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Mechanism Approach to Advanced Intelligence*

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Advanced Intelligence may feature the research of intelligence in the years to come. Its definition is given first and followed is a study on appropriate approach to Advanced Intelligence. It is discovered that the mechanism approach to intelligence research, which is featured with the common and core mechanism of intelligence formation in all possible cases, can well be expressed by information-knowledge-intelligence transformation. It is interestingly discovered that the various AI approaches existed can all be unified within the framework of Mechanism Approach.

Keywords: Natural Intelligence; Artificial Intelligence; Advanced Intelligence; Mechanism Approach.

1. Motivation

The subject of Artificial Intelligence research has extremely high importance at preset time. What are the major lessons one could learn from the past and what will happen in the future? For properly answering the questions, it is necessary to quickly look back the history of AI research.

It was well believed in the past that **structure, function, and behavior of a system are the windows from which one can look into the secrets of a system, particularly a complicated system** and the structure of a system is the most fundamental one among the three. Therefore, human intelligence simulation through the way of mimicking the structure of human brain became most attractive approach. The approach of structural simulation was gradually formed after the logical model of neuron published by McCulloch and Pitts in 1943[1] and many results in research were achieved since then .[2,3,4]

As time went on, it was realized that the complexity related to human neural network may be a limit that the structural simulation approach cannot reach as the biological neural network contains more than 1010 neurons and each of the neuron may have as many as 103 connections to other neurons. On the other hand, if the

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complexity of the artificial neural network is reduced to such an order that modern industry can achieve, the performance in intelligence of the system may drastically be degraded. This is a very tricky dilemma.

New approaches to the simulation of human intelligence that can avoid the dilemma have thus been sought. Artificial Intelligence was born at Dartmouth, Massachusetts, US in 1956 when a group of scientists got together for exploring the secrets of logic thinking in human brain through the way of function, instead of structure, simulation of the human brain by means of software for computer. This approach looked very well at the early stage of its development. Many results (such as Logic Theorist, General Problem Solver, and Means and Ends Analysis, etc), came out as its achievements .[5,6,7]

It was recognized later that it is much too ambitious to deal with the problems solving in general. Therefore, efforts were turned onto the problems in specific domain and the Expert Systems became the mainstream in function simulation of logic thinking. Variety of expert systems appeared during the period of 1970s.[8] It is not long, however, knowledge bottleneck was found a serious obstacle in the process of expert systems designing C the ability in acquisition, representation, and inference of knowledge needed are severely limited and are not easy to get good solution in a foreseeable period of time.

To effectively avoid the difficulties of complexity dilemma in structural simulation and that of knowledge bottleneck in functional simulation, the third research group grew up in early 1990s and that is the research aiming at the simulation of behavior of intelligent beings by using the methodology of Black Box. It is believed that what is needed in artificial intelligence is to simulate the behavior of intelligent systems C taking the right actions in response to the given conditions. That is stimuli C responses relationship of intelligent system, or the so-called sensor-motor systems.[9,10]

It is clear that behavior simulation approach can successfully avoid the difficulties encountered in both structure simulation and function simulation whereas this success leads to another problem C the sensor-motor systems can only satisfactorily simulate the relatively simple behaviors of intelligent systems. In other words, the behavior simulation approach can only deal with the intelligence in shallow level rather than with that in deeper level. This is also a severe limitation.

The three approaches existed so far, the structure simulation approach, the function simulation approach, and the behavior simulation approach, have made impressive progresses during the past decades. On the other hand, each of them also faces critical difficulties not easy to overcome in near future.

