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RESEARCH ARTICLE

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A conjecture on mechanism of information understanding

Abstract All kinds of sensing organs in humans are able to reflect only the formal factors of objects, named formal information. It is believed, however, that not only the formal information but also the content information and value information of objects could play fundamental roles in the process of information understanding and decision-making in human thinking. Therefore, the questions of where and how the content information and the value information be produced from the formal information become critical in the theory of information understanding and decision-making. A conjectural theory that may reasonably answer the question is presented here in the paper.

Keywords formal information, content information, value information, information conversion, mechanism of information understanding and decision-making

1 Introduction: a gap between brain science and cognitive science

It has been clearly proved from the study of brain science that sensing organs of humans, as well as the various sensors in machines, are able to sense, reflect and thus obtain only the formal factors of the objects in the real world, such as the parameters of shapes, scales, colors, sounds, weights, and so on, named the formal information. There have been no such sensors that are able to sense the information about the content and value factors of objects, named content information and value information [1,2].

On the other hand, however, it has also been widely accepted from the study of cognitive science that the processes of information understanding and decision-making need the support not only from the formal information but also from the content information and value information [3,4]. In other words, the processes of information understanding and decision-making would not be possible if there are no content information and value information available beforehand.

Therefore, an apparent gap is discovered between the conclusions from the brain science study and that from the cognitive science study. This is a problem of great significance in information science.

More specifically, a question is raised as follows. How are the content information as well as the value information needed for information understanding and decision-making produced from the formal information that was the only product obtained by sensing organs? What is the feasible mechanism of the information understanding and decision-making?

Based on the results from this study in information, knowledge and intelligence theories, a conjectural theory on the mechanism of information understanding and decision-making is presented in the paper that may reasonably, and innovatively, provide the answer.

For presenting the conjecture, the definitions on formal, content, and value information will be given in Sect. 2. The interrelationships among the formal, the content, and the value information will briefly be discussed in Sect. 3. The conjecture on the mechanism of information understanding and decision-making will then be explained in Sect. 4, and the trend and evidence in technological development are described in Sect. 5. Some of the conclusions, suggestions, implications and open problems on the conjecture will be pointed out in the final section of the paper.

2 Basic definitions

For the convenience of discussions, it would be necessary to define some of the basic concepts that are fundamental and frequently used in the latter parts of the paper.

Definition 1 Formal information. Formal information of an object is defined as the information that concerns only with the formal factors of the object it described without considering the factors of content and value. More specifically, the formal information of an object consists of

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the states the object may have and the manner with which the states may vary [5].

Information in Shannon theory is one of the examples of formal information [6]. If an object X has N possible states $\{x_n|n=1,2,\ldots,N\}$ and if the manner of state varying is probabilistic in nature, then the formal information in Shannon theory can be expressed as the probabilistic space in Eqs. (1) and (2) below:

$$\begin{aligned} &x_1,x_2,\ldots,x_n,\ldots,x_N,\\ &p_1,p_2,\ldots,p_n,\ldots,p_N, \end{aligned} \tag{1}$$

where

$$0\leqslant p_n\leqslant 1,\quad n=1,2,\ldots,N,\quad \sum_{n=1}^{N} p_n = 1. \tag{2}$$

The formal information is not limited, of course, to the statistic information category. It can either be fuzzy information or any other kinds of non-statistical information. In the case of fuzzy information, the parameter p_n should be replaced by μ_n, where μ_n is a fuzzy parameter for state x_n, for all n. Further, the formal information is not also limited to the discrete form. It can be a continuous form. However, any continuous form can, in principle, be conversed into discrete. Hence, only discrete formal information is mentioned here-in-below.

It is necessary to note that the formal information, $\boldsymbol{X}$, about an object, in reality, may have many different parameters, such as $X(1),X(2),\ldots,X(n)$, where n is a certain positive integer. In these cases, $\boldsymbol{X}$ should be expressed as a vector with $X(i)$ as components, $i=1,2,\ldots,n$. For example, $X(1)$ may represent the shape of the object, $X(2)$ the size, $X(3)$ the weight, $X(4)$ the color, and so on. Due to the additive property of information, the total amount of formal information of an object is the summation of that for each of the components of the object.

Definition 2 Content information. Content information of an object is defined as the information that is concerned with the content, or meaning, factor of the object and can, therefore, be judged as true or false in logic [7].

