Cognitive Artificial Intelligence: Brain-Inspired Intelligent Computation in Artificial Intelligence

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***Abstract*—Computation occurred within human brain is very much awesome and is not possible to be emulated 100% exactly in Artificial Intelligence (AI) method-based machines. What scientists did and have been done so far up to now are to try to model it as close as to what exactly occurs within the brain. Human brain has an awesome mechanism in performing computation with the end result is new knowledge and human uses the knowledge to actuate his organs. In this paper we will show a new approach for emulating the computation occured within human brain to obtain new knowledge based on the inputs sensed by the system's sensory system taken from the environment. When this process is carried out recursively, the system's knowledge becomes newer and newer, and it is called as knowledge growing. This approach is designed for an agent that has ability to think and act rationally like human. Our cognitive modelling approach is resulted in a model of human information processing and a technique to obtain the most maximum performance should be taken by the cognitive agent. This method is called as A3S (Arwin-Adang-Aciek-Sembiring), the agent is called as Knowledge-Growing System (KGS) and this brain-inspired method opens a new perspective in AI that we call as Cognitive Artificial Intelligence (CAI).**

Keywords—A3S; Cognitive Artificial Intelligence; intelligent computation; knowledge extraction; Knowledge-Growing System

I. INTRODUCTION

Researches on intelligent agent has been done since a long time ago even though researches in this field started raising in the middle of 1990s. In real life, agent is defined as a thing that causes a significant effect on a situation. In order to give this effect, agent must have capabilities. "Capability" in this circumstance is the ability to manage when the tasks will be carried out, knows where to move, knows how to do the tasks, knows the success level of the tasks being carried out, and the consequences of the tasks being done. All of these capabilities are easy to be accomplished by human agent because he has five sense organs (eyes, ears, nose, tongue, and skin) as the sensors and other parts of the body such as arms and legs as the effectors. The main thing that enables the agent in performing its activities is the brain, a place where the information processing is carried out. This is the most grandeur that is not possessed by other living things.

In accomplishing the assigned tasks, the agent always senses its surrounding environment to get as much as information that can affect its activities. The gathered information is processed in its brain, combining it with the existing information, inferencing on the fused information, performing information-inferencing fusion to obtain new knowledge, and using the knowledge to create the most proper decision for actions to be done for future anticipation or coping with the environment dynamics. In many literatures, agent is stated must have an intelligent characteristic. However, because there is no uniform definition of what agent is. Therefore one common consensus which has been taken is, autonomy or we call this as self-governing, is the essential characteristic. Self-governing means the agent has capability to instruct itself to accomplish the tasks and do self-evaluation to value the success rate of the assigned tasks accomplishment for future enhancement.

The mechanism occurred within human brain from the start, namely sense the phenomenon occurs in the environment, do inference to the information regarding to the sensed phenomenon and continued with formulate the decision, make a decision and act to it, is simply represented by SIDA (Sense-Inference-Decide and Act) cycle in Fig. 1 which models the decision-making cycle occured within human brain.

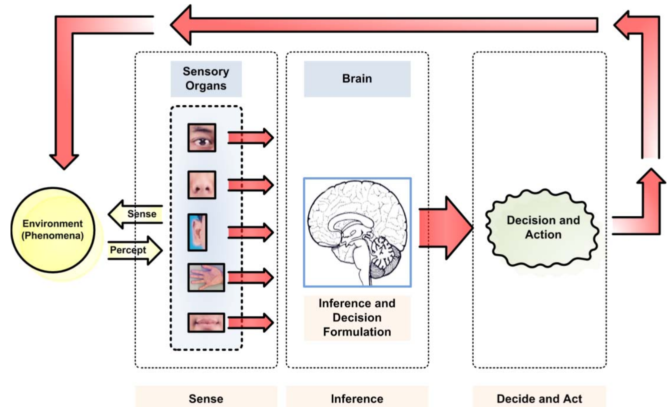

Fig. 1. SIDA cycle [1]

This is a continuous cycle and will never stop. Why? As long as human lives, his information processing system will always work to process the information delivered from his sensory organs. If we take a look deeper on the second phase of the SIDA cycle namely Inference and decision formulation, we

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can see clearly that the information delivered from the sensory organs will be inferenced to obtain inference that is, a guess of the sensed phenomenon. We also have known that the human five sensory organs. The brain can have knowledge from information sensed by only one sensor. But in most cases, in order to have more complete information regarding the sensed phenomenon, information from more than one sensors is more prioritized to ensure its validity. The information from more than one sensors firstly has to be fused before inferenced in the next process.

