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SEMANTIC COLLABORATION AND SENSING AS A SERVICE IN SEMANTIC WEB OF THINGS

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Abstract- The intrinsic contradiction hidden in the Internet of things, which is the mismatching between the diversification of forms expressing the thing's information and the insufficiency of understanding ability of the agents using the thing's information, hinders its intelligent development. Adding a semantic annotation for the expression of thing's information based on ontology will improve the ability to understand, to reason and to obtain information for the agents, and will essentially promote the Internet of things to "semantic web of things". For semantic web of things, its open and dynamic natures inevitably determine it is an open service ecosystem, and whether the hyper world itself and the individual in their sub worlds are in continuous development and evolution, so the semantic web of things must be self-adaptive to provide semantic collaboration services. To achieve all, this is based on "sensing as a service". From different points of view, such as dynamic space, service collaboration and web-based context management services, we analyze semantic collaboration

mechanism. Respectively put forward self-adaptiveness formulas and self-adaptive support framework of semantic web of things, propose the definition and architecture of semantic web of things and present sensing as a service model. This paper discusses semantic coordination mechanism and key support technologies for semantic web of things, which lay a theory and technology foundation for subsequent semantic collaboration application schemas, and the application experiments, validation and evaluation of semantic collaboration support system.

Index terms*:* Internet of things, semantic web of things, semantic collaboration, semantic self-adaptiveness, sensing as a service.

I. INTRODUCTION

In the Internet of Things (IOT) [1], an operating scene is described as: if a RFID (radio frequency identification devices) reader [2] scans RFID electronic tags which are embedded in some things, the information will be uploaded into the internet and global authorized users can browse and use it [3]. The conceived scene can be summarized as "three steps" (uploading the thing's information +transmitting the thing's information over great distance + downloading the thing's information) and "two kinds of agents" (the agents publishing the thing's information and using the thing's information). During uploading and downloading the thing's information, the different natures of the two kinds of agents (such as the professional, the ordinary or the computer) and the different constraints (having the chance to choose information or only passive receiving information) leave an inherent conflict in the structure and operation mechanism in the IOT. That is, the function mismatching (conflict) between the two kinds of agents (with respect to the structure of the IOT) in the course of uploading-transmitting-downloading the thing's information (with respect to the operation mechanism in the IOT).

Firstly, the publishing agents will express the thing's information in different ways. Indeed, experts do not use the same terms to represent same things or do not describe them in the same manner (e.g., fog/foggy). The IOT is open and distributed, that is, the publishing agents at different endpoints can independently upload the thing's information to the internet or other special network (such as sensor network and so on).Although the agents can use the specified UID or EPC code, the codes only realize unity and specification (standard format) for information representation, and not give mandatory requirements about the method to choose terms for the same thing (that is, the terminology standardization). This will lead to such a situation: the information of the same thing will have diversified expressions uploaded to internet by different publishing agents, such as the same thing may have expressions "PC", "CPU" and "Computer", etc.

The using agents are lack of the ability to understand the things' information. Accordingly, different kinds of information, which appear on the screen before the using agents are likely to refer to the same thing. To deal with the situation and correctly understand the information, the using agents must have good knowledge background. For example, they should know "PC", "CPU" and "Computer" are equivalent. Unlike the publishing agents who are professional, the using agents are mainly ordinary and the computer is a more ideal alternative. The original intention on proposition of the IOT is global information sharing, not only for ordinary people but also for computers, and it is more important for the latter to be able to understand and do further intelligent processing. However, both ordinary people and computers are lack of related knowledge background, which leads to incomplete, inaccurate or ambiguous understanding of the thing's information received from the IOT.

Summarizing the above analysis, it is concluded that the inherent conflict hidden in the IOT is diversified forms of the thing's information(caused by the openness and distribution of the IOT) and the insufficient ability to understand the publishing information (whereas the aim of the IOT is to realize ordinary people can use information and computers can automatically process), that is, the object's diversity and the agent's insufficient ability is the intrinsic contradiction and restricts its further intelligent development.

In this paper, Starting from the inherent contradiction of the IOT, we regard Semantic Web of Things(SWoT) [4] as a solution of the internal contradiction in the IOT, and deem semantic collaboration and self-adaptiveness not only the key to realize the SWoT, but also the key to achieve "harmony intelligence" in the SWoT. Only depending on semantic collaboration and self-adaptiveness can we realize the harmony among information/computers, things and people in the SWoT on the basis of the IOT. Therefore, from different points of view, such as the dynamic space, service collaboration and web-based context management services (WCXMS), we analyze semantic collaboration mechanism. Respectively put forward self-adaptiveness formulas and self-adaptive support framework of SWoT. In the SWoT, the open service ecosystem, "Sensing as a

Service" (SenaaS) is the implementation foundation of semantic services and semantic collaboration, so the SenaaS model diagram is proposed in this paper at last.

II. THE SIGNIFICANCE OF THE SWOT

a. The SWoT: a solution of the internal contradiction in the IOT

Actually, the inherent contradiction in the IOT is very similar to a situation "reader cannot read reading ". To achieve the goal of "read", an effective solution is that authors write books more accessible and readers improve their cultural level. However, the former is bad for the publication of the high level theoretical readings; the latter is subject to many factors. More universal and feasible alternatives measures are adding annotation or labeling in readings to help reader understand (e.g., comments and phonetic notation) and stocking general tools(such as dictionary and so on) at readers' hand.

Similarly, improving the application effect of the IOT should also start from two aspects, long-term and short-term. A long-term fundamental solution: Firstly, if the thing's information is written to a RFID electronic tag, the information should fully comply with the global unique terminology standard and format. Secondly, the understanding ability of the agents using the thing's information should be improved. Obviously, the two aspects are not problems that can be solved within the category of the IOT by means of technology or management measures, but problems that can be solved by the integral improvement of global integration. Short-term feasible measures: On the one hand, for the thing's information recorded in the RFID, we should select "standard terms" from a "standard dictionary" which is recognized as a global one; add them to the thing's information in semantic annotation or labeling ways (specifically, the standard terms should be related with each other without semantic conflicts). On the other hand, the using agents around the world (ordinary people, more meaningful computers) should stock the "standard dictionary" at hand (or can obtain it via the network in real time). Cooperation of the two aspects make some information uploaded by the agents all over the world can be "read" by ordinary people and computers. The "standard dictionary" is the knowledge base known as "Ontology" in the field of information science.

The semantic annotation and the introduction of ontology will greatly improve the using agents'(mainly computers') ability to understand information and to further reason so as to obtain the related information, thus the function of the IOT will be intrinsically improved, and the IOT will be essentially promoted to the successor, which can be called SWoT.

The SWoT, which has been regarded as a solution of the internal contradiction in the IOT, is not the simple sum of the IOT and the semantic web but the successor of the IOT, because the syntax matching (that is, keyword matching) in the predecessor will be displayed by the semantic matching (that is, meaning matching) in the successor. Recently, there have been many scholars to explore how to add semantic annotation to the IOT[4-10]. The following figure1 illustrates the relevance between the two internets.