If an object X has N possible states $\{x_n|n=1,2,\ldots,N\}$ and the truth of each state x_n is denoted by t_n, the content information in this case can be expressed as the truth space in Eqs. (3) and (4):

$$\begin{aligned} &x_1,x_2,\ldots,x_n,\ldots,x_N,\\ &t_1,t_2,\ldots,t_n,\ldots,t_N, \end{aligned} \tag{3}$$

where

$$0\leqslant t_n\leqslant 1,\quad n=1,2,\ldots,N,\quad \sum_{n=1}^{N} t_n >=< 1. \tag{4}$$

The expression of the truth of the state indicated in Eq. (4) implies that the quantities of truth of all the states are fuzzy in nature.

Definition 3 Value information. Value information is defined as the information that concerns with the value, or utility, factor of the object and can then be judged as useful or not with respect to the subject's goal [7]. If an object X has N possible states $\{x_n|n=1,2,\ldots,N\}$ and the utility of each state is denoted by u_n, the value information in this case can be expressed as the utility space in Eqs. (5) and (6):

$$\begin{aligned} &x_1,x_2,\ldots,x_n,\ldots,x_N,\\ &u_1,u_2,\ldots,u_n,\ldots,u_N, \end{aligned} \tag{5}$$

where

$$0\leqslant u_n\leqslant 1,\quad n=1,2,\ldots,N,\quad \sum_{n=1}^{N} u_n >=< 1. \tag{6}$$

The expression of the utility of the state indicated in Eq. (6) implies that the quantities of utility of all the states are also fuzzy in nature.

3 Comprehensive information and information conversion

In the theory of information science, the concepts of formal, content, and value information defined in Definitions 1, 2, and 3 above can also be pictorially explained in Fig. 1 below [5,7].

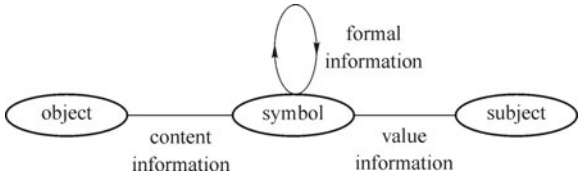

Fig. 1 Concepts of formal information, content information, and value information

It is clear from Fig. 1 that the formal information, as is shown in the middle of the figure, is a formal description about the stream of the symbols that represents the sequential relations between the state on which the object took and the ones on which the object took earlier or later. Therefore, the formal information is an abstract expression about the formal structure of the states of the object without consideration of its meaning and value factors. Yet, whenever the formal structure of the symbols is associated with the object it described, the real meaning of the formal structure of symbols, that is, the content information, will naturally appear, as shown in the left part of the figure. Thus, content information can be judged true or false in logic. Further, as long as a subject is associated with the formal and content information, the value, or utility,

information will immediately come up, expressed in the right part of the figure. The value information will be able to tell whether the object is valuable or not to the subject's goal.

Obviously, having obtained all the three components of information of an object: formal, content, and value, one will be able to know not only the form but also the meaning and the utility of the object toward the subject's goal. In other words, one will be able to understand the object and to make the right decision toward the object through the use of the three components of information, the trinity of which is termed as comprehensive information about the object.

Based on the discussions above, the relationships among the three components of the comprehensive information can naturally be established in the following way, referential to Fig. 2 below.

As can be seen from Fig. 2, the formal information, denoted by $\boldsymbol{X}$, can be obtained from the original stimulus, denoted by $\boldsymbol{S}$, through a sensing system performing a kind of linear mappings, Φ:

$$\Phi : \boldsymbol{S} \mapsto \boldsymbol{X}. \tag{7}$$

On the other hand, the value information, denoted by $\boldsymbol{Z}$, can be produced as long as the goal, $\boldsymbol{G}$, for the subject is defined, or provided by the knowledge base and trigged by $\boldsymbol{S}$, via the calculation:

$$\boldsymbol{Z} \propto \mathrm{Cor}(\boldsymbol{X},\boldsymbol{G}), \tag{8}$$

where the symbol "Cor" stands for the mutual correlation between the vectors $\boldsymbol{X}$ and $\boldsymbol{G}$. Sometimes, $\boldsymbol{Z}$ may directly be given by the knowledge base if the latter already has had the value information corresponding to the formal one beforehand.