The process to obtain inference can also be said as inferring or inferencing but they are different. The different between the two words is not only in their definition but also on the usage of them. Inferring is defined as to derive by reasoning; conclude or judge from premises or evidences. On the other hand, inferencing is the practice of inferring the meaning of an unfamiliar word or expression from the meaning of familiar words occurring with it in a context together with one's knowledge of or beliefs about the world. Inferring just needs premises or evidences to obtain an inference but inferencing is more complicated because it requires knowledge to obtain an inference. Even though those terminologies come from psycholinguistic field, word “inferencing” has wider application other fields such as Artificial Intelligence (AI) field [2]. Inference as the guess of the sensed phenomenon will become brain’s new knowledge regarding such phenomenon and it will be used to guess the future phenomenon sensed by the sensory organs. **The process of obtaining an inference to become new knowledge is called as knowledge extraction**.

Brain is a living information processing system especially its ability to grow knowledge. The mechanism occurred within the brain that makes intelligence in human has been a mystery since a long time ago. Researches on human brain and how it creates intelligence have been done by various field studies including psychology, informatics, electrical engineering, mathematics, and social science. The increasing interest in the research on human brain created a new field called Artifcial Intelligence (AI). In this paper we will reveal a part of this mystery, a part of how human brain does computation to obtain new knowledge and uses it to solve real-life problems.

In order to give a concise explanation on our concept and the application of the concept, the delivery in this paper will be as follows. A short introduction regarding the essence of the paper has been given in Section I. Some essential theoretical background will be given in Section II, followed by Section III where we will show you the development of the method for knowledge extraction. An example on the method application to give a solution to a real-life problem will be given in Section IV. The last part is Section V where we give some remarks regarding the method as well as the next step of our research.

II. Theoretical Background

A. Models of Information Processing System

Essentially, information processing model is a theory of human development that uses the computer as a metaphor for explaining thought processes. Similar to computers, humans transform information to solve cognitive problems. Development is viewed in terms of changes in memory-storage capacities and use of different types of cognitive strategies [3]. On the other hand, information processing can be defined as the acquisition, recording, organization, retrieval, display, and dissemination of information [4]. Information processing model can be viewed from diverse disciplines ranges from psychology science to social and sport sciences. Therefore the models proposed are based on its own necessity. In this section we only take a look on three information processing models, namely Wicken’s model, Welford’s model, and Whiting’s model.

1) Wickens' Model: Wicken models the human information processing by dividing it into seven parts namely[4], sensory processing, short-term sensory store, perceptual encoding, decision making and response selection, response execution, feedback and information flow, and attention. Wicken’s model is used for giving an introduction of some of the basics of cognitive science that apply to Human Factors design, which in this case is given to people who work in aviation industry.

2) Welford’s Model: Another better known model is Welford’s information processing model as depicted in Fig. 3. As summarized by [6], this model has three processes namely stimulus identification stage, response identification/ selection stage, and response programming stage. The elements of the model are sensory input, short and long term memories, decision process, and action. The decision process is represented by a process named translation from perception to action which is a selection the most appropriate response from alternatives as the resulted of information processing. After the decision is made, the effector control controls which effector will do the response in term of action. This action is done to the phenomenon in the environment which is represented by external object

3) Whiting’s Model: Whiting’s model of information processing introduced in 1969 as comparison to Welford’s model. This model has seven elements [7] with some relevan modifications namely, things, input data, receptor systems, perceptual mechanism, translatory mechanism, effector mechanism, output, and feedback data. The most important matter in this model is the inputs from perceptual mechanism are directly processed by translatory mechanism to become knowledge to be delivered to effector mechanism.