It is noted that there have been a number of novel books published in the area of artificial intelligence recent years. The book titled with Artificial Intelligence: A New Synthesis by Nilsson [11] and the one titled Artificial Intelligence: A Modern Approach by Russell et al [12] are the representatives. Both the books have the feature that all the materials have been organized in the line of agent evolution, from the simple one (sensor-motor system) to the advanced one (neural network and expert system). It seems yet that there is lack of the essential links among the three simulation approaches in both books and all the materials have been just simply put together in a very straightforward way. It seems no progress with respect to new approaches to Artificial Intelligence research up to the present

Are the three approaches to AI research perfect already? Why do they stand alone in AI research all the time? Is there any possibility for finding a unified approach to AI research? These are what the author concerned the most. Finding the solution to the questions becomes the major motivation of the paper.

2. What and Why Is Advanced Intelligence?

In August 1-3, 2006, there was an International Conference on Artificial Intelligence held in Beijing, China for celebrating the 50th anniversary of Artificial Intelligence. More than two hundred delegates from five continents (Asia, America, Africa, Europe, and The Great Ocean) got together for summarizing the experiences that were achieved in the past decades in Artificial Intelligence research, not only related to the function simulation approach but also to the other two approaches. At the same time, the problems confronted with all the three approaches were also reviewed. One important understandings reached among the participants of the conference is that, based on the summarization of the past experience and the problems faced, a new feature of the Artificial Intelligence research should be emphasized for the next 50 years.

The new subject of the intelligence research in next 50 years was suggested and was named as **Advanced Intelligence**. Interestingly enough, both the terms of Artificial Intelligence and Advanced Intelligence can be briefed as AI. This shows the link between the two on one hand but they are greatly different, on the other hand, Advanced Intelligence facing in the future and Artificial Intelligence experienced in the past.

Professor Loft A. Zadeh, chair of International Advisory Committee of the Conference, and I, general chair of the conference, jointly proposed the following features as good marks: (a) both the natural intelligence and artificial intelligence should be closely interacted in Advanced Intelligence study, instead of separate from each other like what it was during the past and (b) the significant frontiers in natural and artificial intelligence should receive much more attentions in the research of Advanced Intelligence, in addition to the elementary issues. Based on these explanations, emotion, consciousness, cognition and intelligence should receive the necessary attention in the Advanced Intelligence study.

Taking the view of agent issues as Nilsson and Russell did not long ago, the Advanced Intelligence research should cover such advanced topics as human intelligence, advanced agents, the intelligence in human society and the agent society as well as the interaction and cooperation between humans and agents. This, of course, does not mean that all the other issues are no longer important. As a matter of fact, many issues related to the simple agent may better be solved when the issues related to advanced intelligence and advanced agent are solved.

Because of the fact that the three existing major approaches, the structural simulation approach, the functional simulation approach, and the behavioral simulation approach, have all been confronting with critical problems as mentioned above, it is absolutely necessary to make efforts for finding a new, and better, approach to AI research in the next stage. On the other hand, because of the fact that the new stage of the research, i.e., the Advanced Intelligence research, has been stood in front of researchers, the proper approach to the Advanced Intelligence research is also reasonably demanded.

3. Advanced Approach to Advanced Intelligence

For meeting the requirements from the Advanced Intelligence research, the approaches currently used might not be proper. A new approach, named Advanced Approach for instance, to the Advanced Intelligence research would thus be requested.

From the point of view of methodology, a better candidate for the approach to the research of intelligent systems should be the one that is able to effectively bring to light the mechanism of intelligence formation. This is because of the fact that all the secrets concerning the intelligence can only be made clear via the understanding of the mechanism of intelligence formation, instead of the structure, the function, or the behavior. Such a kind of approach revealing the secrets of intelligence formation can reasonably be named the Mechanism Approach.

This is to say that the **Advanced Approach** to the research of **Advanced Intelligence** that we are now seeking for in this paper should in principle be the **Mechanism Approach**.

Intelligence is a sort of process that is pervasively existed in the real world of living beings. Human intelligence is however the most typical example for Advanced Intelligence. It would thus be reasonable to take human intelligence as a model in our study below.

To begin with, a general description for the entire process of human intelligence formation is necessarily given as a basic background of the discussions that will be carried on in later parts of the paper.