As far as the content information, $\boldsymbol{Y}$, is concerned, it can only be produced when both $\boldsymbol{X}$ and $\boldsymbol{Z}$ are available. As a matter of fact, $\boldsymbol{Y}$ can be regarded as the result of logic operation over formal and value information:

$$\boldsymbol{Y} = \lambda(\boldsymbol{X},\boldsymbol{Z}), \tag{9}$$

where the symbol "λ" represents some logic operation performed.

Note that, quite different from formal information and value information that can all either be sensed or experienced, content information is an abstract concept, which cannot be seen, heard, smelled, and touched directly. This, of course, does not mean that content information is arbitrary in nature. As a matter of fact, it can, and only can, be deduced by joint logic function λ over $\boldsymbol{X}$ and $\boldsymbol{Z}$ as shown in Fig. 2.

In the simplest case, however, $\boldsymbol{Y}$ can be delimited by the conjunction operation in logic, or simply logic "and", of $\boldsymbol{X}$ and $\boldsymbol{Z}$ as shown in the following equation:

$$\boldsymbol{Y} \approx \boldsymbol{X} \cap \boldsymbol{Z}. \tag{10}$$

This is to say that the joint statement of "If the formal information is $\boldsymbol{X}$ and at the same time if the value information is $\boldsymbol{Z}$" itself has clearly defined the content information $\boldsymbol{Y}$.

For example, given an apple, we may have its content information,

$$\boldsymbol{Y} = \{y | \boldsymbol{Y} \approx \boldsymbol{X} \cap \boldsymbol{Z}\},$$

where

$$\boldsymbol{X} = \{\text{Shape: as a small ball. Size: as a fist. Weight: approximately 0.2 kg. Color: yellow.}\},$$

$$\boldsymbol{Z} = \{\text{Good taste and good for fit.}\}.$$

This means that the joint statements, "If a fruit has a shape like a ball and has a size like a fist and has yellow in color and weighted round 0.2 kg." and "It has good taste and is good for fit." may very well imply the content information of an apple. Otherwise, how would you describe the content of an apple?

In fact, the methodology of producing the content information through conjunction operation from its counterparts, formal information and value information, is commonly accepted either in academic circle or in daily life.

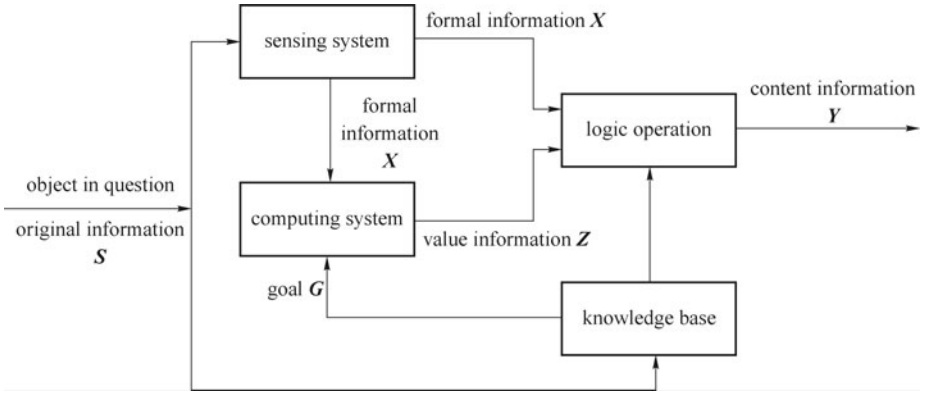

Fig. 2 Interrelationship among formal, content, and value information

See more examples.

Example 1 Content information $\boldsymbol{Y}$ of "person" can be jointly delimited by its counterparts, formal information $\boldsymbol{X}$ and its value information $\boldsymbol{Z}$:

$$\boldsymbol{Y} = \{y|\boldsymbol{X} \cap \boldsymbol{Z}\},$$

where

$\boldsymbol{X}$ = {A living being as tall as 1.6–2.0 m and as heavy as 50–80 kg with a head on the top of its body, with two arms, one on the left side and the other on the right side and two legs for walking, … .},

$\boldsymbol{Z}$ = {It is able to create and use tools for living, to speak with natural language, to cooperate for better life, … .}.