B. Theories of Knowledge Generation

How knowledge is generated has been studied since a long time ago. The works in this field were done earlier researchers by such as Seymour Papert, Jean Piaget, and Lev Vygotsky. Even though they have different perspectives on the knowledge generation in human brain, they share the same idea that is later called as constructivism [8][9]. In its very simple definition, constructivism is a theory of learning or theory of knowledge (epistemology) which states that humans generate knowledge and meaning from experiences and interactions. Fundamentally, constructivists believe that humans “construct” their own knowledge and understanding through ideas, content, events, etc. that they come in contact with [8]. This theory is used extensively in education field in order to obtain the most

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appropriate techniques in teaching and learning [10]. We brought it into AI field.

The term "knowledge generation" in constructivism is the basis for our term of "knowledge growing". The important difference of those two terms is in the process in generating the knowledge. Instead of the knowledge is generated by experiences, the knowledge generation in knowledge growing term is carried out in just-in-time manner especially when humans interact with the world (environment). In the other words, the knowledge is grown from nothing to some extent that is satisfied for humans to understand the observed phenomenon. The initial knowledge that is stored in brain will be prior knowledge that will be used for growing new knowledge after humans perceive new information regarding the phenomenon

1) Psychological Perspective

From psychological perspective we review some human thought models and try to find their relations to our concept of knowledge growing in order to apprehend how inference occurs in human brain. Therefore our primary aim is to obtain a Human Inference System (HIS) model. It is not easy to find literatures on such models. Most of the models found are models for human information processing. Human information processing models are a good start for obtaining our HIS model. Within the HIS model there is a mechanism of growing the knowledge that can be apprehended by using human thought models.

There are some models that we consider as human thought models that had been proposed by some earlier researchers and practicians. These models include Galileo Model, Piaget Model, Feynman Model, Pooper Model, Cognitive Psychology Model, and Decision Cycle Model.

2) Mathematical Perspective

The way of humans thinks in general is full of judgement or always taking into account any information before making decision. This way of thinking shows that the way of human brain processes information it receives is in probabilistic manner or probabilistic thinking. Thinking is a method in finding and selecting amongst potential possibilities, that is, actions, beliefs, or possible personal objectives [11]. When thinking, the brain performs reasoning to form belief or certainty that is measured with a parameter called Degree of Belief (DoB) [12] or Degree of Plausibility [13], or Degree of Knowledge [14], or Degree of Certainty (DoC) [15].

Belief or certainty is a form of new knowledge which can be obtained directly or through argumentation, reasoning that is carried out deductively or inductively. The method that is related with argumentation part is probability theory because it treats different degrees (of belief) where the results are final or not [16]. History also shows that the most successful method up to now for handling uncertainties is with the application of probability [17]. The most mature probability-based method that has been used in AI for a long time is Bayes Inference Method (BIM) which computes all possible hypotheses given fact. The best hypothesis of all possible ones is selected by applying Maximum A Posteriori (MAP) technique or point estimation [18].

There are strong reasons why we selected BIM as the basis of our KGS. Firstly, humans' reasoning follows a complex version of BIM [19]; secondly, humans' thinking process is fundamentally a mathematical thinking process and its characteristic is probabilistic [13]; and last one, Degree of Knowledge or Degree of Certainty is an epistemic perspective [14]. BIM is only applied for finding the most proper hypothesis from multi-hypothesis faced to single-data. In reality, a decision or the most proper hypothesis needs multi-data in order to ensure its precision. For such cases, BIM has to be enhanced and its enhancement is called as Maximum Score of the Total Sum of Joint Probabilities (MSJP) method 2008 by [20]. The MSJP method is presented in (3).

$$P\left(A_i \middle| B_1 \,\&\ldots\&\, B_m\right)_{estimated} = \frac{\max\limits_{i=1,\ldots,n}\left(\sum_{i=1}^{n}\sum_{j=1}^{m} P\left(A_i \middle| B_j\right)\right)}{j} \quad (3)$$

where $i = 1,2,\ldots,n$ is the number of hypotheses and $j = 1,2,\ldots,m$ is the number of facts.

