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Ontology-Based Home Service Model

Moji Wei1, Jianliang Xu2, Hongyan Yun2,
and Linlin Xu2

[1]Information Research Institute, Shandong Academy of Sciences,
19th Keyuan Road, Jinan, Shandong Province, China
weimoji@126.com
[2]Department of Computer Science, Ocean University of China,
238 Songling Road, Qingdao, Shandong Province, China
{xjl9898, yunhongyan, gxl0216}@gmail.com

Abstract. This paper researches Home Service retrieval and invocation for smart home. We represent ontology-based Home Service Model to retrieve and invoke services according to user's needs automatically. Firstly by analyzing the context of home service, we differentiate key concepts in the field and analyze the relations among them, and as a result, an upper ontology as a fixed viewpoint for further more detailed conceptualization is achieved. Then by reifying the concepts of the upper ontology, we construct two domain ontologies which are Function Concept Ontology and Context Concept Ontology to annotate the semantic of Home Service from different facets. The Function Concept Ontology is constructed with the guidance of Maslow's Hierarchy of Needs to annotate the goal of service for automating service retrieval. For service invocation, the Context Concept Ontology is constructed by analyzing the contents that services operate. Finally two scenarios for different types of services are given to demonstrate the usage of the model.

Keywords: Smart Home, Home Service, Domain Ontology, Need, Function

1. Introduction

The convergence of Telecommunication Network, Internet and CATV Network enhances Home Area Network (HAN). The enhanced HAN connects almost all the home appliances and integrates various services which were restricted in one single network. The central of the HAN is a residential gateway which bridges the HAN and the Internet. It manages multiple devices to connect to the Internet simultaneously. With the services provided by various devices, in home users could access Internet facilely, and outside home they could control the devices remotely. Accordingly invoking proper services to drive the devices performing suitable functions becomes the key of satisfaction of needs.

For communication within HAN, various standards have been given by different alliances from different perspectives. According to the alliances, existed standards could be classified into four categories. The first kind of standard is supported by network equipment manufacturers, such as OSGi (Open Service Gateway Initiative) [1, 2], IHA (Internet Home Alliance), etc. The second kind of standard is proposed by IT vendors, like DLNA (Digital Living Network Alliance) [3], UPnP (Universal Plug and Play) [4], etc. The third kind of standard is advocated by home appliance manufacturers, such as ECHONET (Energy Conservation and Homecare Network) [5] etc. The last kind of standard is lead by manufacturers of automatic control, like LonMark [6] etc. Besides above alliances, many International Organizations for Standardization like CEA (Consumer Electronics Association), ITU (International Telecommunications Union), ETSI (European Telecommunications Standards Institute), etc found institutions for HAN framework either. The standards offered by the alliances are different in technical layer because of different perspectives, but the models of HAN are similar. Figure 1 depicts the general HAN model. In Home Area Network, all the appliances are connected to residential gateway directly or indirectly, and access information from Internet through the gateway. Furthermore, in order to manage home appliances remotely, users would employ controller or other devices which could access Internet and send instructions to the gateway, then the gateway would distribute instructions to relevant appliances. The residential gateway-centered HAN forms the infrastructure of smart home.

