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Cognitive Model-based Evolution Mechanism of the Information Status in Internet of Things

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Abstract: Object interaction in Internet of Things (IoT) should be dependent on intelligent information processing. Since, the information in IoT is heterogeneous, dynamic and somewhat unpredictable, straightening out the evolution process of information status is necessary for information management and processing. Firstly, the lifecycle of IoT information was analyzed by referencing and imitating the information processing system of human brain and the evolutionary mechanism of information status based on cognitive theory was expounded. Secondly, the information characteristics of each evolutionary stage were analyzed and some typical technologies of information management and intelligent processing were introduced. Finally, the comparative experiments to evaluate the effectiveness of the proposed method were given. The experimental results show that the algorithm is able to get the better solution by less target evaluation times and it can improve the optimization efficiency and realize intelligent processing of the information in IoT.

Key words: Internet of things, information evolution, information lifecycle

INTRODUCTION

Compared with traditional Internet, Internet of Things (IoT), Conti (2006) and ITU (2005) has some distinctive characteristics: Widely interconnected, thorough information perception and intelligent service (De Saint-Exupery, 2009). Intelligent information processing realizes reasoning and semantic understanding of sensing data, which is one of the most important technologies in IoT (Xiong and Chen, 2006). The results of information processing provide intelligent service to interactive objects. Information processing follows the resources development chain: Fact→data→information→knowledge→wisdom→innovation. The information lifecycle of IoT includes acquisition, organization, delivery, absorption, application and regeneration. Information status evolutionary patterns can be inferred from its lifecycle.

In this study, the lifecycle of information in IoT was analyzed by imitating the information processing system of human brain and the evolutionary mechanism of information status based on cognitive model was expounded. These would be laid a foundation for the implementation of intelligent information processing under the environment of IoT.

INFORMATION PROCESSING IN IOT

Information processing is one of core content of IoT. IoT obtains data by perceiving the behavior of objects and new knowledge is generated through data mining and integration of related knowledge. Then, new knowledge forms the strategies and they are applied to physical objects in the real world. Since, the data of IoT is heterogeneous, mass-scale and somewhat unpredictable, using new methods and technologies in conjunction with existing technologies is necessary for information processing. According to the information processing of human brain, the lifecycle of information in IoT is divided into three stages, that is knowledge content, application environment and knowledge cognition. In this process, the information granularity becomes larger or smaller according to the requirement and the transformation is occurred in the form of syntax, semantics and pragmatics, the information may be associated with each other and so on. The information statuses are natural dynamic, relevant and orderly. Thing-to-Thing and Human-to-Thing interaction in IoT are dependent on intelligent information processing based on a cognitive model. The lifecycle of information in IoT is shown in Fig. 1.

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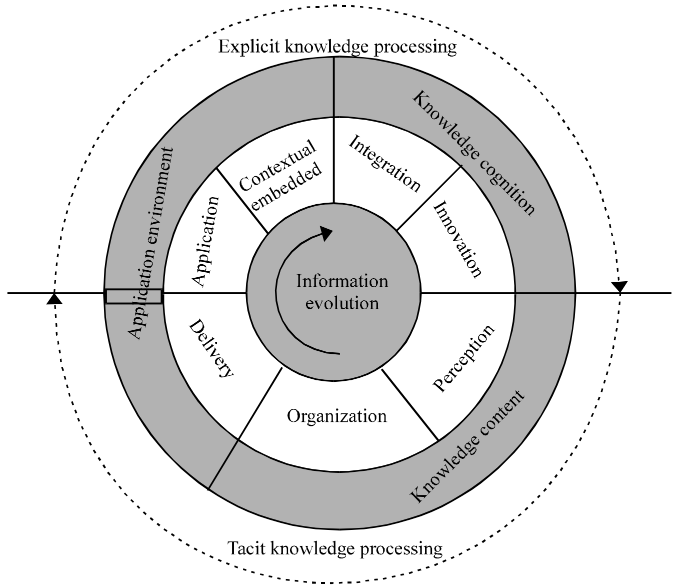