The MAP decision rule in Bayes method only takes the greatest value of a posteriori conditional probability from the available hypotheses as the best outcome. On the other hand, the MSJP method applies the total sum of joint (a posteriori conditional) probabilities from the available hypotheses and selects the greatest value as the best outcome. The use of $P\left(A_i \middle| B_1 \,\&\ldots\&\, B_m\right)$ notation represents fused (joint) probability of all a posteriori probability values obtained from the computation, while the word "estimated" indicates the selected fused probability is the most likely hypothesis.

C. Information Fusion

The information fusion originates from the examination of how human can make a decision or an action in accurate and quick manner after having much information regarding a certain situation. Besides that, human can also predict or estimate the situation that is probably occurred in the future by combining recent information with his previous knowledge. Human obtains much information from his sensing organs which comprises eyes, ears, nose, skin, and tongue. Based on this observation, the primary key of knowledge generation in human brain is information fusion. This mechanism we call as knowledge growing, meaning knowledge that is grown by the brain after processing information delivered from the system's sensory organs.

On the other hand, human also gains information from other information multi-source such as making communications with other people. After gathering information for multi-source, the brain does its job by fusing the information to become comprehensive information as the basis for decision making. This mechanism is called as human information fusion system and it is done continuously in human everyday life. This mechanism is depicted in Fig. 2.

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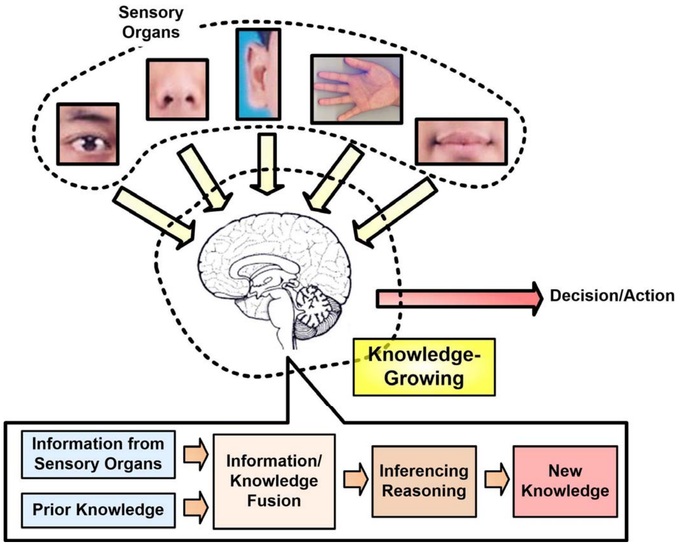

Fig. 2. Human information fusion system [21]

III. Brain-Inspired Intelligent Computation

In this section will be shown a new model that combines human information processing model and human information fusion model, the computation method for knowledge growing and the computation example on the use of mentioned method. Actually we have done some researches on a new field called knowledge-growing which have resulted two inventions namely new perspective on AI called Knowledge-Growing System (KGS) [22] and the method for growing the knowledge in KGS called A3S (Arwin-Adang-Aciek-Sembiring)[23]. A3S method is the enhancement of MSJP method.

A. Human Inference System (HIS) Model for KGS

Adopting the concept of human information processing models and human information fusion model, our HIS as the basis for our cognitive agen called KGS is depicted in Fig. 3. In this model we assume that any new information is a product of fused information that is perceived by two or more sensory organs or sensors. Based on HIS concept, we generalize the model to a system that is equipped with a set of sensors $\boldsymbol{n} = 1, \ldots, \boldsymbol{i}, \ldots \boldsymbol{\delta}$. Therefore, the number of fused information is $\boldsymbol{\lambda}$, so the number of fused information can be obtained by using (4).

$$\lambda = \left(2^{\delta} - \delta\right) - 1 \qquad (4)$$

Each fused information has an inferencing or a conclusion given information, data, events, facts, or indications perceived by the sensors. The inferencing becomes new knowledge if it is satisfied enough to describe the observed phenomenon in the environment. If not, the next process will be information-inferencing fusion after it receives new information at the next observation time.

