment. This idea follows the construction of the realistic model for the interface, which forms the background of the discussions in this paper.

There are still other important problems not discussed in this paper. Some of those are discussed in the following. One is the problem of learning. The information processing mechanism for learning is very important, in whatever information processing system, whether it is a human or a computer. Especially, the learning ability of the user in the interface has a great influence on the design of the interface. The human learning ability, however, is complex, and there are still only a few studies concerning computational models for learning [18]. Although many basic studies have been done for algorithms for machine learning, few are extended to practical applications. Under these circumstances this paper did not discuss the problem of learning. It is important, however, to provide a learning function to functional modules.

The second is the problem as to what the model is computing. When the whole system is divided into the user and the system, the computation in the integrated model is distributed over individual computational procedures of the component modules and their message exchange. It may cause the model to lose transparency though there is little problem from the viewpoint of the performance. One of the recent achievements in psychology and artificial intelligence is that the model for the knowledge information processing by the user and the system can be considered separately from the viewpoint of the information processing function inherent to the user, or the hardware and software functions inherent to the system. To provide a larger transparency to the integrated model, not only the user model, but also a model which explicitly represents the forementioned aspect should be considered [19].

The third problem is to give more insight into the cognitive model of the user. Most of the past cognitive models have been proposed within the framework of cognitive psychology, and have not been specialized enough to handle the design of the interface explicitly. From such a viewpoint, studies should be developed in the future, which are more directly useful to the interface design [20].

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