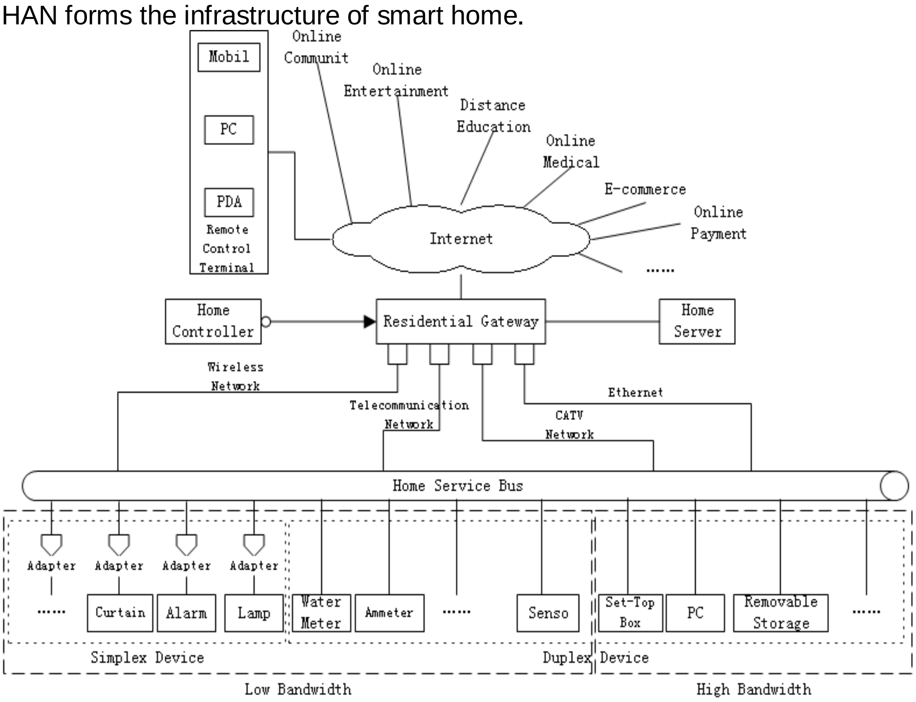

Fig. 1. Home Area Network Model

Home Services, which are implemented by home appliances, have narrow sense and broad sense. In a narrow sense, Home Services just mean the services used to control home appliances, thus the interactions among the services are restricted in HAN. While in a broad sense, Home Services also contain the services that interact with applications running on the Internet, for instance online medical services and distance education services are such services. Correspondingly researches about Home Services mainly come from two fields. One is field about automatic control of home appliance, which focuses on automation and responding rate of devices. It researches how to operate the devices correctly in different situations according to users' expectation, and rarely concerns the ability of network access. The other field originates from Web Service, and it focuses on the communication among services.

In order to facilitate Home Service accessing, the alliances mentioned above provide APIs for users or use the sophisticated protocols like HTTP, SOAP, etc. However these interfaces or protocols are informal expressions, therefore the service retrieval and invocation are based on syntactic matching. As other Web sources retrieving, the syntactic approach which uses keywords to match service has several drawbacks, including problems with synonyms (semantically similar but syntactically different services) and homonyms (syntactically equivalent but semantically different services).

Firstly in service discovery and selection, keyword-based mechanism, which does not consider the semantics of the requested services, usually illuminates the services with WSDL [7] which just describes the interface features. As a result the services selection can only retrieve service references that exactly match the service interface name in the query or whose properties include the same syntactic keywords when using a filter. It might result in a list of retrieved services which have the same interface but different functions.

Secondly in services invocation, keyword-based solution mandates that the consumer should know the name of service and the number and types of parameters. This is clearly an obstacle in a pervasive environment, because it prevents unaware services from dynamically invocation.

The automation of service retrieval and invocation demands computer-interpretable description which could not be tackled in syntactic layer. Therefore the service should be semantically annotated with a formal language. Ontology which is a formal, explicit specification of a shared conceptualization provides a common understanding by annotating the knowledge with concept. So in home field, domain-specific ontologies that semantically organize typical Home Services are critical to automate service retrieval and invocation.

Researches have proposed an upper ontology called OWL-S [8] for Web Service based on OWL (Web Ontology Language). It provides three essential classes for service: ServiceProfile, ServiceModel and ServiceGrounding. ServiceProfile is used for advertising and discovering services. ServiceModel gives a detailed description of a service's operation. ServiceGrounding provides details on how to interoperate with a service, via messages. In OWL-S, both the ServiceProfile and the ServiceModel are thought of as abstract representations; only the ServiceGrounding deals with the concrete level of specification, it could be thought of as a mapping from an abstract to a concrete specification of those service description elements that are required for interacting with the service. OWL-S, in conjunction with domain-specific ontologies for smart home field, provides standard means of specifying declaratively descriptions for Home Services that would enable retrieval and invocation automatically.

Home Service is an extension of Web Service for smart home. However comparing with Web Service [9, 10] on the Internet, Home Service owns inimitable features.

Firstly, most Web Services on the Internet are run on the computers, while the devices which run Home Services are various home appliances not limited to computers, therefore the equipments Home Services use are much more abundant.

Secondly, Web Services on the Internet focus on the communication among services rather than the interaction between services and environment. While an important function of Home Services is to control the devices adjusting states of environment. They play an important role in physical effects, hence the interaction between Home Services and environment could not be ignored.