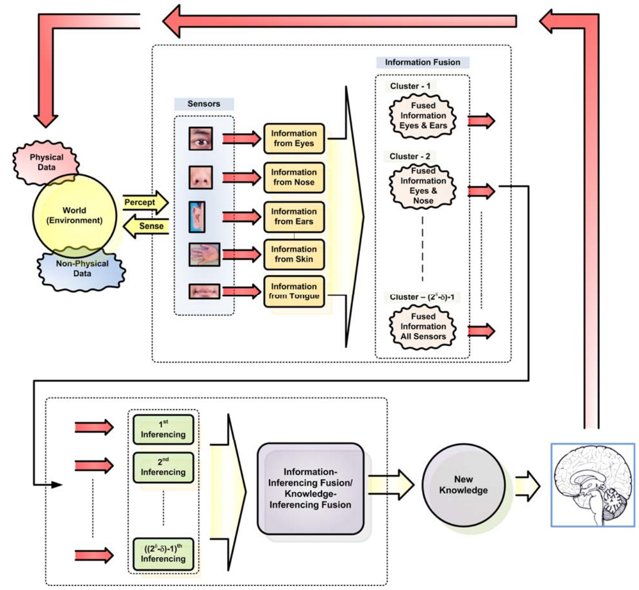

Fig. 3. Human Inference System (HIS) model as the basis for KGS[22]

B. Knowlegde-Growing as the Mechanism to Obtain New Knowledge – the Emulation of How Human Thinks

Inference and Decision Formulation in SIDA cycle is the phase where knowledge-growing mechanism occurs through fusion or combination of new information with the existing knowledge in order to obtaining inference or new knowledge. The algorithm of knowledge-growing mechanism is depicted in Fig. 4.

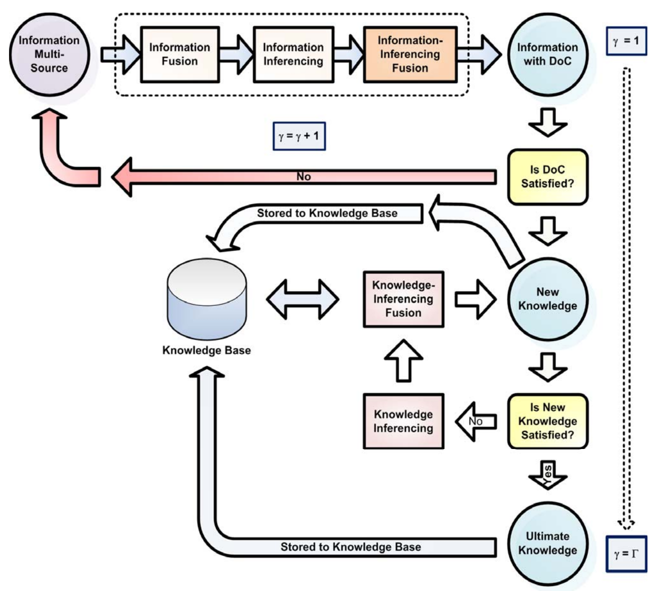

Fig. 4. Knowledge growing mechanism for brain-inspired KGS[23]

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Let us assume that $\delta = 1, \ldots, i, \ldots, n$ is the number of sensor or information source of information multi-source or multi-sensor, $\lambda = 1, \ldots, j, \ldots, m$ is a collection of hypotheses or multi-hypothesis of phenomenon regarding the information supplied by the multi-sensor. At the end of the computation, λ is also functioned as the numbers of fused information from multi-sensor that explain a collection of individual phenomenon based on the multi-hypothesis.