Fig. 1: Lifecycle of information in IoT

Knowledge content: Knowledge content means the transformation from physical sensing data into logical data which is easy to understand by machine. It includes data perception and organization:

- **Data perception:** In order to sense an event in IoT, it requires the deployment of many types of sensing devices to monitor different attributes of the event. They can detect external environmental signals, including heat, power, light, electricity, sound and others and can provide the raw data which for data transmission. Data perception is occurred through the integration of sensing data (Nakamura and Loureiro, 2008). Multi-sensor information integration process and analyze the sensing data through smart technologies, such as data mining, optimized algorithm, machine learning and so on. These technologies can be divided into probability statistics-based methods and Artificial Intelligence (AI)-based methods. Bayes and alternative methods are typical probability statistics methods (Messaoudi *et al*., 2010). AI methods mainly include D-S evidence reasoning (Basir and Yuan, 2007), fuzzy and rough sets (Zhou *et al*., 2013), Artificial Neural Network (ANN) (Zhou, 2009), Support Vector Machine (SVM) (Wang *et al*., 2010), Genetic Algorithm (GA) (Zhou and Sun, 2005) and so on. Data perception includes feature extraction, data association, state estimation, classification and recognition
- **Data organization:** Data organization mainly realizes all kinds of sensor data is stored by a unique schema. In order to implement information fast retrieval, distributed storage strategy is used. There are mainly three kinds of data structures: logical representation, rule representation, semantic network and frame representation

Application environment: Application environment includes delivery, application and contextual embedded. In this stage, it realizes knowledge retrieval and application according to interactive object and application environment:

- **Delivery:** IoT is consist of numerous distributed information resources. It is necessary to develop intellectual retrieval for searching and discovering such resources according to object's capabilities, location and/or the information they can provide (e.g., indexed by the unique IDs of objects, transactions etc.). The intellectual retrieval mechanism of search engine is the key technology, includes searching on the basis of object or attributes matching, applying data mining on sensor information, analyzing interactive object's information demands and offering individual and specialized searching service. For efficient search and discovery, metadata and semantic tagging of information is very important. It must ensure that the information can be generated without human intervention. It is also notable how to establish cross-referenced between the terrestrial mapping data with logical locations and establish the search and discovery mechanisms are able to handle criteria involving location geometry concepts, such as spatial overlap and separation

- **Application:** Application is based on semantic interconnection and intelligent integration between knowledge contents, according to object's own needs. Knowledge application is as service to achieve. These services play a key role in the mapping between physical objects and their digital and virtual counterparts from a multitude of fragments of information owned and provided by different objects. These services will be utilized not only by human but also by smart objects. A smart object is an object that can describe its own possible interactions. They help to gather complete sets of information from across diverse sources, in order to support smart objects with their needs for transportation and handling, heating/cooling and so on. The issues of knowledge application are to be stated: (1) Device discovery, positioning and localization; (2) Mapping of real, digital and virtual objects; (3) Terrestrial mapping data, semantic tagging and search; (4) Universal authentication mechanisms
- **Contextual embedded:** The encoded knowledge is decomposed into smaller granularity and is embedded in a specific application in this stage. Contextual embedded is to perceive and understand the environment of objects. As an object moves through the real world in IoT, it will encounter different environments and both the smart things and other agents. It requires situation embedded discover what capabilities are available within the local environment of the object. It will discover the existence and identity of related objects and their locations. Locations might be expressed as abstract or logical locations, which are expressed as 3D terrestrial spatial location co-ordinates. One challenge of the contextual embedded is to exploit the changing environment with a new class of applications that are aware of the situation in which they are moved. Three principal aspects of contextual embedded are: where the object is, who are with it and what resources are nearby

Knowledge cognition: This stage includes knowledge integration and innovation. Knowledge integration is the process of incorporating new information into a body of existing knowledge. Knowledge innovation realizes knowledge assimilation and regeneration. Prior knowledge base is updated through knowledge integration and innovation:

- **Knowledge integration:** This process involves identifying and evaluating the interaction between new and existing knowledge and how the new information should be modified in light of the existing knowledge. Knowledge integration is one of the most critical components of information evolution mechanism, which can integrate the sensor information in order to generate new knowledge. It can also optimize their structure and provide knowledge-based service during the integrating process. Knowledge integration is valuable for research on knowledge discovery and how to create, organize, evaluate and optimize new knowledge objects (Pan *et al*., 2003)
- **Knowledge innovation:** Knowledge innovation is the core of intelligent information processing, which will be processing the objective things and revealing their distinguishing features based on the prior knowledge. Through understanding and grasping the characteristics of the object, its basic meaning and the internal logic can be brought into the cognition structure. The substance of knowledge innovation is the formation of cognition structure that is highly summarized (Lu *et al*., 2010). Depends on the priori knowledge reorganization, it is possible to understand the recent correlation and new aspects of the object. Knowledge innovation has the generality and the indirectness. The generality is to extract the essential common features and law of class, so as to recognize the properties of such things and the relationship with other class. The indirectness is to find universal relations or inevitable relations from the fact that some things are interconnected and to be extended to the analogous phenomena

EVOLUTION MECHANISM OF THE INFORMATION IN IOT

For the cognitive model-based evolutionary framework of information status in IoT, five stages are defined: Information perception, memory storage, creative thinking, evaluation system and execution module. It is depicted in Fig. 2:

- **Information perception:** The main purpose is mapping information for knowledge. It is divided into two steps: Information sensory and information perception. Information sensory is defined as follows.

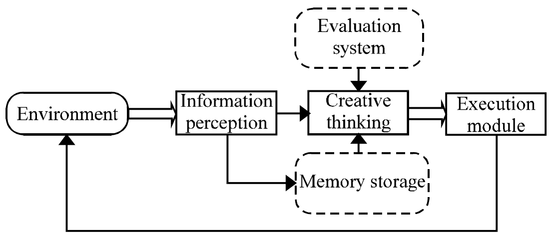

Fig. 2: Cognitive model-based evolutionary framework of information status in IoT

F-sense (A, B, C, ...) = S1 (a, b, c, ...), F-sense (A, B, C, ...) denotes information sensory processing; A, B, C is the set of certain types of information collected; a, b, c is the accurate value of certain types of information collected. Information perception is defined as follows.

F-perception: S1 (a, b, c, ...) 6→KC, F-perception: S1 (a, b, c, ...) denotes information perception processing; KC is knowledge cluster and is defined as follows:

$$KC = \{(tar\_o, (ro_1, ro_2, ..., ro_i), (r_1, r_2, ..., r_i) | ro_i \in O, r_i \in Re\}$$

where, tar_o denotes target object; ro_i is related objects; O is the set of objects; Re is the set of relationship between the target object and the related objects.

The process of information perception is as follows:

- RO = ϕ; R = ϕ; S1 = ϕ; // RO is the set of related objects, R is the set of relationship, *S*1 is the set of sensory information
- for i = 0 to FS. length do //FS is the set of all kinds of sensory information
- F-sense (fs_i)
- S1.add (new $sense_i$)
- end
- RO⇐Pattern_rec(*S*1) // Pattern_rec() is a function about object recognition
- tar_oZtar1
- for i = 0 to Ro.length do
- if (r_i = Relate (tar_o, RO_i) >Δre // Relate () is a function about Correlation, Δre is threshold;
- $HashSet_o$ ⇐RO_i, $HashSet_r$⇐r_i
- end
- end
- KC = {tar_o, $HashSet_o$, $HashSet_r$}

Memory storage: Memory storage includes long memory storage and short memory storage, is defined as follows: M = <LTM, STM>, STM is mainly used to store clusters and the data for innovative thinking. STM is defined as STM = $\{kc_i | i = 1, 2, .., n\}$, where, $kc_i = < D_{kc_i}, t_{kc_i} >$, D_{kc_i} is stimulus intensity, which denotes the impact of kc_i on target environment, t_{kci} is storage time. LTM is defined as.