According to the current knowledge we have had from brain and cognitive science, human intelligence formation process consists of the following six steps in logic order.

(1) When facing a **problem** in real world, humans should first be able to set up a **prescribed goal** in the brain for itself to deal with the problem in later stage. Note that how a person can set up the prescribed goal properly is another theme (called the implicit intelligence) that is a more complicated problem and needs to intensively study not in this paper but in the future.

(2) The sensing organs are then asked by the brain to acquire the information concerning the problem and the environment that will exert **constraints** to

the process in dealing with the problem. This is the process of information acquisition. The information concerning the problem and the constraints, both from the real world, is often termed the **original information**.

(3) When all kinds of information needed are obtained already, that are named the **acquired information**, they should be passed, via nerve system, to the brain for processing, analyzing and utilizing. This is the process of information transferring.

(4) When the acquired information is sufficiently available, the brain will have to refine them into the related **knowledge**. This is the process of cognition and its output is knowledge.

(5) If the information and the knowledge related to the goal, the problem and the constraints are available the brain should have to produce the **strategy** for the problem solving. This is the process of decision-making and its output is strategy.

(6) The strategy will then be passed, also via nerve system, to the actuators where the strategy will be conversed into the corresponding **action** through which the problem will be solved if all the steps mentioned above are all right. This is the process of Execution of the strategy.

If the problem is not solved satisfactorily, the error, which is the difference between the present state of the problem and the prescribed goal, will serve as newly occurred information and the loop from (1) to (6) will be recycled again till the problem is solved satisfactorily. This is a process of self-learning.

It is noted that the strategy is the embodiment of intelligence and often referred as **intelligence in narrow sense** whereas the ability embedded in the entire process from steps (1) to (6) is referred the **intelligence in completed sense**.

The process analyzed above also shows how the intelligence in narrower sense is really formed from the related knowledge and information. It is evident from the process that the core mechanism of human intelligence formation is implemented through a series of transformations that will be discussed in more detail below.

For the conciseness of the paper, however, only the crucial parts (the core) of the series of the transformations that can converse the original information to sensed one, and then to knowledge and further to strategy in the process of intelligence formation, corresponding to (2), (4), (5) and (6) in the six steps described above, will be discussed in the section of the paper whereas the other parts of the transformations will have to be omitted for the moment yet without the loss of the generality.

Transform 1. from Original Information to Acquired One

The first function for an intelligent system to perform is to get the information directly related to the problem (P) to be handled under given constraints (C) and the prescribed goal (G). The information on G will be stored internally within the system while the information on P and C will have to be acquired from the outside world where the problem is presented. This is thus a conversion from original information, denoted by I_O, to the sensed information, denoted by I_E:

$$T_1 : I_O \mapsto I_E. \tag{1}$$

The definitions on I_O and I_E in (1) are given below:

Definition 1. **Original Information** *of an event in real world is defined as the events self-description about* ***the states*** *at which the event may stay and* ***the manner*** *with which the state of the event may vary .*[13]

Note that the original information, I_O, is the purely objective facts about the event itself, the states and the manner, and thus is really original source of information.

Definition 2. **Acquired Information** *of an event is a kind of description, given by the subject (or user), describing* ***the states*** *at which the event may stay and* ***the manner*** *with which the state may vary.*

Because the subject has the abilities to sense the form and to understand the meaning and has goal to measure the utility, the description on the state and the manner should be concerned with their form, meaning and utility with respect to his goal that are respectively called the *Form Information*, the *Meaning Information*, and the *Utility Information* whereas the trinity of the three is named the *Comprehensive Information.*[13]

The transformation, T_1 shown in Eq. 1, which transforms the original information to the acquired information, may be implemented through different systems depending on which component of sensed information is required. If, for instance, only form information is required, a specified kind of sensing system is then a good choice. If, however, the comprehensive information, including all the three components, is required at the same time, the sensing system combined with a proper knowledge base and a certain kind of logic algorithm will be needed. This can better be shown in Fig. 1 below.