According to comparison between Home Service and Web Service on the Internet, it can conclude that OWL-S could formally describe the semantics of Web Services, however it is still not sufficient for the description of device, context and human's need. First OWL-S supposes that all the services are run on the computers, accordingly it has no concept for device. But in smart home the service is implemented on multifarious devices, thus the device concept could not be ignored. Second OWL-S just describes the effect which means the change of the context brought by service implementation, and the effect is treated as expression. However, in smart home, the context of Home Service is much more complicated than the context of Web Service. So in order to guarantee service invocation correctly, the context should present semantic information that context-aware services can use. It means that just using expressions to describe context is not enough, we should provide ontology rather than expression for context description. Finally human plays an important role in smart home and human's need is a key factor for service retrieval and invocation, but the need is not involved in OWL-S.

Many literatures [11-17] have proposed relative domain ontologies of smart home for the concepts like device, place, policy, etc. The domain ontologies provide semantic information for Home Service from different facets. However to the best of our knowledge no attempts have been made to construct a domain upper ontology for smart home. Namely literatures independently construct various ontologies for the classification of concepts of smart home field without defining the concepts themselves and the relations among them formally. The absence of upper ontology would lead to concepts misuse. The current state of the literatures of home domain ontologies lacks the understanding of the correlation and inter-dependency of concepts within the field. In turn, this obscurity is hindering the advancement of this research field. As a result, the introduction of an organization of the domain knowledge and their relations is necessary to help the research community achieve a better understanding of this field.

The contribution of this paper is three-fold. First it presents Home Service Ontology which is domain upper ontology of smart home. The ontology explicates the key concepts abstracted from home context and presents the relations among the concepts formally, especially it differentiates the concepts of need and function which are two easily-confused concepts. Second with the domain upper ontology as a fixed viewpoint, we reify the concepts in it and propose several domain ontologies for further more detailed conceptualization. Finally we propose an ontological model for Home Services to organize the ontologies and services layered.

The rest of this paper is organized as follows. Section 2 extracts the concepts from the field of smart home and describes the relations among them based on the analysis of Home Service context, and then proposes our model for Home Service. In section 3 the Home Services are classified into two types according to the property of HAN. Then according to the types of services, section 4 represents two relevant scenarios to demonstrate the usage of the model proposed in the second section. Section 5 shows how to search the Home Services which are mentioned in above two scenarios in details. Related works about Home Service Model and Function Concept Ontology are introduced in section 6. The final section concludes the paper and presents the future work.

2. Home Service Model

2.1. Environment Analysis of Smart Home

Home Service is a software component that is implemented on the computer. Here the computer is a broad sense computer including PC (Personal Computer), SCM (Single-Chip Microcomputer), etc. In order to achieve specified function that user expects, the service should control home appliance to interact with the context. Consequently, to extract service-related concepts from the field of smart home, we should analyze the context where Home Service is run first.

Rosenman and Gero [18, 19] extend function-behavior-structure framework for improving intelligence of design system in mechanical manufacture, they analyze the relations among techno-physical environment, nature environment and socio-culture environment which have close relation with artifacts. For concept explanation they distinguish the context into three parts: External World, Interpreted World and Expected World.

Home Service is also an artifact. However, unlike other artifacts, Home Service as a software component is not substantial. It means that the implementation of service requires device as its carrier. So, Computer World as the carrier of service should also be involved in Home Service context.

Therefore we distinguish the home context into four parts: External World, Interpreted World, Expected World and Computer World. Figure 2 depicts the relations among the four worlds.