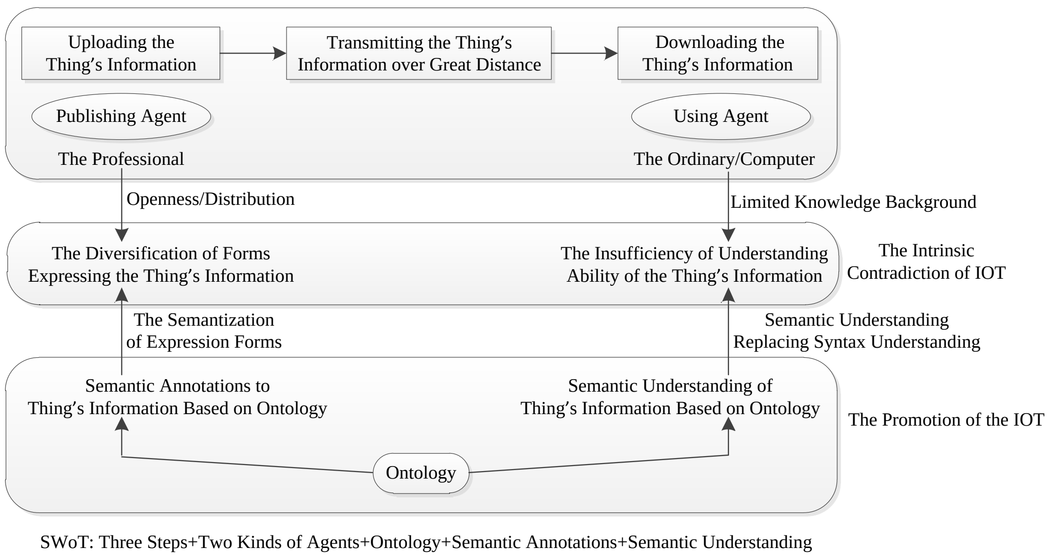

Figure 1. Relevance between the IOT and SWoT

b. Semantic collaboration: the key point to accomplish the SWoT

In figure1, it is clear that the emergence of the SWoT will be inevitable, and an objective logical sequence is: the IOT → it's intrinsic contradiction in the IOT(the diversification of forms expressing the thing's information + the insufficiency of understanding ability of the agents using the thing's information) → targeted improvement (semantic annotations to the thing's information based on ontology + semantic understanding of the thing's information based on ontology) →SWoT.

Unlike the IOT, the semantic in the SWoT means the semantic annotations to the thing's information based on ontology leaded by the publishing agents (the professional) and semantic understanding of the thing's information based on ontology leaded by the using agents (the ordinary/the computer). Hereinafter, the semantic in the SWoT is referred as semantic collaboration for the SWoT, which is the practical application of semantic collaboration in the IOT and the key point to accomplish the SWoT.

The term semantic collaboration means that multiple agents distributedly comply with some accepted standards to achieve information interchange and information sharing at the semantic level. Semantic collaboration is thought to be synonymous with Semantic Interoperating, and both of them aim at semantic interoperability. But the latter, which is authoritatively defined by ISO/IEC2382, is the concrete realization of interoperability.

Generally, interoperability can achieve the following levels, including morpheme level, lexical level, syntactic level, grammar level, semantic level and pragmatic level; interoperability can achieve following degrees, including conflict level ,chaos level, coordinative level, collaborative level and harmonious level. Semantic collaboration aims at reaching the semantic interoperability with the level of semantic layer and the degree of collaborative level. An interesting prediction is the semantic collaboration will eventually evolve into semantic harmony, pragmatic collaboration or pragmatic harmony.

Semantic collaboration itself means interchanging and sharing information annotated with semanteme (that is, the information attached with semantic annotation), and the semanteme are from an accepted domain ontology.

Semantic collaboration for SWoT means that, based on ontology of the SWoT, multiple distributed publishing agents (the professional) add semantic annotation to all the thing's information, which will be uploaded, and multiple distributed using agents the thing's information(the ordinary/the computer) download and understand the annotated thing's information.

Semantic collaboration for SWoT is the key point to realize the SWoT. Unlike other semantic collaboration, the Semantic collaboration for SWoT of things has following characters: the number of the two kinds of agents is numerous, because the production and consumption of things are the most basic human activities; the computer becomes the important using agents; the number of information category is only one, because the category of interchanging and sharing information is mainly the thing's information; two kinds of activities are semantic annotations to the thing's information based on ontology and semantic understanding of the thing's information based on ontology.

At present, the IOT has been established as a key strategy in national development, while the SWoT is one of the ideal realization forms of the IOT in academic community [11-14].

III. THE UNDERSTANDING OF SEMANTIC COLLABORATION

a. From the perspective of dynamic space

As mentioned above, as the successor of the IOT, the SWoT is similar to the IOT with openness and distribution, so publishing and using the same information need the support of related knowledge background "semantic" to correctly and comprehensively understand information in the SWoT. And the formal formula of semantic collaboration for the SWoT is as follows:

$$\begin{aligned} &\text{Semantic Collaboration} \\ &= \text{semantic annotations to the thing's information based on ontology} \\ &\ + \text{semantic understanding of the thing's information based on ontology} \\ &= \text{Semantic Matching}_{(\text{ontology, information})} \\ &\times (\text{Semantic Annotation}_{(\text{the thing's information})} + \text{Semantic Understanding}_{(\text{the thing's information})}) \end{aligned} \quad (1)$$

SWoT is open, distributed and dynamic, so the semanteme is directly affected by the agents publishing the thing’s information and the agents using the thing’s information is dynamically affected by its time, is closely related with its context. Generally, only contacting the word or sentence with its context can we understand its meaning better. Whereas, a semantic context means the semantic environment and the semantic interoperating environment, namely, the environment of service consumer (including service requests) and the environment of service provider. The three-dimensional dynamic relationships among the semanteme, the agent, the context and the time are shown in figure 2.

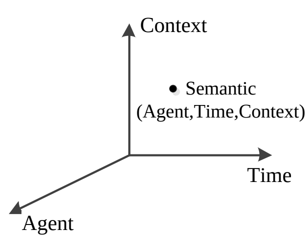

Figure 2. Semantic three-dimensional space

b. From the perspective of service collaboration

From the point of providing sensing service and semantic service in web-based context management services (WCXMS), the semantic collaboration for SWoT can be understood as a semantic collaboration triangle. It can start from obtaining sensor data and service requests (SD&SR), then process the sensor data based on the current context (including service requests, etc.)by semantic and context processing(S&CP) to gain the context knowledge (CK). After that, based on the context (including service requests, etc.) and the results of semantic reasoning, the service environment(SE) can make service decisions, drive sensing equipment(SE) to complete the service decision actions(SDA) and feedback decision strategy to the service consumer(SC). As mentioned, the figure of the semantic collaboration triangle is shown in figure 3, in which Sensing Equipment & Service Consumer is abbreviated as SE&SC.

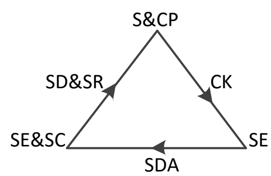

Figure 3. Semantic collaboration triangle

c. From the perspective of WCXMS

Presently, in terms of research hot spot in the IOT, because the SWoT can properly solve the inherent contradiction in the IOT, so it is essential the intelligent promotion of the IOT. In SWoT, every agent can be aware of both itself and its surrounding to provide the right service for the given agent at a given time and context. The SWoT is a hyper world[15-16], which is composed of three parts, namely: a physical world composed of things (the physical world), a network world mainly composed of information and computers(the cyber world), and a human relationship world (the social world). In SWoT, all kinds of intelligent technologies are the keys to collaborate the relationships among the three sub worlds, and they can be utilized to harmonize information, computers, things, and persons.

The sensing equipment in the physical world can provide sensing sources for the service consumer in the social world; can provide semantic collaboration sources for the service environment. The semantic collaboration, which exists between the service consumer and the service environment in the cyber world, can provide semantic interoperating services for them.