Example 2 Content information $\boldsymbol{Y}$ of a "car" can be jointly described by its counterparts, formal information $\boldsymbol{X}$ and value information $\boldsymbol{Z}$:

$$\boldsymbol{Y} = \{y|\boldsymbol{X} \cap \boldsymbol{Z}\},$$

where

$\boldsymbol{X}$ = {Outline, structural form, energy type and other descriptions.},

$$\boldsymbol{Z} = \{\text{Functions, performances.}\}.$$

Equation (10) used as a description for content information is rationalized and also feasible because of the facts that all kinds of formal information of objects can be observed via sensing, and all kinds of value information of objects can be calculated or experienced in practice, while the content information, which is abstract in nature, can, in principle, be inferred by the corresponding formal information and value information.

On the other hand, Eq. (10) also explains the complication associated with the content information: different people may have different content information toward the same things due to different goals people may have, even if they have the same formal information. It is possible for people to have same content information if, and only if, people have the same formal information and value information.

It is shown from Fig. 2 and Eqs. (7)–(10) that it is possible and also feasible to produce the content information and value information, which are needed in the processes of understanding and decision-making, from the corresponding formal information, which can be observed directly by sensing organs for humans and by sensors for machines.

4 A conjecture on mechanism of understanding in human brain

All the discussions carried on up to present in the paper indicate clearly the following results, which are of high importance.

1) It is true according to the study of brain science that sensing organs in humans, as well as sensors in machines, can only perceive, and receive, the formal information about what they currently observe, having nothing to do with the content and value factors.

2) It is also true according to the study of cognitive science that if anyone wants to know the formal outline, which is a shallow-level understanding, about the object, he/she should have its formal information; if anyone wants to know the meaning, which is a deeper-level understanding, about the object, he/she should have both its formal information and content information; and finally, if one wants to know the entirety, which is the deepest-level understanding, about the object, he/she should have all its three components of comprehensive information, that is, the formal, content, and value information.

3) It is important that it is possible and feasible to produce the content information and value information, which are needed for better understanding and right decision-making, from formal information, which has been received from sensing process, in accordance with the principles in Fig. 2 and Eqs. (7)–(10).

4) Having had the comprehensive information about something, it is feasible for the user to make a decision toward the thing because the form, the content and the utility, no matter it is positive, or negative, or neutral, provided by the thing to the user have been clear.

Based on the results stated above, 1)–4), a proposed theory concerning the mechanism of information understanding and decision-making is presented as a)–e) below.

a) Total understanding means to have comprehensive information

By "understanding something", it means to have the comprehensive information concerning the thing in consideration. This is because of the facts that the formal component of the comprehensive information could provide to the user the information about the form of the thing; the content component of the comprehensive information could provide to the user the information about the meaning of the thing, and the value component of the comprehensive information could provide to the user the information about the utility of the thing. Any subject who has already had the information about the form, the meaning and utility of a thing can be regarded as having totally understood the thing.

b) Making good decision must have comprehensive information

"Decision-making" can be carried on if, and only if, the comprehensive information is already available, as the form, content and utility concerning the thing to the decision-maker have been made clear by having comprehensive information. One of the keys for making decision in this case is to take the action that is able to make the value information being the maximum.

c) Mechanism of understanding is information conversion: from form to content and value

The mechanism of understanding and decision-making can be explained by Fig. 2 and Eqs. (7)–(10) and is a process of information conversion, that is, from formal information conversed to content information and value information. This indicates that "understanding" is possible not only for humans but also for machines depending on whether the comprehensive information is available or not.

d) Understanding needs knowledge

For producing value information and content information from formal information, it needs knowledge so that the goal for producing value information can be derived, and the logic operation for deducing content information can be implemented as can be seen from Fig. 2.

e) Understanding may have various solutions

Among the three components of the comprehensive information, the formal information will normally be unique, rather than arbitrary, to the normal observers, while the content information and value information may be different to different observers if they have different goals in their mind as can be seen from Eq. (10). This is in agreement with the results from cognitive science.

It can be seen from Eqs. (7)–(10) that the essence of the related processes is a series of transforms that converse the formal information to value information, supported by the goal from knowledge base, and further to content information, based on the logic operation and knowledge base. This is a category of information conversions.