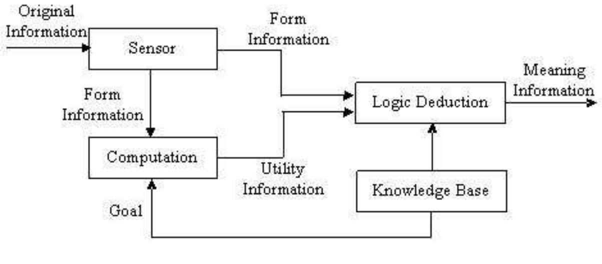

Fig. 1. Transformation conversing I_O to I_E.

Fig. 1 shows that the form information can be obtained from the output of a related sensing system and the utility information can be derived via the computation based on the comparison between the current form information with the ones stored in knowledge bases, in which the relations between the form and the utility information have been stored beforehand, whereas the meaning information can then be produced via a logic deduction with respect to the form and utility information. For more detailed explanations, see the reference.[13] After all, the transformation 1 can well be implemented with no difficulty in principle and the only conditions needed are the knowledge related to the problem to be handled.

Transform 2. from Information to Knowledge

The transformation 2 converses the acquired information to the knowledge. The basic concepts related to this transformation can be given below.

Definition 3. **Knowledge** *concerning a certain category of events is the description, made by subjects, on* ***the states*** *at which the events may stay and* ***the law*** *with which the states may vary.*

As the subjects have abilities to sense the form, to understand the meaning, and to measure the value, the description should also include the three components: *the form of the states and law observed that is called the formal knowledge, the meaning of the states and law understood that is named the content knowledge, and value of the states and law with respect to the subjects goal that is termed value knowledge. All the three aspects of the description constitute an entirety of knowledge.*[14]

Comparing the Definitions 2 and 3 indicates that the crucial difference between the two definitions lies on the two key words: **the manner** in information and **the law** in knowledge. As a matter of fact, **the law** of state varying can generally be abstracted from **the related manners** of state varying. Thus, the transformation from acquired information to knowledge can be implemented through the inductive-like algorithms as expressed below:

$$K \Leftarrow \cap\{I_E\}. \tag{2}$$

The symbol $\cap$ in Eq. 2 stands for a class of inductive operators; $\{I_E\}$ the sample set of the acquired information whereas K the knowledge produced from $\{I_E\}$. In some complicated cases, there may need a number of iterations between induction and deduction. The deduction itself can be expressed as

$$K_{new} \Leftarrow \Re\{K_{old}, C\}. \tag{3}$$

The symbolin $\Re$ in Eq. 3 represents the deduction operator, K_{old} the old knowledge already knew before deduction while K_{new} the knowledge newly deduced from K_{old}, and C stands for the constraints that the deduction must follow.

More specifically, the formal knowledge can be refined from form information and value knowledge from utility information whereas content knowledge from meaning information through induction/deduction as indicated below:

$$K_F \Leftarrow \cap\{I_{sy}\}. \tag{4}$$

$$K_V \Leftarrow \cap\{I_{pr}\}. \tag{5}$$

$$K_C \Leftarrow \cap\{\Re(K_F, K_V, I_{sem}, C)\}. \tag{6}$$

The symbols K_F, K_C and K_V in Eqs. 4 - 6 respectively stand for the formal, the content and the value knowledge while I_{sy}, I_{sem} and I_{pr} for form, meaning and utility information. The detailed description on general algorithms related to Eqs. 4 - 6 can also be referred to the reference.[14]

Note that the theme of data mining and knowledge discovery, very hot topics in literature these days, is in principle a special case of the transformation from form information to formal knowledge. Considering that most algorithms presented in data mining and knowledge discovery are statistics in nature, they may be assigned in the category of the algorithms expressed in Eq. 4. For example, a well-known data mining algorithm for association rules between sets of items in a large database in [14] is a typical inductive algorithm of this kind.