In the hyper world, the sensing equipment is mainly responsible for providing the raw data to be processed; the service consumer will make service requests; the semantic collaboration process will provide the semantic and context processing. To obtain the high-level context knowledge (HLCK) that is more complex and abstract, the raw data, service requests, and the semantic and contextual processing are all indispensable.

Thus, on basis of a tetrahedron method and the semantic collaboration triangle, we can get a tetrahedron hierarchy diagram (that is, relationship hierarchy diagram in the WCXMS).We regard the diagram as our foundation of research on service operations, data lifecycle and complexity levels of the context in the WCXM.

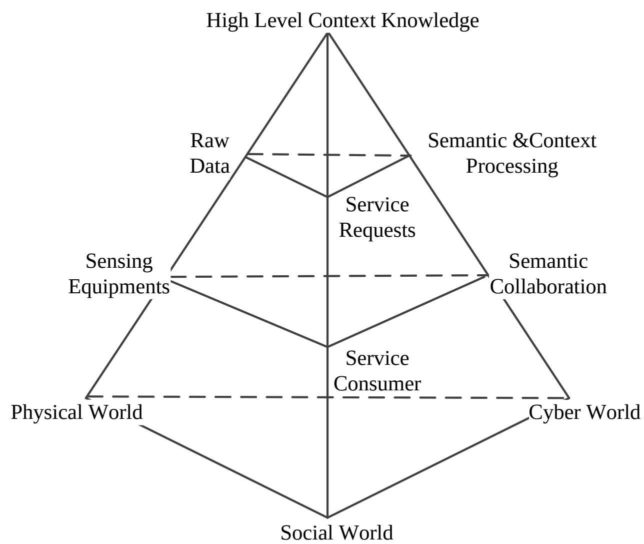

Figure 4. Relationship hierarchy chart in WCXMS

IV. OPERATION CYCLE IN WCXMS

Based on the SWoT and the classic lifecycle diagrams, such as ILM, ECM and Hayden's Data Lifecycle, etc. [17-21], we get an operation-cycle diagram for context service (operation cycle in WCXMS).As shown in figure 5, according to roles, the operating cycle can be respectively divided into three parts: the data source provider, the service broker and the service consumer. In the SWoT, the data source provider and the service consumer belong to the third party applications.

The service operations provided by the data source provider include sensor data acquisition, sensor data manipulation and sensor data transmission &transportation. The sensor data acquisition is mainly responsible for obtaining the raw data from the data source provider, after that the sensor data manipulation main is mainly responsible for preprocessing of the raw data. The preprocessing is that experts supplement the missing data to the raw data, discretize the raw data and abandon the unreasonable data, etc.; then the sensor data transmission & transportation will transfer the preprocessed data to corresponding distribution points for the next steps.

The service operations provided by the service broker include context transformation, context classification, context computing, context reasoning, context dissemination and service maintenance. Thereinto, context transformation operations are mainly responsible for centralizing (gathering) the preprocessed low-level context information; context classification operations are mainly responsible for semantically classifying information on the basis of context ontologies; context computing operations are mainly responsible for intelligently calculating and processing the classified information in view of service requests; context reasoning operations are responsible for drawing reasoning strategy for computed information on the basis of reasoning mechanisms and granularity standards; context dissemination operations are responsible for transferring knowledge to the service consumer; context maintenance operations are responsible for regularly storing contexts into repositories, deleting contexts from repositories, selecting data source according to service feedbacks of the service consumers, guiding the data source provider to obtain the raw data and directly transferring contexts in repositories to other context operations according to requirements.

The service operations provided by the service consumer include context usage, service assessment and service request. The service consumer sends service requests to the service broker, that is, directly to its context dissemination to process. After using contexts, which are provided by the service broker, the service consumer will assess the provided service (on rationality of the context)and the assessment will be directly feedback to the service maintenance of the service broker.

As mentioned above, a diagram of the operation cycle in WCXMS is shown in figure 5.

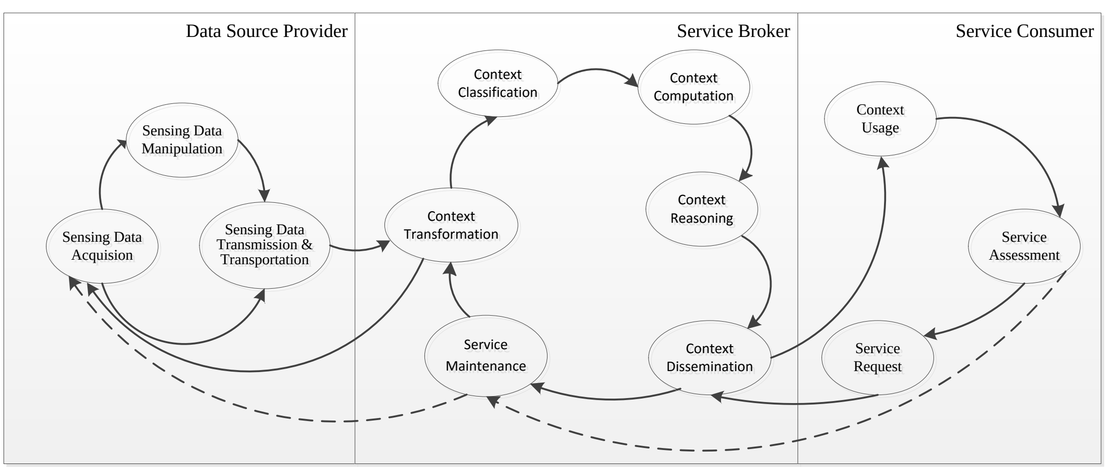

Figure 5. Operation cycle in WCXMS

V. DATA LIFECYCLE IN WCXMS

In figure 5, the figure of the operation cycle in WCXMS, source objects and target object in those operations are all kinds of heterogeneous data, information and knowledge. Establishing an efficient operation cycle and a data lifecycle are good for realizing the harmonious coexistence of heterogeneous objects in the hyper world. According to the operation cycle in WCXMS, the figure of the data lifecycle in WCXMS is shown in figure 6. The concrete operation procedure is shown as follows.

Data Source Provider→Sensor data: By an information sensing equipment and application system (such as sensor networks, Radio frequency tag reading device, GPS and other short-distance wireless self-organizing networks on the basis of M2M) at an application endpoint in SWoT,we can contactlessly scan RFID electronic tags and obtain the thing's information in real time. In fact, thing's sensing information include real-time sensor data and non-real-time sensor data. Except the real-time sensor data mentioned above, thing's sensing information also include the historical data, directly from the internet, and the processed data after computing and other operations. Different types of sensor data are distributed to and gathered in every data center in the internet.

Sensor data→Low Level Context Data: According to the user service requests, we can select the low level context data directly from the sensor data, then process the data in other relevant steps, or upload the data directly into the internet via the application endpoint of any access network.

Low Level Context Data→ Low Level Context Information: After data extraction, data conversion and data concentration operations, by means of data analysis technology, data reorganization technology and data mining technology, correspondingly, low level context data can be processed as multi-granularity and multi-level low level context information. Moreover, the low-level context information will be processed in relevant data security steps. Then the low context information is still stored in the data center or low level context information repository.

Low Level Context Information→ Semantic Context Information: After semantic request extraction, semantic matching and semantic annotation operations, the low level context information can be processed as semantic context information. Noting the semantic context information is the primary ones in high level context information.