Notation $P\left(\upsilon_j^i\right)$ represents the probability hypothesis j is true given information sensed and perceived by sensor i. The Degree of Certainty (DoC) [23] represented by $P\left(\psi_1^j\right)$ defines that hypothesis j is selected based on the fusion of the information delivered from multi-sensor, that is, from $P\left(\upsilon_j^1\right)$ to $P\left(\upsilon_\delta^j\right)$ where $j = 1, \ldots, \lambda$. The subscript "1" in notation $P\left(\psi_1^j\right)$ means that the computation results are DoC at time 1 or the first observation time. This number is required if we want to have the next observation to be computed. The information fusion to obtain a collection of DoC is given in (1).

$$P\left(\psi_1^j\right) = \frac{\sum_{i=1}^{\delta} P\left(\upsilon_j^i\right)}{\delta} \tag{5}$$

where $P\left(\psi_1^j\right) \in \Psi$ and it is called as New Knowledge Probability Distribution (NKPD) [1][24]. This is a collection of information that can be furthered extracted to obtain inference or new knowledge. The inference or new knowledge at this point can be obtained by applying (6).

$$P\left(\psi_1^j\right)_{estimate} = \odot\left[P\left(\psi_1^j\right)\right] \tag{6}$$

where $\odot[\ldots] = \max[\ldots]$. This is a new notation proposed as a part of A3S information-inferencing fusion method which is the basis for KGS knowledge-growing mechanism [1]. $P\left(\psi_1^j\right)_{estimate}$ is the inference of $P\left(\psi_1^j\right) \in \Psi$ which later become new knowledge of KGS. The growing of knowledge over time is obtained by replace the first column of Table I to time parameter. The advancement of A3S method that already involves time parameter gave rise to new method called Observation Multi-time A3S (OMA3S) method and knowledge distribution resulted from the application of this method is called as New Knowledge Probability Distribution over Time (NKPDT) [23].

C. Knowlegde-Growing as the Mechanism to Obtain New Knowledge – the Emulation of How Human Thinks

Rational action is an action that maximizes its performance measure (in expectation) given the evidence provided by the percept sequence and whatever built-in knowledge the agent has [12]. Rational agent is an agent that is capable of maximize its performance and it is measured by DoC.

The mechanism occurred in Fig. 4 illustrates that the brain tries to guess or recognize the observed phenomenon or external object by collecting information through its sensory organs (multi-sensor). Actually in the beginning it knows nothing about the phenomenon. The knowledge acquired in one-time observation to it can be measured using (7).

$$DoC = \left|P\left(\theta_j\right)_{estimate} - \phi_1^j\right| \times 100\% \tag{7}$$

with $P\left(\theta_j\right)$ is information-inferencing of $P\left(\psi_\gamma^j\right)$ after several observation time to the observed phenomenon and ϕ_1^j is the knowledge probability of the most proper fused-information j which represents the observed phenomenon at observation time γ_1. In the case of knowledge extraction, (5) can be used to assess how good is the extracted knowledge compared to the true phenomenon being observed.

When the knowledge is not sufficient to recognize it, then multiple observation time can be carried out and utilize other sensory organs. When using different sensor, it may perceive the same observed phenomenon as different one. By using information from several sensors simultaneously, it will have more complete knowledge regarding the observed phenomenon. The knowledge acquisition in more-than-one observation time is carried out by using OMA3S in order to ensure sufficient knowledge has been acquired to recognize it. The quality of the grown knowledge is measured using (8).

$$DoC_{\gamma_i} = \left|P\left(\theta_j\right)_{estimate} - \phi_i^j\right| \times 100\% \tag{8}$$

where $i = 1, \ldots, n$ is number of observation time.

D. The Computation Example of A3S Method – Brain-Inspired Intelligent Computation

In this section we will deliver an example of the use of A3S method for extracting new knowledge from patterns of phenomena. We did this research in one of Indonesian national body and developed an intelligent information fusion system for decision support which is tasked to obtain new knowledge after given a series of pattern from a sensed phenomenon. The system has 42 indications as the generalization of sensors and 8 hypotheses as the generalization of possible answer of the sensed phenomenon.