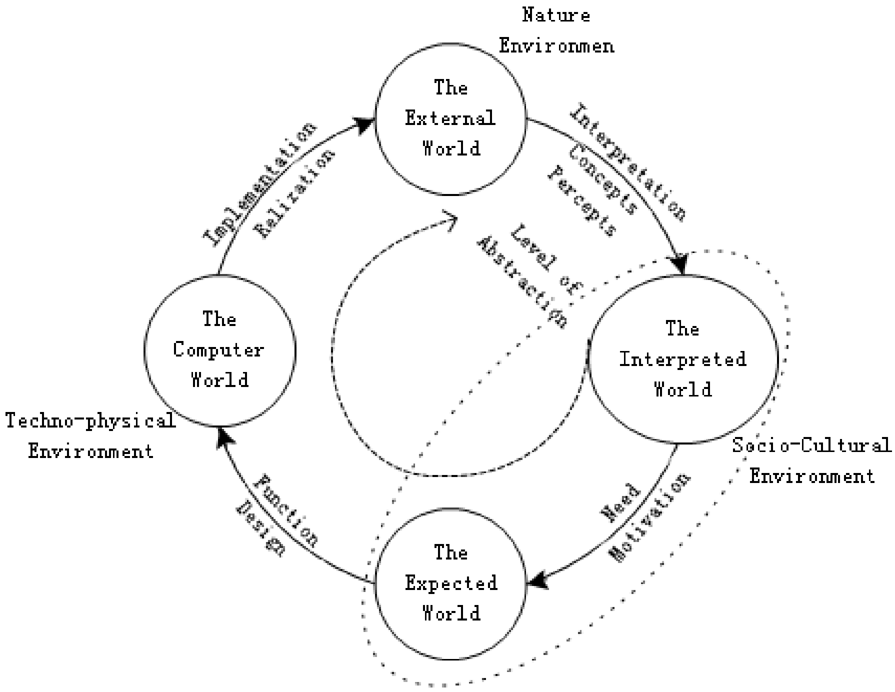

Fig. 2. Four Worlds

The External World pictures the current states of the physical world.

The Interpreted World is the one built up inside the human beings in terms of sensory experiences, percepts and concepts. That is, the internal representation of the External World that human interacts with. It triggers lots of unsatisfied needs.

The Expected World is the one being produced by using devices so as to satisfy the needs of human beings. The functions of devices can be imagined according to current goals of human and interpretations of the current states of the world.

The Computer World is the one consisting of devices which are designed to provide specific functions. It is responsible for transforming the expected world into the external world.

The four worlds are recursively linked together by four classes of processes. The Interpretation process transforms variables sensed in the External World into interpretations of sensory experiences, percepts and concepts which in turn become part of the Interpreted World. This process is done by the interaction of sensation, perception and conception processes. Then in Motivation process the Interpreted World is transformed into the Expected World motivated by needs which are generated by human experiences. The needs are expressed as goals in the Expected World. The devices in the Computer World are designed to achieve the goals proposed in the Expected World. The Design process transforms the goals which are proposed in the Expected World into the functions that could be provided by devices, and then the devices in the Computer World would be designed according to the functions. Finally the process of Implementation is an effect which brings about a change in the External World according to the function provided by the Computer World. The four worlds from the Interpreted World to the External World materialize conceptions of human beings gradually, and the level of abstraction is decreased as well. The Home Service which is a kind of artifact just sites in the Computer World and would satisfy users' needs by controlling the device to realize specified function.

2.2. A Domain Upper Ontology

By distinguishing home context into four worlds, we could abstract six service-related concepts including "Need", "Context", "Device", "Function", "Content" and "Service". The following would explicate these concepts respectively.

Home Service would influence the external world by device operation. The effect of service is recognized as function which implies the goal of service. We say that the service satisfies need, when the effect plays a positive role for human. Need and function are two easily-confused concepts. So we distinguish the two concepts from origination first. As figure 2 shown, they are abstracted from different processes. Need originate from the Motivation process where the Interpreted World is transformed into Expected World; while function sites in Design process where the Expected World is transformed into Computer World. The levels of abstraction of two concepts are different as well. According to above section analysis the need concept is more abstract than the function concept.

In addition, the service as software may operate some data which is defined as content in the paper. The service would be recognized as different applications when cooperating with different contents. Take the questionnaire service as example, when the content consists of simple choice questions of some course, the service becomes an examination; while the service becomes a psychological test if the content consists of choices to certain circumstances one meets in daily life.

2.2.1 Home Service Ontology

To clarify the concept relations among need, function, service, content etc, this paper constructs Home Service Ontology as an upper ontology for smart home field. The ontology is expressed in the form of RDF diagram in figure 3.