Semantic Context Information→ High Level Context Information: In view of application request, semantic context information can be processed as high level context information after relevant computing and intelligent processing operation. The high level context information is stored in each distributed sharing and interaction information repository.

High Level Context Information→ High Level Context Knowledge: By means of distributed information sharing and interactive uncertainty theory, clustering technology, belief revision technology and semantic matching technology, the high level context information can be semantically analyzed and reasoned to generate high level context knowledge. The high level context knowledge is stored in every interconnected repository.

High Level Context Knowledge→ Service: By means of service publishing technology and service management technology, the high level of context knowledge can be processed as semantic services. Semantic services can provide semantic collaboration service for agents in the SWoT on the basis of the distributed information sharing and interactive technology, agent technology, service gathering technology and dynamic and binding technology together.

Service→ Service Consumer: Based on all kinds of knowledge repositories, a friendly, transparent, efficient, safe and reliable service platform built by means of intelligent technology and intelligent strategy integratedly. The platform can provide the required semantic service for the service consumers. Thereinto, the service demand includes the individual demand, the demand agent, companies and organizations, and a variety of other third party applications.

Service Consumer→ Data Source Provider: In the process of obtaining the required services, the service consumer will continuously provide service evaluation and feedback results to the data source provider and service broker. And the feedback will continuously stimulate and influence the data source provider and service broker correspondingly. At the same time, the service broker will drive and guide the data source provider according to service decisions.

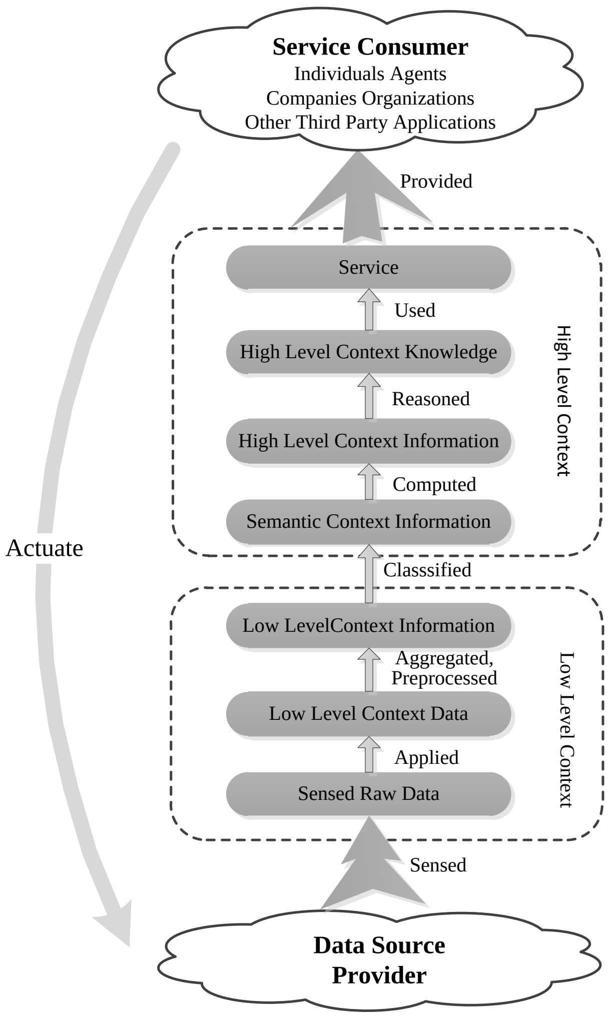

Figure 6. Data lifecycle in WCXMS

In figure 6, the context service lifecycle diagram (Data Lifecycle in WCXMS), various kinds of sensors, repositories (database, information repository and knowledge repository) and all kinds of calculation and processing application endpoints provide platforms storing and transforming data in the data lifecycle, while the SWoT provides collaborative and intelligent network transmission channels for all kinds of data in the data lifecycle. Therefore, constructing a SWoT which can process all data perfectly is the only way to intelligently obtain the data, information, knowledge and service.

VI. COMPLEXITY LEVELS OF THE CONTEXT

In order to facilitate understanding the relationship between context service operations and context in the WCXMS, before introducing other contents in detail, we will analyze the complexity levels of contexts and the hierarchy of technology levels and their corresponding relationship.

In the WCXMS, according to relationships between the application sequence of technology and context levels, technologies for obtaining context are correspondingly divided into five levels: sensing technology, database technology, semantic technology, intelligent computing and intelligent reasoning technology.

Moreover, technologies for obtaining context correspond to service operations for obtaining context. We explain that in detail as follows.

Sensing technology corresponds to operations for sensor data obtaining. Data preprocessing technology corresponds to preprocessing operations for sensor data (such as sensor data manipulation, sensor data transmission & transportation, context transformation). Semantic Technology corresponds to operations for context classification. Intelligent computing technology corresponds to operations for context computing. Intelligent reasoning technology corresponds to operations for context reasoning.

In the WCXMS, according to the obtaining sequence of context and context levels, contexts are all divided into five levels: Raw Data, LLCI (Low Level Context Information), SCI (Semantic Context Information), HLCI (High Level Context Information) and HLCK (High Level Context Knowledge).

As shown in figure 7, the complexity Levels of the contexts correspond to the abscissa while the technology level hierarchy corresponds to the ordinate. Accordingly, we put forward four relationship equations in context hierarchy.

1) LLCI=Raw Data+Preprocessing+Service Requests
2) SCI=LLCI+Semantic Information
3) HLCI=SCI+Intelligent Computing Processing
4) HLCK=HLCI+Intelligent Reasoning Processing

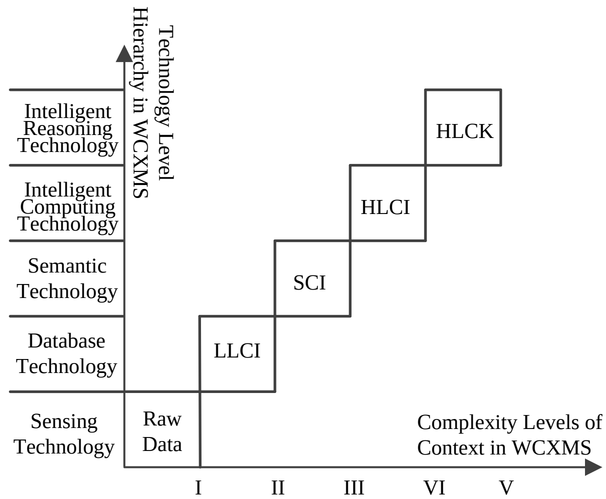

Figure 7. Complexity levels of the context

VII. SELF-ADAPTIVENESS FORMULA OF SWOT

In SWoT the hyper world, we need to gather data from vast network on the basis of distributed storage and distributed computation to provide a friendly, transparent, efficient, safe and reliable Service platform and further to provide decision-making knowledge and semantic intelligent service for users.

The semantic collaboration for SWoT that is the specific application of semantic collaboration in the IOT is the key to realize the SWoT. Figure 5, figure 6 and figure 7 illustrate the data lifecycle, the operation cycle and the relationship between operations and contexts, and further analyze the formal formula (1) of Semantic collaboration, and state the theory of semantic collaboration.

In SWoT, all kinds of intelligent semantic technologies can collaborate three sub worlds and make the information/computer, objects and people be in harmony. In addition to the semantic collaboration, the adaptiveness of smart technology is also the key to realize the harmony. Therefore, to provide intelligent semantic service, sensing equipment, databases and semantic processing technologies must have the ability of adaptiveness. The adaptiveness can make the SWoT intelligently select the data source provider, computing objects and semantic services in view of the different needs of users.