If the indication is represented by a variable ID_i where $i = 1, \ldots, n$ and n is the number of indication. Then, the indications will be coded as ID_1 to ID_{42}. The same procedure applies to the hypothesis by representing it with H_j where $j = 1, \ldots, m$ and m is the number of hypothesis. Then, the hypotheses will be coded as H_1 to H_8. As the example, we only use 10 indications as the inputs to the system which then are given to the system via a form as depicted in Fig. 5. To obtain NKPD from the first observation, $P\left(\psi_1^j\right)$, just click "Submit" button and the result is shown at the left side of the form. Fig. 6 shows the graphic of NKPD and this result can be saved to be used for the next computation.

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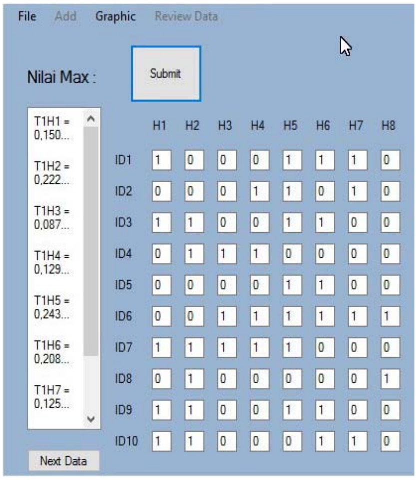

Fig. 5. The information as the inputs to the system is shown at the right side while the system's output in for of NKPD is shown at the left side with variable named $T_i H_j = P\left(\psi_1^j\right)$

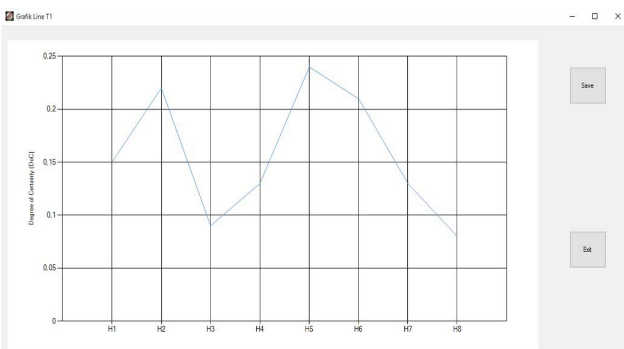

Fig. 6. The graphical view of NKPD

The new knowledge from the first observation can be exracted by applying (6) as follow.

$$
\begin{aligned}
P\left(\psi_1^j\right)_{estimate} &= \odot\left[P\left(\psi_1^j\right)\right] \\
&= \odot\left[0.15, 0.22, 0.09, 0.13, 0.24, 0.21, 0.13, 0.08\right] \\
&= 0.24
\end{aligned}
$$

The result shows that the $P\left(\psi_1^5\right)$ has the highest probability, meaning that H_5 is the extracted knowledge from a pattern of 0s and 1s of the sensed phenomenon given to the system as shown in Fig. 5. The DoC of the system at the first observation time regarding this new knowledge is obtained by applying (8) as follow.

$$
\begin{aligned}
DoC_{\gamma_1} &= \left|P\left(\theta_5\right)_{estimate} - \phi_1^5\right| \times 100\% \\
&= \left|0.24 - 0\right| \times 100\% \\
&= 24\%
\end{aligned}
$$

The process of obtaining new knowledge does not stop at the first observation. We did the second and third observation with the results in graphic form as depicted in Fig. 8.