Properly understanding is the necessary foundation for making decision, and making the correct decision is the key and nucleus in all kinds of human abilities for dealing with any problems in the real world. The proposed theory on the mechanism of information understanding and decision-making, that is presented for the first time in literature, is therefore of great importance.

From all discussions we have had in the paper so far, it is reasonable to present a conjecture on the functions performed in human brain, particularly based on the mechanism of understanding that was discussed in detail above, that there must be such an organ in the brain that performs the functions to converse formal information, received from the sensing organs, to value information and content information, which are needed in the stages of understanding and decision-making. The functional structure of the organ in brain may, to a certain extent, be similar to what is shown in Fig. 2.

We also postulate that the organ in the brain that performs the functions of information conversion (conversing the formal information to value information at first and to content information at the second) may locate at somewhere before the frontal lobe, where the decision is made, and after the joint areas formed by parietal, occipital and temporal lobes, where the information is integrated. This is because of the fact that information conversion is no longer needed after a decision was made at the frontal lobe, and it is impossible to perform the function of information conversion before all kinds of the formal information received by sensing organs and converged at joint areas.

Further, it is assumed that the process of information conversion (that converses the formal information to value information at first and to content information at the second) would better be performed at the place closely associated with the working memory that is somewhere in between short-term memory and long-term memory in the brain, which can be seen in Fig. 3 below. A part of long-term memory may serve as "knowledge base" to provide the goal needed for value information derivation and to provide the capability of logic deduction for producing the content information, as was mentioned in Fig. 2.

It can be seen from Fig. 3 that the formal information received by sensing organs enters firstly into the short-term memory and then goes to the working memory in which it is conversed to produce the comprehensive information and finally stored in long-term memory. The explanation on the function of information conversion performed in Fig. 3 is supposed to be the same as that in Fig. 2.

It is believed that comprehensive information, as the trinity of formal, content, and value information, would be stored in the long-term memory in a way greatly different from what it is at the present time. It is well known that what is stored in all kinds of memories in current data architecture/organization is purely the formal component of comprehensive information, having nothing to do with both its content and value components. Nonetheless, the processes of understanding and decision-making would not be appropriate if they lack content information and value information, as mentioned previously. Therefore, the

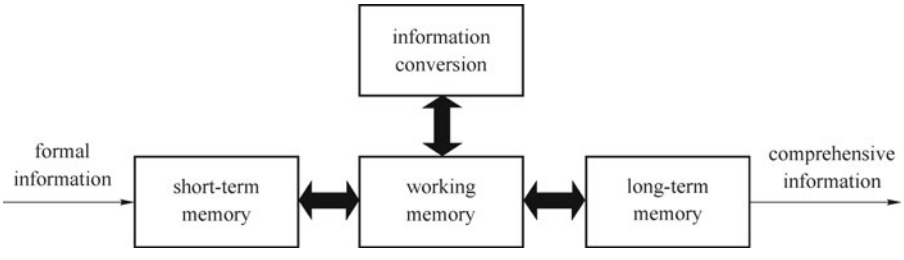

Fig. 3 Conjecture on information conversion in brain

current knowledge about architecture/organization of information storage should be rethought.

For making the processes of understanding and decision-making carried out in the brain convincible, at least the long-term memory should have to store the trinity of formal, content and value information, rather than the formal information only. It may be proper to name such a kind of long-term memory as the "comprehensive information memory".

The new architecture and organization in "comprehensive information memory", which is a part of the long-term memory, is inferred to have two segments: the first segment is "index", and the second segment is the "information related to the index", as is shown in Fig. 4 below.

Either formal information or content information or value information could serve as the index of the comprehensive information stored in the comprehensive information memory. Whenever an index is indicated, the related parts of the comprehensive information should immediately be retrieved. It seems that the retrieval of information may be more efficient if the content information served as an index, and this is the so-called "retrieval by content".

The presented conjecture about the mechanism of information understanding and decision-making and the postulates about the location, architecture and organization of the long-term memory in the brain are believed to be rationale and reasonable. This is because of the following facts supported by the study of brain science and cognitive science:

1) There are as many as 10^{10}–10^{12} neurons contained in the cerebral cortex of human brain, and each of the neurons would have connections with approximately 10^4 other neurons.

2) Each neuron has two states to take place, either positive or negative, while the strength of the connection between neurons may take an arbitrary value between zero and one.