The so-called adaptiveness refers to the ability that a system can transform its structure and/or behavior according to its internal and/or external environment changing. And self-adaptiveness refers to the ability that a system only relies on its own learning to adapt to its environment without too much intervention from the outside. Accordingly, the semantic collaboration and adaptiveness are the key technologies to realize "harmonious intelligence", and only depending on them can we realize the harmony among information/computers, things and people in the SWoT on the basis of the IOT. Thus we get the following formulas:

$$\text{SWOT} = \text{WOT} + \text{Semantic collaboration} + \text{Adaptiveness} \tag{2}$$

Thereinto, with reference to the semantic coordination formula (1) above, we know the semantic collaboration is a procesure in which collaboration add a semantic annotation for the expression of thing’s information based on ontology and at the same time, they exchange and share annotated semantic information. Therefore, from the point of self-adaptiveness,we can get another formula of the semantic collaboration:

$$\begin{aligned}&\text{Semantic Collaboration}_{\text{(of/in SWOT)}}\\&= \text{Ontology} + \text{Interaction} + \text{Semantic self - adaptiveness}\end{aligned} \tag{3}$$

Noting the semantic processing and the intelligence processing of context is inseparable; the semantic & context processor composed of the processing mentioned above, shall be regarded as a complete semantic subsystem in the SWoT. The semantics self-adaptiveness means the semantic &context adaptiveness, so the semantics self-adaptiveness includesthe adaptiveness of the semantic processing and the adaptiveness of the intelligence processing of context.Accordingly, we can get the formula of the self-adaptiveness:

$$\begin{aligned}&\text{Semantic Self - adaptiveness}\\&= \text{Adaptiveness}_{\text{(semantic processor)}} + \text{Adaptiveness}_{\text{(context intelligen t processor)}}\end{aligned} \tag{4}$$

The ancient Roman poet Lucretius had a well-known saying "All things flow" that emphasizes anidea that things are changing. And the basis of the thought is the ancient Greek philosopher Heraclitus’s remarks "Everything changes and nothing remains still” and "You always step twice into the same stream”. ZhongNing etc. think the wisdom of the SWoT must be embodied in which it can timely provide appropriate services to an object in right context [22]. Also, as mentioned above, the SWoT is open, distributed and dynamic, a semantic is directly affected by the publishing agents and the using agents, dynamically affected by its time, is closely related with its context (as shown in figure 2, Semantic Three-dimensional Space).So, in the SWoT, all objects should provide dynamic and right services for changing objects in view of their requeries at a dynamic time and context. In other words, an object in the SWoT must be able to be aware of and adapt to itself and its dynamic environment; be able to adapt to the dynamic changes of itself and its dynamic environment. Therefore, we get the formula of the SWoT adaptiveness:

$$\begin{aligned} &\text{SWOT Adaptiveness} \\ &= \text{Adaptiveness}_{\text{(objects/components)}} + \text{Adaptiveness}_{\text{(objects/components, environment/context)}} \end{aligned} \tag{5}$$

And compared to CAS proposed by Holland [23], the hyper world SWoT is a more complex adaptive system. The SWoT can be regarded as an open service ecosystem, in which information, people and things are all treated as objects, and the system consists of the homogeneous and heterogeneous individuals or objects. From the point of view of the ecosystem, the SWoT adaptiveness can be divided into two levels: system level and component level. At system level, as an ecosystem, the SWOT need to adapt to its environment or context; at component level, each object or subsystem needs to be able to adapt to other individuals and be in harmony with them. Therefore, the SWOT adaptiveness can be further abstracted as follows:

$$\begin{aligned} &\text{SWOT Adaptiveness} \\ &= \text{Adaptiveness}_{\text{(system-level)}} + \text{Adaptiveness}_{\text{(component-level)}} \\ &= \text{Adaptiveness}_{\text{(ecosystem, environment/context)}} + \text{Adaptiveness}_{\text{(components, components)}} \end{aligned} \tag{6}$$

Referring to the food chain in natural world, for the open service ecosystem SWoT, its "food chain" is a "data information chain" which is made up of data, information, knowledge and service in obtained sequence. Source data objects composed of raw data locate at the bottom of the chain (data lifecycle). Therefore, for the Operation Cycle in WCXMS of the SWOT "Sensor data Obtaining" is the beginning operation; for the Data Lifecycle in WCXMS its foundation is " Data Source Provider→Sensor data";for the figure 7 about the complexity levels of contexts and the hierarchy of technology levels (Complexity Levels of the Context), its lowest levels are Sensing technology at the bottom of the Technology Level Hierarchy and raw data at the bottom of the complexity levels of contexts. Therefore, the SWOT adaptiveness is the SenaaS adaptiveness [24-25]. As mentioned above, we get the following formula:

$$\begin{aligned} &\text{SWOT Adaptiveness} \\ &= \text{Adaptiveness}_{\text{(objects/components)}} + \text{Adaptiveness}_{\text{(objects/components,environment/context)}} \\ &= \text{Adaptiveness}_{\text{(system-level)}} + \text{Adaptiveness}_{\text{(component-level)}} \\ &= \text{Adaptiveness}_{\text{(ecosystem, environment/context)}} + \text{Adaptiveness}_{\text{(components, components)}} \\ &= \text{Adaptiveness}_{\text{(SenaaS)}} \end{aligned} \tag{7}$$

Analyzing the Operation Cycle in WCXMS, after the service consumer use context services provided by the service broker, the service consumer can fed back service evaluation to the service broker directly, then the service broker will drive data source provider, reselect data source provider again and guide data sources to obtain raw data by the service maintenance operations. The Data Lifecycle of WCXMS which corresponds to the content above is “Service Consumer→ Data Source Provider” and the Service Consumer will drive and actuate the data source provider according to decision-making and service evaluation. As a result, "SenaaS adaptiveness" can be defined as the sum of two adaptiveness functions (i.e., a service adaptiveness function and a data source adaptiveness function), whose common parameter is "feedback". In essence, two adaptiveness functions are respectively the re-composing and re-selecting of services and data resources, and the function “recompose/re-select (data resources)” services for the function “recompose/re-select (service)”. Accordingly, the formula of the SenaaS adaptiveness is shown as follows:

$$\begin{aligned} & \text{Adaptiveness}_{\text{(SenaaS)}} \\ & = \text{Adaptiveness}_{\text{(service, feedback)}} + \text{Adaptiveness}_{\text{(data resources, feedback)}} \\ & = \text{Recompose/re-select}_{\text{(service)}} + \text{Recompose/re-select}_{\text{(data resources)}} \end{aligned} \tag{8}$$

VIII. SELF-ADAPTIVENESS SUPPORT FRAMEWORK OF SWOT

In the middle of the 19th century, Charles Robert Darwin established the scientific theory of biological evolution. Darwin's theory of evolution whose core is natural selection. As the second major scientific breakthrough in human history, the theory of evolution is undisputed within the scientific community, and the fact of evolution is the conclusive proof of evolution. The evaluation points out that creatures evolve from junior to senior, from simple to complex and continuously develop by genetics, variation and natural selection.

An ecological system is a unified one composed of creatures and environment in a certain space of the nature. In the ecological system, creatures and environment mutually influence, restrict and continuously evolve. Therefore, in essence, the system will be in a relatively stable state of dynamic balance in a certain period of time.