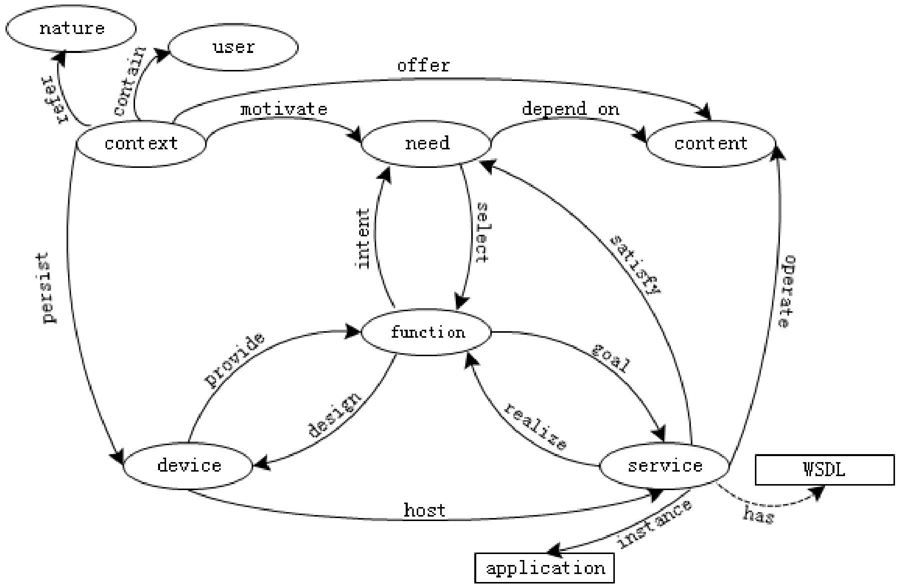

Fig. 3. Home Service Ontology

As shown in figure 3, human's *need* is *motivated* by *context*. Since the context varies dynamically, the needs are changeful and diverse in daily life. On the one hand a need could be satisfied by various services; on the other hand one service could satisfy a variety of needs motivated by different contexts. For example, an alarm informing need is motivated when insecure situation occurs in smart home. Then for residential users, the need could be satisfied by audio-playing service which is run on audio device, and for outworkers, they could be informed the alarm by using SMS service provided by cell phone. Besides the alarm informing need, other needs like note reminding need and music playing need could also be satisfied by the audio-playing service. So it is not proper to annotate the audio-playing service with alarm informing need, namely the need concept could not explicate the semantic of service. Psychology researches that with the same need the goals may be such differences for kinds of people, and on the other side to the same goal the needs from different people are inconsistent as well [20, 21]. If we examine carefully the average needs that we have in daily life, we find that they have at least one important characteristic, i.e., that they are usually means to a goal rather than goals in themselves. Usually when a conscious need is analyzed we find that we can go behind it, so to speak, to other, more fundamental intentions of the individual. It is characteristic of this deeper analysis that it will always lead ultimately to certain intentions behind which we cannot go; that is, to certain intention-satisfactions that seem to be goals in themselves and seem not to need any further justification or demonstration. The fundamental or ultimate intentions of all human beings do not differ nearly as much as do their conscious everyday needs [22]. The intentions are always implied in the needs. Therefore to satisfy a need, consumer usually has to select a proper *function* which reflects the *intention* implied in the *need*. Moreover the function presents the *goal* of the *service*, and meanwhile it also guides the *design* of *device*, hence the device *provides* the function exactly. The *realization* of given function relies on service implementation, and the precondition is that the device which *hosts* the service should be persisted in the context. Additionally the service would be implemented as different *applications* when cooperates with different *contents*, so we can conclude that the need *depends on* specific *content* as well. All the contents that the service *operates* are *offered* by the context. The home context consists of *device*, *user* and *nature* environment. Thus the content comes from above three sources.

2.2.2 The functional Semantic of Service

The Home Service Ontology explicates our viewpoint and formally defines service-related concepts from the unified viewpoint. In the ontology we differentiate function from need, which are usually confused with each other in other literatures. For instance other literatures recognize “illumination” and “guard” as the functions of “turn-on light” service. However from our viewpoint described above, the intention of “turn-on light” service is to adjust the brightness state of the External World, accordingly the service influences human vision, and then the function of the service is vision-related. The service which realizes vision-related function would actually alter the states of External World, and in different contexts the altered states may lead to different effects which eventually satisfy various needs such as “illumination” or “guard”. In our opinion, the function of a service is unique and fixed, while the needs which a service could satisfy are diverse with different contexts. Thus, annotating service with function could explicate the functional semantic of service.

The Home Service Ontology as domain upper ontology defines key concepts in the field, and formalizes relations among them. It formally clarifies the whole process from need motivation to service invocation, therefore annotating the service with the concepts in the ontology could promote the automation and intelligence of smart home. However, the concepts described above are highly abstracted, they can hardly be used to annotate services for exactly service searching. Thus we construct domain ontologies for smart home by reifying the concepts in Home Service Ontology.

2.3. Function Concept Ontology

As Home Service Ontology analysis shown in figure 3, function which indicates the goal of service and the intention of need bridges the need and the service. Annotating service with function would automate service retrieval based on human’s need. Therefore to classify service in semantic layer we should research the category of function.