LTM = $\{ku_i | i = 1, 2, ..., n\}$, ku_i is knowledge unit. KU (Knowledge Unit) is defined as follows:

$$KU = \{(sg_i, sg_j, r_{ij}) | sg_i, sg_j \in \Omega, r_{ij} \in SG_{Re}\}$$

where, Ω is sub-target space, SG_{Re} is the set of relationship between the sub-targets.

- **Innovative thinking:** Innovative thinking is divided into two steps: Divergent thinking and convergent thinking. Divergent thinking is the process of knowledge units reorganized. It includes two steps: Memory retrieval and knowledge assembly. Memory retrieval achieves knowledge unit extraction by its fitness and storage time in LTM. The memory retrieval model is established as follows:

$$GK(ku_i)=F_{ku_i}e-\lambda t_{ku_i}$$

where, GK (ku_i) is extracted strength, F_{kui} is fitness. The extracted knowledge units are assembled knowledge structure. For example, knowledge structure can be represented with tree. Knowledge Structure Tree (KST) is defined as follows.

KST = <g,SG, DB, P>, g is target node. It reflects the purpose of divergent thinking. SG is the set of sub-target nodes. DB is the set of edges. P is the relationship parameter of each node to maintain.

For example, the knowledge units are provided:

- A→D
- A→B→D
- C→B
- C→A→D

If D is selected as the target node, this KST is assembled as Fig. 3.

The knowledge path C→B→D (Fig. 3) shows does not exist in the extracted knowledge units, it is generated by C→B and A→B→D assembled. This shows that divergent thinking has the capabilities of combining innovation. Convergent thinking chooses optimal solutions from the KST by convergence operation, modification operation and innovation operation. Convergence operation is defined as follows.

Focus() = <f (kp_i), n_{con}>, where n_{con} is convergence latitude, f (kp_i) = V_{kpi} (KST), f (kp_i) is focus function, V_{kpi} (KST) is the value of the i-th knowledge path of KST. Modification operation is defined as follows.

Modification() = <sg_i, G, E, R>, where sg_i is modified sub-target, G is the desired goal, E is the environment of modification operation, R is resource constraints. Innovation operation is defined as follows.

Innovation (FKP_{sgi}), FKP_{sgi} is the i-th sub-target on focus knowledge path.

- **Evaluation system:** The main purpose of the evaluation system is to assess the satisfaction of the solution. It is defined as follows:

$$\mathrm{SAT}(\mathrm{KST}_{kp_i}) = 1 \frac{V_{ge} - V(\mathrm{KST}_{kp_i})}{V_{ge}}$$

where, V_{ge} is the expected value of the target; V (KST_{kpi}) the value of the i-th knowledge path, it defined as follows:

$$V(\mathrm{KST}_{kp_i}) = w_1 V(kp_i(sg_1)) + w_2 V(kp_i(sg_2)) +, ..., + w_j V(kp_i(sg_j))$$

where, w_j is weights, V ($kp_i(sg_j)$) is the value of the j-th sub-target to achieve the overall goal on the i-th knowledge path.

Process of information status: The process of the cognitive model-based evolutionary mechanism of the information status in IoT is shown as follows:

1. Parameter initialization: C_{LM}, n_{con}, cre_style; //cre_style is innovative style
2. F-sense (fs_i)⇒S1; // information sensory processing
3. KC_construct(S1)⇒STM; // information perception processing
4. ku_I = learn (TSM)⇒LTM; // knowledge learning process
5. Divergent (STM, LTM)⇒KST;
6. SAT (KST_{kpi}):
    Focus (KST_{kpi});
    if cre_style = 0
        Static innovation;
    else
        Dynamic innovation:
if $\alpha^* \geq$th
        modification (sg_i, G, E, R)⇒ku_{new};
else innovation (FKP_{sgi}) ⇒ku_{new}
7. execution (ku_{new}) and $ku_{newYLTM}$;
8. evolution (LTM_{ku});