The SWoT is open and dynamic. Its environment is dynamic too. The environment which decides the SWoT is necessarily an open service ecosystem. In this system, all of things are in continuous evolution, and the whole system gradually evolves because of the development of individuals and their environment. Therefore, accurately understanding the process of the SWoT adaptiveness and perfectly building a SWOT's self-adaptive support frame are the basis of understanding the concept of the SWoT, and have a very important role in further building the overall architecture of the SWoT.

Figure 8 depicts a self-adaptive support framework of the SWoT, which is composed of the physical world, the cyber world and the social world from the perspective of the WCXMS, just like figure 5 (Operation Cycle in WCXMS) and figure 6 (Data Lifecycle in WCXMS).The frame consists of two kinds of adaptiveness loops, namely, external adaptiveness loop and internal adaptiveness loop, or global adaptiveness loop and local adaptiveness loop.

In the system, local adaptiveness loops include two internal adaptiveness closed loops, one closed loop is for semantic & context processing and the other closed loop is for Service Database. The closed loop for semantic & context processing includes the adaptiveness of the semantic processing and the adaptiveness of the intelligence processing of context, just like Semantic self-adaptiveness formulas (4). The closed loop for Service Database corresponds to the adaptively learning process of Service Database. The Service Database can effectively process the evolution of knowledge by their own learning mechanism, so as to cope with different requests and provide better service forconsumers.After the adaptive learning process. The Service Database can provide better service for different consumers' requests and adapt to the dynamic change from its internals and externals eventually.

The global adaptiveness loop is from the perspective of the whole open service ecosystem. The SWoT obtains context and environment information from external environment and adjusts the behavior of the system to adapt to the environment or context.

We can realize the process of the SWoT adaptiveness referring to the following process:

1) At first, the global adaptiveness loop receives service requests from the service consumer. Then the requests are decomposed into operation requestsand application requests by the service request analyzer, and two types of requests are passed to the service database by the service request analyzer.
2) At the same time, system monitors in the physical world monitor the changes in its environment and context, and real-time sense and obtain raw data to preprocess.
3) Based on web service ontology and web domain ontology provided by the SWoT, the service database performs matching reasoning operations in view of operation requests and application requests that the service database makes intelligent service decisions.

4) Then intelligent service decisions are converted into certain decisive actions by a translator and directly transmitted to operation objects. The decisive actions will indirectly affect all individuals in the SWoT and the entire environment.
5) After that, the SWoT senses and obtains affected context information, and processes the low level contexts by semantic and context processing to get high level contexts. According to the information and processed knowledge, the intelligent reasoner of the semantic and context processor gives assessment result and adjusts all kinds of parameters, weights, and inference rules of an intelligent computer and an intelligent reasoned timely to complete the process of autonomous learning of the semantic and context processor.
6) According to high level contexts and expected service decisions, the service database adjusts all kinds of parameters, weights and strategy structures of intelligent matching strategies and reasoning mechanisms in the database. And update high level context knowledge, matching strategies and reasoning mechanisms in order to achieve its self-learning process.

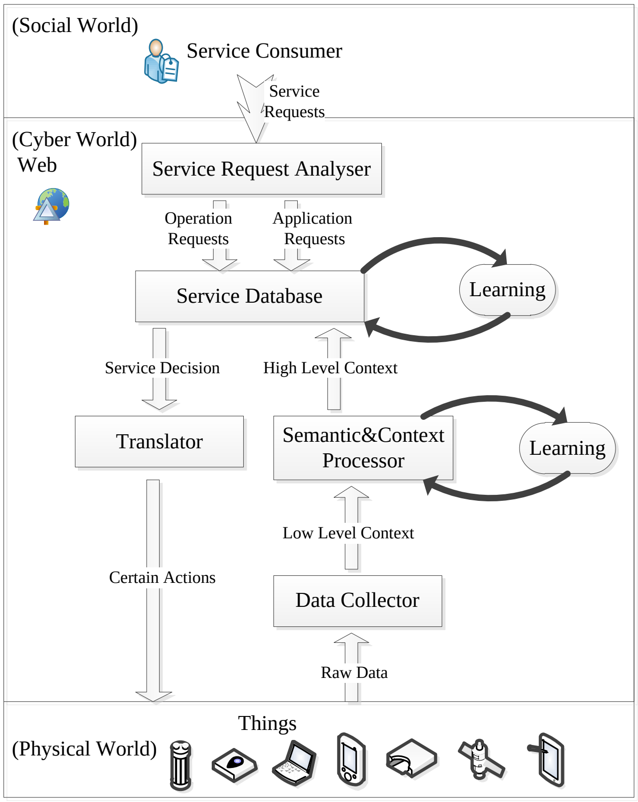

Figure 8. Self-adaptive support framework of SWoT

IX. THE DEFINITION AND OVERALL ARCHITECTURE OF THE SWOT

The fundamental goal of the IOT is to facilitate interchanging and sharing thing's information spread all over the world, that is, to facilitate collaboration of thing's information. The SWoT promotes the collaboration of the thing's information from the grammar level to the semantic level, so as to intelligently realize purification, fusion and relevance among thing's information according to their essence meaning (rather than their surface forms), the results of high level information can be exchanged and shared by worldwide users (computers will account for a large proportion), can be realized.

The innovation of the SWoT embodies in "introducing semantics" and "emphasizing collaboration", the former makes operations, publishing the thing's information and using the thing's information, more completed by computers automatically; the latter facilitates three steps, the semantic annotation to the thing's information, the long-distance transmission and the semantic understanding of the thing's information, constituting an organic integrity.

The scientific significance of the SWoT is to promote the understanding of the thing's information for computers from the grammar level to the semantic level, to accelerate computers intelligently understanding information from the IOT, to solve the intrinsic contradiction hidden in the IOT, to push the realization of the ultimate goal of the IOT. The goal is real-time sharing of information globally.

It is important to note that in the SWoT, an open and dynamic service ecosystem, as all objects interchange and share semantic information, themselves adaptively and dynamically changing to achieve harmonious coexistence of three sub-worlds.

To achieve this goal, the wireless sensor network (WSN) will be widely spread calculation which must be fused with its environment and the computer recedes from view; The service consumer will obtain and process semantic services at any time, any place, in any way. Therefore, the SWoT ecosystem needs to be based on pervasive/ubiquitous computing mode [25-28].

The traditional computing system satisfying consistent requirements is a closed and homogeneous environment, while the SWoT ecosystem dissatisfying consistent requirements is an open and heterogeneous environment. Under the heterogeneous mechanism, to solve contradictions, part of the objects need to achieve an acceptable solution by some consultation mechanisms. Minsky called the object of the computing system as agent, and called the computing society organically composed of these objects as multi-agent system [29-31].So the SWoT ecosystem must base on multi-agent system.

At present, different researchers and research institutions, such as the FIPA (Foundation for Intelligent Physical Agent), Wooldridge, Franklin and Graesser, Hayes Roth and Macs give definitions of the Agent from different perspectives. And the agents, in the SWoT ecosystem, refer to those are in the environment and can fuse with the environment harmoniously, can autonomously real-time sense states of the dynamic environment, can autonomously reason to explain sensing information, to solve problems, and to give inference and decision results, can take actions to affect the state of the dynamic environment, at the same time can adaptively establish their own individual decision-making mechanism to cope with other agents of the dynamic environment in the future. In this definition, the agent which is regarded as a "living" individual of the ecosystem can be a thing in the physical world, the information or computer in the cyber world, or a person in the social world. The SWoT ecosystem, an open system, has to input energy continuously to maintain its own stability, while service requests and dynamic changes from individuals and environment of the ecosystem are just the energy sources to drive system evolution.