3) The number of possible combinations of the states of all neurons in the cerebral cortex in the brain may, therefore, be regarded as many as infinity, and there would be no problem for the human brain to express the huge amount of the comprehensive information received from the real world during life time.

4) In accordance with the results in cognitive science, content, or equivalently the meaning, is always the dominant issue within the process of human cognition. In other words, good understanding and reasonable decision-making would be impossible if there are no content information and value information.

5 Good trend and evidence in technological development

There has been good trend carried on for quite a number of years in the field of natural language processing and understanding which supports and proves the theory of mechanism of information understanding and decision-making presented in this paper.

What is meant is the technological trend worldwide. The research of information retrieval has been going from World Wide Web to Semantic Web. Yet the most essential progress made from World Wide Web to Semantic Web is just the utilization of the content information of the language, which is also termed semantic information in the field of information science. This is why the new stage of the Web is named Semantic Web.

It has been well known that one of the major problems associated with the World Wide Web services is its very poor performance, particularly the very low precision in its retrieval. In fact, when giving key words to the World Wide Web system, the user may receive more than a million pieces of the information feedback, of which only a very small part seems useful, whereas most pieces of the information feedback may have nothing to do with what the user really needs.

This is due mainly to the poor understandability of the system toward the information, which, in turn, is resulted from the complete lack of content, i.e., semantic, information. The principle that World Wide Web works is merely the "formal matching" between the key words the user gave and the words in documents stored in databases of Internet. The "formal mating" is simply the comparison between the forms of the related words (i.e., formal information) without any consideration of the content information, or the semantic information, of the words. In other words, the search engine of the World Wide Web system does not completely understand the words it faces. This is the root for its poor performance.

For overcoming the weakness of World Wide Web, which is due to the lack of understandability, Ref. [8] proposed in the year of 2001 an idea of "Semantic Web". The key of the idea is to introduce to the system the "understandability" toward the text by utilizing the content information, in addition to the formal matching of words. For this purpose, the concept of ontology has been

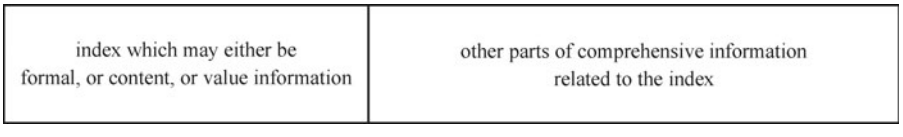

Fig. 4 Organizational architecture of comprehensive information memory

employed as a frame for expression of formal information and content information, and the descriptive logic is used as a tool for understanding the content information. It is widely believed that the performance of Semantic Web, specially its precision of retrieval, will be much better than that of World Wide Web. This technological development strongly proves the importance of content information in information understanding.

An apparent prediction can be made that Semantic Web will be better in performance than World Wide Web because of the use of semantic/content information, whereas the performance of Semantic Web would further be improved if value information is also utilized, according to the theory of mechanism of information understanding and decision-making—by using merely formal information, only shallow-level understanding can be achieved; with the use of content information, deeper-level understanding can be reached; and if the comprehensive information, which is again the trinity of formal, content and value information, can be used, the deepest-level understanding can then be obtained.

This has led to a newer idea of "comprehensive information-based Web", CI-Web for short [9–14], featured with the full utilization of the comprehensive information in an information retrieval system. Considering the demand from modern society that the Web services should be more personalized and individualized, the utilization of value information will be more contributive, and thus of more significance, in this regard.

The conceptualized principle of CI-Web, compared with World Wide Web and Semantic Web, can be illustrated as in Table 1 shown below.

Table 1 Comparison among World Wide Web, Semantic Web and CI-Web

	feature of bases	feature of search engine
World Wide Web	formal information	key words matching
Semantic Web	formal and content information	semantic understanding
CI-Web	comprehensive information	comprehensive understanding

There should be no doubt that the CI-Web will be in the best rank of the performance comparison for information retrieval relative to that of Semantic Web, not to say that of World Wide Web. This is because of the fact that it seeks the most full utilization of comprehensive information in CI-Web.

There may be something uncertain concerning the performance of the practical systems as none of the Semantic Web and CI-Web has been in complete operation. Both of them are still in the process of development. As far as the principles are concerned, the conclusions above should be believable.