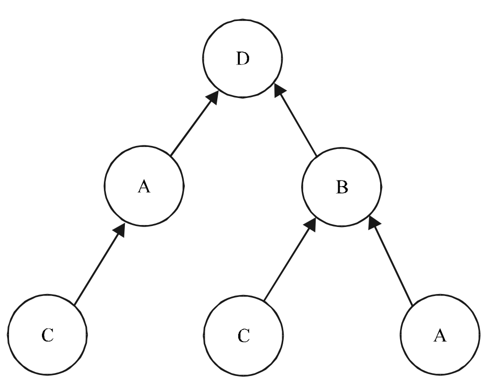

Fig. 3: A Knowledge Structure Tree ,¨D as the root node of the tree

RESULTS

To evaluate the effectiveness of the proposed information evolution method based on cognitive model, the method is named as ICEA (Information Cognitive Evolution Algorithm) are compared with other Artificial Intelligence algorithms which are called Genetic Algorithms (GA), Estimate Distribution Algorithms (EDAs) and Ant Colony Optimization (ACO). Parameter settings for each algorithm are shown in Table 1.

Table 2 shows the comparison of average distance, average time and average assessment value between different algorithms.

The experimental results indicate that ICEA and EDAs have higher optimization consequences than GA and ACO. The average time of ICEA is much higher than other algorithms because it requires complex learning and thinking operation. The divergent thinking module will consume more run time with the knowledge units gradually increased in LTM. This shows that it has a higher knowledge utilization rate. Average assessment value of ICEA accounted for 4.5-8% of the other algorithms. ICEA, it can greatly reduce the objective evaluation time.

Through analyzing the experimental results, ICEA has higher efficiency than GA, EDAs and ACO algorithms which are commonly used in current. It can be improved efficiency, through using knowledge and the creative thinking process.

The proposed information evolution method can realize information process in reference to the relative research achievements in brain cognitive theory. It is compared with previously published studies, which has the following significant characteristics: The process of ICEA evolution can be explained, because it direct

Table 1: Parameter values used in experiment for ICEA, GA, EDAs and ACO

Algorithm	Parameter settings
ICEA	C_{LTM}=50, C_{STM} = 10000, n_{con}= 1, cre_style = 1
GA	Populations = 80, iterations No. = 50, crossover probability = 0.9, mutation probability = 0.1
EDAs	Populations = 300, iterations No. = 50, selective probability = 0.2
ACO	Information heuristic factor = 0.8, expected heuristic factor = 0.6, pheromone evaporation rate = 0.5

GA: Genetic algorithms, EDAs: Estimate distribution algorithms, ACO: Ant colony optimization

Table 2: Experimental comparision results of the of ICEA and GA, EDAs, ACO

Algorithm	Average distance	Average assessment value	Average time (sec)
ICEA	6.215	220	9.27
GA	5.450	2500	8.15
EDAs	6.273	4520	0.42
ACO	5.875	2980	5.16

GA: Genetic algorithms, EDAs: Estimate distribution algorithms, ACO: Ant colony optimization simulates human cognitive behavior and in accordance with human cognitive habits, while the other information process algorithms do not have this characteristic. This algorithm treats knowledge as a core and information process as a knowledge-based innovative thinking process. This method fully develops innovative thinking skills of knowledge in an information process. It is a further attempt to convert the abstract conception of brain cognitive science to specific and operable research routes and strategies.

CONCLUSION

Studying on information evolution mechanism of IoT is helpful to straighten out information evolution process and to understand information status in different developing periods. With the information evolution mechanism as infrastructure, some pertinent psychological intelligent information processing for improving the quality of knowledge service has been supplied.

However, information evolution mechanism based on a cognitive model in IoT is still in the preliminary stage. The formalized definition of information in each stage deserves serious study. The dynamic environment constructing mechanism, knowledge automatic adaptation and knowledge evolutionary algorithm are the essential future work.

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