Thus, we attempt to put forward the definition of the SWoT. That is, based on pervasive computing/ubiquitous computing and multiple-agent, the SWoT is a worldwide intelligent network, which can accomplish the semantic collaboration of M2M with self-adaptiveness. We present the overall architecture of the SWoT in figure 9 and the architecture consists of five layers as followings.

Application and service layer (User Interface): An application and service layer is responsible for a user interface access management.

Service management layer (Collaboration Agent Management): A service management layer is mainly responsible for publishing and managing semantic service to realize the semantic collaboration service finally. This layer is also responsible for structural analyzing and processing requests based on ontology, service category matching, assigning requests to agents' corresponding and managing all service agents.

Knowledge interconnection layer: A knowledge interconnection layer can transmit the semantic information, collected from the semantic support layer, to data processing center to store and intelligently process information by means of technologies, such as the cloud computing technology, the artificial intelligence technology and the distribution share and interaction technology, in accordance with different requests [32-33]. And it can also reason the semantic information by decision rules and reasoning strategies in order to realize the integration and real-time share of the semantic information.

Semantic support layer: A semantic layer can structurally process data transmitted from the sensing layer, classify data based on domain ontologies and annotate data based on specific domain ontologies. It can also accomplish semantic modeling based on the techniques, including modeling technology and semantic space technology and so on.

Sensing layer: By means of sensors, RFID and two-dimension code, a sending layer can obtain information and identify states about static and dynamic state information of environment on a large and distributed scale, such as material properties, environment states and behavior tendencies and so on. And it can implement preprocess raw information, including extracting data, transforming data, analyzing data and gathering data, etc.

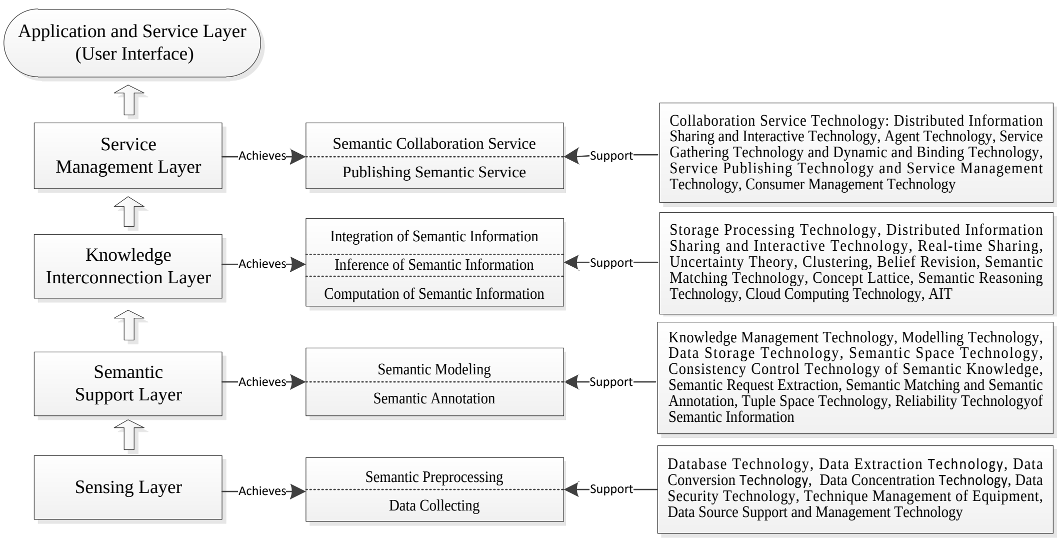

Figure 9. Overall architecture of the SWoT

X. SENAAS MODEL

To date, lots of researchers and research organizations have given definitions of the cloud computing. Among them, Garter defined the cloud computing as a calculation mode. Based on the internet technology, the mode can provide a great deal of extensible information technology to many external customers in the form of service [34].That is, the cloud computing is a calculation mode, which can provide dynamic, scalable and virtualized resources in the way of serviceby the internet.

The cloud computing mainly includes three service levels (the so-called level is the "level" in the layered architecture): infrastructure as a service (IaaS), platform as a service (PaaS) and software as a service (SaaS). IaaS, PaaS and SaaS are respectively implemented at the infrastructure layer, open platform layer of software and application layer of software. Each layer has been comprehensively discussed in the paper [34], not detailed here.

The essence of cloud computing is the XaaS. The XaaS is a general designation. It stands for "X" as a service, "anything as a service" or "everything as a service" and appears simultaneously with cloud computing models. In addition to the most common examples of the XaaS above, other examples include storage as a service (SaaS), communication as a service (CaaS), network as a service (NaaS), monitoring as a service (MaaS), database as a service (DBaaS), data as a service (DaaS), ethernet as a service (EaaS), identity and policy management as a service (IPMaaS) and sensing as a service (SenaaS), etc. [35-36].

The cloud computing plays a vital role in the SWoT, which makes it possible to realize the SWoT. In figure 5, 6 and 7, we can see the operation of "sensing data acquisition" is the foundation of other operations in the operation cycle in WCXMS, the step of "Data Source Provider→Sensor data" is the foundation of other subsequent transformation steps for data in the data lifecycle in WCXMS. Raw data and sensing technology are at the lowest level of the complexity levels. Similarly, according to the formula (7), the SWOT adaptiveness is essentially the SenaaS adaptiveness. Therefore, in the SWoT, the SenaaS is the implementation foundation of semantic services and semantic collaboration. Therefore, we only talk about the SenaaS model diagram in this paper.

Still from the perspective of the hyper world and context service, we build the first layer model of the SenaaS and give its detailed models step by step. The first layer model of the SenaaS is mainly composed of the data source provider, the service broker and the service consumer. Among them, the data source provider submits publishing requests to the service broker and the service consumer submits service requests to the service broker. Accordingly, the service broker gives the feedback of publishing requests to the data source provider and provides the response of service sources to the service consumer based on the result of service matching.

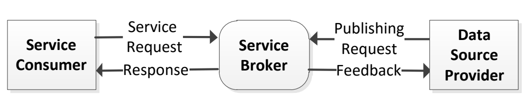

Figure 10. SenaaS model

As shown in figure 11, the second layer model of the SenaaS includes service consumer, domain agent, service index registry, mediator, service provider, data collecting/preprocessing subsystem and sensor data collector. Among them, the domain agent, service Index registry, mediator and service provider belong to the service broker in the first layer; data collecting/preprocessing and sensor data collector belong to the data source provider in the first layer.

Obtaining data from the data source provider: All kinds of sensors obtain state data of their environment in real time and connect with Sensor Hubs via the API (Application Programming Interface) in data collecting/preprocessing subsystem. The sensor hub generates configuration files of sensors connected to it and the configuration handler of the subsystem sends the definition files to the sensor data collector. The sensor data collector sends back configuration information, which contains collector's port number where needs to send data, to the configuration handler. Then the configuration handler transfers the port number to the data streamer. Thus, an automatic configuration process is comprehensive, and the data streamer starts sending data stream to the collector.

Publishing data for the data source provider: The sensor data collector submits publishing requests to the service request monitor of the service provider. Once the service request monitor feeds back an agreement response, the collector will start sending data stream to the semantic & context processor of the service provider.

Publishing services: The semantic and context processor receives service requests from the service request monitor and data stream from the sensor data collector, and sends context knowledge to the service database.

The service database can regularly submit requests of registering service to the service index registry in order to register and form context service with an account. In the service index registry, after the registry interface receives requests of registering service, the service registry will review the information of the registering service and create an account for the past registration information. Then the account and relevant information will be stored into the web service ontology and the classified results of accounts by the classifier will be stored into the web domain ontology.