6 Conclusions

Both the ability of information understanding and decision-making, either in humans or in machines, are widely accepted in academic circles as the most crucial and important indicators in the research of both natural intelligence and artificial intelligence. Due to their high complexity, however, there have been quite a few literatures directly touching these hard nuts so far. As the advancement of intelligence theory and technology, the issues of understanding and decision-making become unavoidable.

A conjecture on the mechanism of information understanding and decision-making in the brain has been presented in the paper. A number of supportive concepts such as comprehensive information (which is the trinity of formal information, content information, and value information), comprehensive memory, the information conversions, and so forth are also introduced.

The major conclusions the paper achieved include the following which may be the right answers to the important questions which were raised in Sect. 1.

1) Total understanding means to have comprehensive information concerned in which formal information contributes to the understanding of the formal outline of the object (the shallow level of understanding); both the formal information and content information together will contribute to the understanding of the meaning of the object (the middle level of understanding), while comprehensive information will contribute to the understanding of the utility of the object to the subject (the deepest level of understanding).

2) Good decision-making means to utilize the comprehensive information related, and the latter of which makes the decision not only correct in form but also reasonable in content and beneficial in value.

3) Sensing organs in humans and sensors in machines can only receive formal information of objects, whereas the content information and value information can be produced from the formal information through the way of information conversion as is shown in Fig. 2 and Eqs. (7)–(10). Therefore, the information understanding and decision-making can, in principle, be implemented in humans as well as in machines as long as the related comprehensive information can be sufficiently produced.

4) Many evidences indicate that there should be "comprehensive memory" existed at least in long-term memory in the brain. It is thus suggested that the memory systems in technology should have new architecture and organization to have comprehensive information stored so that both the processes of understanding and decision-making can be realized.

An open problem is stated as follows. It would be highly interesting and greatly beneficial to the academic circles, the author believes, if the conjecture presented in the paper

could really be verified by finding the biological organisms in the human brain where comprehensive information is being stored and utilized.

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References

1. Sun J R. Introduction of Brain Science. Beijing: Peking University Press, 2001 (in Chinese)
2. Luo Y J, Jiang Y, Cheng K. Foundation of Cognitive and Neural Science. Beijing: Peking University Press, 2006 (in Chinese)
3. Wu X B, Miao L, Wu L J, Zhang H. Introduction to Cognitive Science. Beijing: Science Press, 2007 (in Chinese)
4. Wilson R A, Keil F C. The MIT Encyclopedia of the Cognitive Science. Cambridge, MA: MIT Press, 1999
5. Zhong Y X. Principles of Information Science. 3rd ed. Beijing: Beijing University of Posts and Telecommunications Press, 2002 (in Chinese)
6. Shannon C E. A Mathematical Theory of Communication. Cambridge, MA: MIT Press, 1949
7. Zhong Y X. Cognetics in Machines. Beijing: Science Press, 2007 (in Chinese)
8. Berners-Lee T, Hendler J, Lassila O. The Semantic Web. Scientific American, 2001, 284(5): 34–43
9. Li L. Key technologies in intelligent services from info-net. Dissertation for the Doctoral Degree. Beijing: Beijing University of Posts and Telecommunications, 2000 (in Chinese)
10. Liu J Y, Zhang P F, Wang C, Guo Y H, Li Y. Design and implementation of high-performance E-mail filtering system. Application Research of Computer, 2005, 22(4): 224–225 (in Chinese)
11. Li L, Zhou Y Q, Wang J H. Comprehensive information based Chinese information extraction system and application. Journal of Beijing University of Posts and Telecommunications, 2005, 28(6): 48–51 (in Chinese)
12. Li L, Xu J, Gong Y, Zhou Y Q, Wang Z, Zhong Y X. CI-NLU based text processing after speech recognition. Journal of Beijing University of Posts and Telecommunications, 2006, 29(supplement 2): 192–196 (in Chinese)
13. Zhang P F. Language for agent communication based on comprehensive information. Dissertation for the Doctoral Degree. Beijing: Beijing University of Posts and Telecommunications, 2007 (in Chinese)
14. Wu C H. A tour guide system based on comprehensive information. Dissertation for the Doctoral Degree. Beijing: Beijing University of Posts and Telecommunications, 2007 (in Chinese)