In addition to what discussed above, it is also important to note that a fundamental aspect of knowledge theory is the ecological properties of knowledge that has been ignored in almost all literatures till the present time. In accordance with the different degree of maturity in the process of its growth, knowledge can be classified into three categories: the empirical knowledge (the lower level of the degree of maturity), the regular knowledge (the standard level of the degree of maturity) and the common sense knowledge (the over matured level of the degree of maturity). All the three categories of knowledge are rooted from the instinctive, or inherent, knowledge. The corresponding definitions needed here are given below.

Definition 4. Empirical Knowledge: *The knowledge produced by inductive leaning yet without positive verification is termed the empirical knowledge denoted by KE. It may also be called the potential knowledge, or pre-knowledge.*

Definition 5. Regular Knowledge: *The regular knowledge, KR, can be defined as matured knowledge. It is the second stage of knowledge growth. The empirical knowledge may grow into regular knowledge if it was positively verified through a certain scientific means.*

Definition 6. Commonsense Knowledge: *Commonsense Knowledge, KCS, is such part of regular knowledge that has been over matured and well popularized.*

Learning and reasoning processes are not necessarily needed in this category of knowledge.

The relationship among the different categories of knowledge in the cycle of growth can well be explicated in Fig. 2 below.

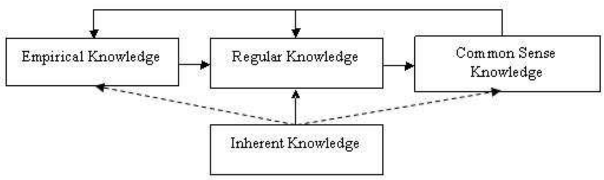

Fig. 2. Ecological link of knowledge.

It is seen from Fig. 2 that inherent knowledge is the root from which empirical, regular, and the commonsense knowledge can grow up one step after another with different degree of maturity. On the other hand, the commonsense knowledge also serves as bases for the growth of empirical and regular knowledge. It is well known that the inherent knowledge is the congenital one resulted from the long-term biological evolution whereas the empirical, the regular and the common sense knowledge are acquired through the process of training, learning and practice, but not innate.

It seems also worth of mentioning here that some parts of the commonsense knowledge may grow into inherent knowledge in next generations so that the inherent knowledge can be expanded from generation to generation. This may serves as a postulation needed to be proved in the future.

Transform 3. from Knowledge to Intelligence in Narrow Sense (Intelligent Strategy)

The major task for decision-making is not as simple as to make a choice from a set of alternatives as was described in many books, but rather it has to create an intelligent strategy guided by the prescribed goal and based on the related knowledge and information. The so-produced strategy itself can be regarded as an intelligent guideline, or intelligent procedure, for the system to follow for problem solving successfully.

Definition 7. Strategy: *Intelligent Strategy for solving a problem is a sort of procedure or guideline following which the given problem could be satisfactorily solved, meeting the constraints and reaching the prescribed goal.*

The transformation from the related knowledge and the specific information to the intelligent strategy, directed by the prescribed goal, can generally be expressed as

$$T_3 : (P, C, G; K) \mapsto S. \qquad (7)$$

The symbol T_3 denotes the transformational map, P the problem to be handled, C the constraints set up by the given environment, G the prescribed goal for problem solving, K the knowledge related to the problem solving and S the space of strategies.

Theoretically speaking, for any reasonably given P, C, G and K, there must exists a group of strategies such that the problem can be solved satisfactorily and among the strategies there may be at least a one leading to the optimal solution. The specific implementation of the transformation will be dependent, of course, on the properties of the problem given, the constraints, the goal prescribed, and the knowledge possessed, particularly on the type of acceptable strategy as stated in the following:

– If there is information related to P, C and G but no sufficient regular knowledge available and **empirically intelligent strategy** is acceptable, the empirical knowledge will be sufficient and the Eq. 7 can then be established via learning, training, testing and revision approaches. As has been well known in literature, the discipline of ***Artificial Neural Network*** [3,4] is proper means for this purpose.