Putting forward service requests: The service consumer can directly submit the request of searching service to the service index registry to obtain search result. In addition, it can collaborate with domain agents or mediates to get the required services information.

The service consumer can provide its context and profile & interest information (including a special user name, date of birth, gender and occupation, etc.) to domain agents. Based on consumer's profile & interest information, the domain agents will form a fundamental interest list stored into the consumer context ontology. According to user's feedback, the agent will modify the list in real time and alter levels of interest attributes. The domain agent can predict interesting services by the inference engine for consumers, and search domain by the service index registry to push service information to the consumer. The process is similar to the push-pull way adopted in obtaining sensor data [37-40].

The service consumer can also summit service requests to a mediator. Firstly, the Service mediate will search service index information through the service index registry. After the Service mediate receives the search results, it will establish interlink age with the service provider (via the web service interface) and deliver the index information of service requests to the provider, then receive services information provided by the service database and feedback them to the service consumers.

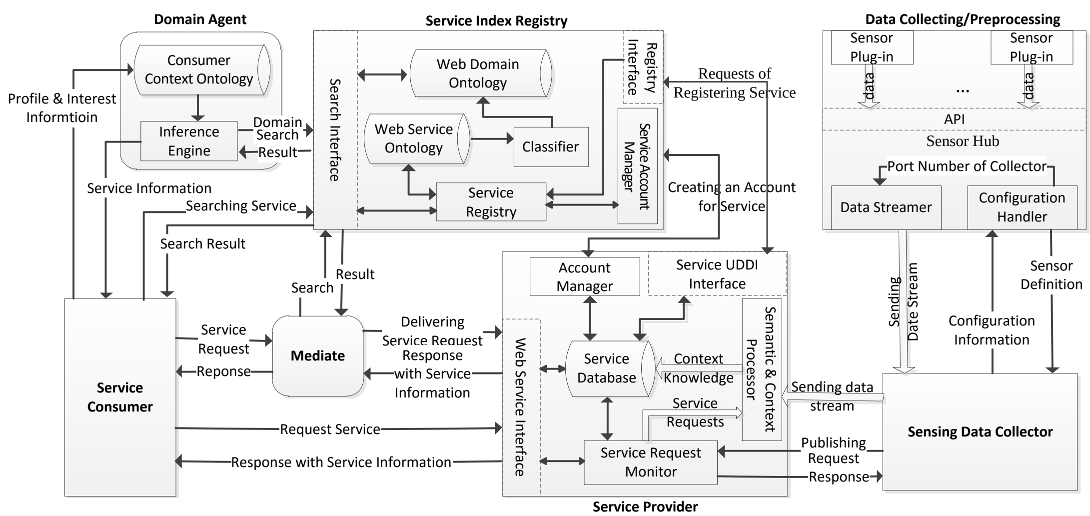

Figure 11. An insight of SenaaS model

The third layer model of the SenaaS (as shown in figure 12) is a further detailed model for the semantic & context processor. It is composed of a semantic processor and a context processor. The fourth layer model of the SenaaS (as shown in figure 13) is a further detailed model for the semantic controller.

The semantic processor receives service requests and data stream via the data collecting interface. On the one hand, the data collecting interface classifies the data. Then, it sends raw data stream to a raw data repository and sends semantic data to a semantic data repository. The semantic data repository gradually sends the semantic data to a semantic controller. The semantic controller is composed of a data modeling transformer and a semantic matcher. The data modeling transformer can analyze data and extract data profile which will be sent to the semantic matcher. The semantic matcher will semantically match the data profile and semantic information from ontology to create new semantic data. The semantic data will be stored into ontology. And the semantic matcher will automatically and adaptively send semantic requests to the external according to the match result. On the other hand, the data collecting interface will send service requests to a requirement distributer. The requirement distributer will disassemble the service requests into application operations and recourse requests. Based on them, the ontology can determine the scope of the semantic information to be processed. The context processor will receive the unprocessed semantic information and application operations sent by the semantic processor. Then, by means of its intelligent computer, the context processor converts them into high level context information to the intelligent reasoner. Based on fact information and rule information, the intelligent reasoner can produce high level context knowledge and transfer them to the service database of the service provider. The service provider will finally publish the high level context knowledge to provide the context services.

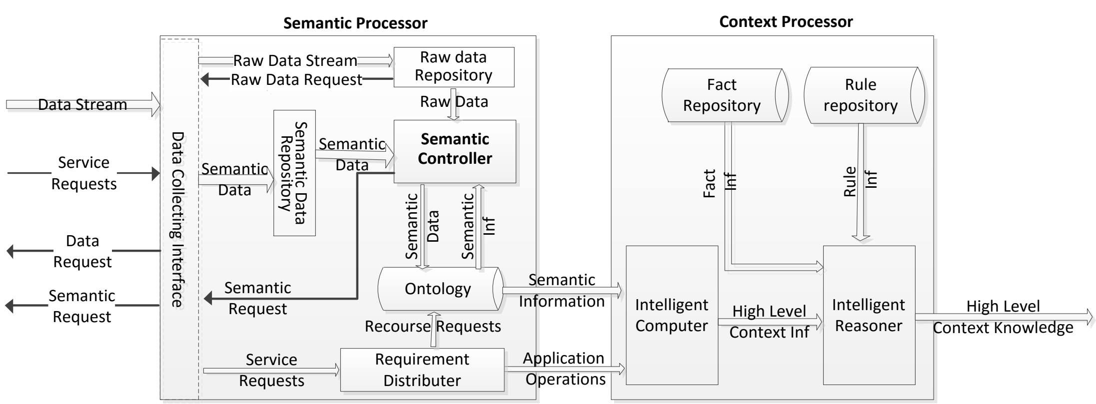

Figure 12. Semantic & context processor

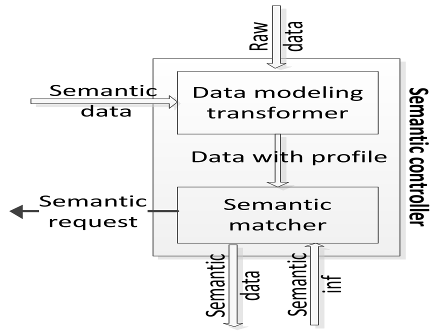

Figure 13. Semantic controller

XI. CONCLUSIONS

The IOT extends the traditional information communication network to the broader physical world, but the mismatching between the diversified forms of thing's information leads to the internal contradiction of the IOT and hinders its intelligent development. An effective way is to add semantic annotations for the expression of thing's information by ontology and essentially promote the IOT to the SWoT based on technology properties of the IOT and the semantic web.

Because the system and its individuals (things in the physical world, information and computers in the cyber world and people in the social world) are in continuous evolution, as an open service ecosystem, the SWoT must have semantic collaboration and self-adaptiveness. In this paper, we give the definition of the SWoT, analyze the semantic collaboration mechanism and put forward the self-adaptiveness formula and self-adaptive support framework of SWoT. Because the SenaaS is the implementation foundation of semantic services and semantic collaboration, the SenaaS model diagram is proposed here eventually.

This paper discusses semantic coordination mechanism and key support technologies of the SWoT, which lay a theory and technology foundation for subsequent research work, including the design of semantic collaboration application schemas for the SWoT, the layout of semantic collaboration support system for the SWoT and the application experiments, validation and evaluation of the semantic collaboration support system.

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