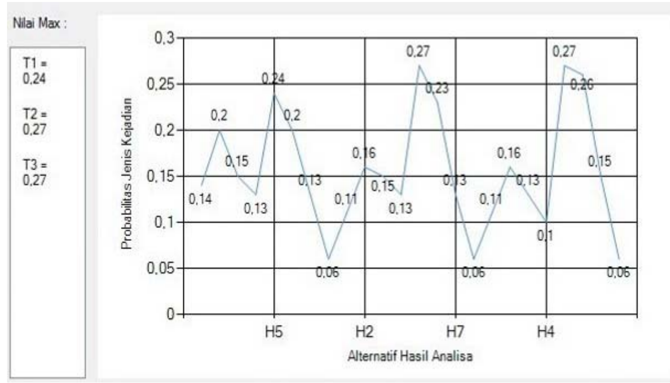

Fig. 7. The computation result from the second and third observation

The summary of all observations is given in Table I and its graphical view is depicted in Fig. 8. Because for the next computation we involve time as the measurement of the observation, so there is a slight change for the row variable.

TABLE I. CONFIGURATION OF TIME AND HYPOTHESIS

-t time	-j hypothesis							
	H_1	H_2	H_3	H_4	H_5	H_6	H_7	H_8
γ_1	0.14	0.2	0.15	0.13	0.24	0.2	0.13	0.06
γ_2	0.11	0.16	0.15	0.13	0.27	0.23	0.13	0.06
γ_3	0.11	0.16	0.13	0.1	0.27	0.26	0.15	0.06

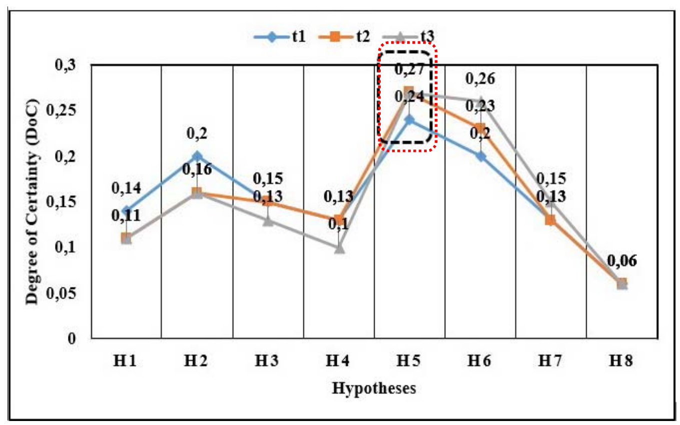

Fig. 8. This chart is graphical view of Table III to show the new knowledge extracted by the system after three observations over time

Directly, we can compute system's DoC in observation time at t_2 and t_3 for H_5 as follow.

$$
\begin{aligned}
DoC_{\gamma_2} &= \left|P\left(\theta_5\right)_{estimate} - \phi_2^5\right| \times 100\% \\
&= \left|0.27 - 0\right| \times 100\% \\
&= 27\%
\end{aligned}
$$

$$
\begin{aligned}
DoC_{\gamma_3} &= \left|P\left(\theta_5\right)_{estimate} - \phi_3^5\right| \times 100\% \\
&= \left|0.27 - 0\right| \times 100\% \\
&= 27\%
\end{aligned}
$$

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E. The Findings

From the computation example given in previous subsection, we have two proofs as follow.

1) We have proved human information processing models and human information fusion system can be combined into one model that is, Human Inference System (HIS). This model can be served as the architecture of human thought and as the guidance to develop Cognitive AI-based machines.

2) We also have proved that rational thinking carried out by human can be emulated by enhancing BIM to A3S method. The latter method is capable of handling a phenomenon which multi-hypothesis multi-data with the most proper decision as the answer to it.

IV. Concluding Remarks

Computation within human brain even though cannot be emulated 100% exactly, it can be approached from probabilistic method by apprehending that in many cases human thinks probabilistically. We approached this intelligent computation from agent perspective by devising a new model for human though called Human Inference System. Based in this model, we developed our own method called A3S (Arwin-Adang-Aciek-Sembiring) information-inferencing fusion method. The combination of those two is an approach to build an agent that thinks and act rationally like human as theorized by Russel & Norvig. Having proved our approach along with a real-life example, we are glad to declare that HIS model along with A3S method as the new approach to AI. Because our approach is based on cognitive modelling, we are also very glad to declare that our approach opens new perpective in AI called **Cognitive Artificial Intelligence (CAI)**.

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