– When regular knowledge is available and **regularly intelligent strategy** is demanded, the regular knowledge must be fully used in this case and the Eq. 7 could be implemented via a series of logic reasoning based on regular knowledge stored in knowledge bases. Obviously, this is the well-known approach of intelligent strategy formation called ***Expert System***,[7,8] or traditional AI sometimes. It may be necessary to mention that a well-known discipline, the Knowledge Engineering proposed by Feigenbaum et al in 1970s for dealing with the issues of knowledge reasoning in Expert Systems, is a typical example of the implementation of the Eq. 7 of this kind. The Eq. 7 may of course have more forms for implementation as logic theory develops in the future.

– Whenever **stereotyped intelligent strategy** is concerned, the common sense knowledge, including the instinctive knowledge and popular knowledge, will be used and the Eq. 7 could be implemented by directly linking the input patterns and the corresponding output actions. As long as the specific input pattern is recognized the related output strategic action can directly be determined with no reasoning needed. This is the typical feature of intelligent strategy formation in the category of ***Sensor-Motor Systems***.[9,10]

Up to this point, all the processes in the core transformations, conversing information to knowledge and then further to intelligence, have been described in brief in the section. It is seen that all the related algorithms needed for implementing the transformations are in principle feasible.

It has been clear that the two units of information cognition and decision-making are the two consecutive inner cores of the intelligent system: the former unit converses the acquired information into knowledge and the latter unit converses the knowledge, combining with the related information and the goal, into the intelligence. They are non-linear transformations in general cases and even often cannot be implemented merely by pure mathematical operations.

In summary, *the transformations briefly discussed in Section 3 do form the core mechanism of intelligence formation in general cases. What should be kept in mind is that it is the synergetic collaboration among all the transformations, expressed in Eqs. 1 to 7, that makes it possible for a system to have intelligence to a certain extent.* This is what we mean the core mechanism approach to AI research.

4. Concluding Remarks

As summary of the discussions carried on in previous sections, a number of contributions of the paper can be pointed out as follows.

(1) A new subject, Advanced Intelligence, has been set forth and defined clearly for the intelligence research.

The importance of intelligence research has been very clear and, on the other hand, the problems encountered by the three approaches to Artificial Intelligence have also been obvious. To remedy the situation, a new subject in intelligence research, namely Advanced Intelligence, was defined in the paper to guide the research in a more correct and more meaningful direction. Under the umbrella of Advanced Intelligence, it should be possible to gradually establish a harmonious theory unifying such important concepts as perception, consciousness, emotion, cognition and intelligence.

(2) A newer, and more advanced approach, the Mechanism Approach to AI, was presented in the paper.

It is recognized via investigation in depth that comparing with the structural, functional and behavioral features of any intelligent systems, the mechanism of intelligence formation is much more essential to the understanding of intelligence. Hence, the approach directly attacking the mechanism of the intelligence formation, the Mechanism Approach proposed in the paper, should be of much more significance than the others.

(3) The approaches to AI existed so far have been unified within the framework of Mechanism Approach.

Even more interestingly, as was discussed in previous section, the neural networks (an embodiment of structure simulation approach), the expert systems (an embodiment of function simulation approach), and the sensor-motor systems (an embodiment of behavior simulation approach) are three special cases of mechanism approach under different, and yet complementary, conditions. The Mechanism Approach can thus be regarded as *General Approach to Intelligence research* while the structure simulation, function simulation, and behavior simulation can be regarded as *special approaches.*

It is the authors belief that the Mechanism Approach to Advanced Intelligence will play important role in the research of intelligence science in the years to come. Furthermore, the author would like to discuss the issues on the Mechanism Approach to the research of consciousness and emotion in another paper in near future.

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