As interpreted in figure 2, people perceive the External World with multi-sensory organs such as eyes, ears, nose etc. As a result in Interpreted World the conception model which represents External World that the human interacts with is also combined with many factors. Then the ideal model of Expected World evolves from conception model is also composed with multi-factors. It means that the satisfaction of need often refers to several factors.

On the other hand service which is implemented in Computer World is software component. The essence of component determines that service could only adjust limited states of External World, i.e. the functions realized by service are limited. According to software engineering the module should be highly cohesive and loosely coupled. Based on the principle an optimal service should just realize one function and alter one factor only. Consequently to automate service retrieval for need, the need should be decomposed according to factors. The decomposed factor should coincide with the service. So the factors decomposition is vital for automation.

The need situates in the Motivation process from Interpreted World to Expected World, namely need stimulates conception model to ideal model. While the target of our research is how to reuse existed services to satisfy need with matured ideal model, therefore our focal issue situates in the Design phase that transforms Expected World to Computer World. Accordingly we should abstract factors for service annotation in Design phase.

From relations of concepts shown in figure 3, it is known that the device in techno-physical environment is designed for specific function which denotes the goal of service. By annotating the goal of service with function, the service could be searched semantically. We differentiate function from need and annotate service with function rather than need, however the function still reflects intention which is implied in need and function selection relies on need as well. It means that the function can not isolate from need absolutely.

In conclusion, we should construct Function Concept Ontology to decompose factors with the guidance of a need theory, and then annotate the service with the classified function to present functional semantic information.

2.3.1 Maslow’s Hierarchy of Needs

Maslow’s hierarchy of needs [23] is layered need theory in psychology. Many researches have advanced Maslow’s theory and proposed several need theories [24-27] for different social formations and technology domains. However, to the best of our knowledge there is still no need theory is provided for smart home. Hence in this paper we would use Maslow’s hierarchy of needs as guidance and consult existed services to construct our Function Concept Ontology for service annotation.

Maslow's hierarchy of needs is often portrayed in the shape of a pyramid, with the largest and most fundamental levels of needs at the bottom, and the need for self-actualization at the top. It has five layers: Physiological need, Safety need, Belongingness and love need, Esteem need and Self-actualization need.

In Maslow's theory, Physiological needs are the literal requirements for human survival. If these requirements are not met, the human body simply cannot continue to function. Physiological needs are usually related to body senses. With their physical needs relatively satisfied, the individual's Safety needs take precedence and dominate behavior. These needs have to do with people's yearning for a predictable orderly world in which perceived unfairness and inconsistency are under control, the familiar frequent and the unfamiliar rare. In the world of work, these Safety needs manifest themselves in such things as a preference for job security, grievance procedures for protecting the individual from unilateral authority, savings accounts, insurance policies, reasonable disability accommodations, and the like. After Physiological and Safety needs are fulfilled, the third layer of human needs is social and involves feelings of belongingness. This aspect of Maslow's hierarchy involves emotionally based relationships in general. Humans need to feel a sense of belonging and acceptance, whether it comes from a large social group, or small social connections. They need to love and be loved by others. After that all humans have a need to be respected and to have self-esteem and self-respect. Also known as the belonging need, esteem presents the normal human desire to be accepted and valued by others. People need to engage themselves to gain recognition and have an activity or activities that give the person a sense of contribution, to feel accepted and self-valued, be it in a profession or hobby. Finally the Self-actualization need pertains to what a person's full potential is and realizing that potential. Maslow describes this desire as the desire to become more and more what one is, to become everything that one is capable of becoming.

2.3.2 The Method of Function Extraction

Referring to Maslow's hierarchy of needs, our Function Concept Ontology is also classified into five layers. In each layer we collect relative needs and then extract functions from the needs. The following would give the method of how to extract functions from needs.

As Home Service Ontology defined, both of need and function which reflect people's intention are subjective. The difference between them is that function is context-independent while need interprets the intention additional with special context. Intuitively as shown in figure 3, the "need" concept is directly connected with "context" concept by the object property "motivate"; while the "function" concept has no relation with "context" concept. Since the context varies dynamically, the needs are changeful and diverse in daily life. Extracting from specific context, the function directly depicts the intention which is more fundamental.

In conclusion the difference between function and need is whether the interpretation of intention depends on the context. For instance the alarm informing need for insecure situation, the music appreciation need for entertainment, and the voice reminding need for important message are different needs motivated by different contexts. Eliminating the context, the intention of the needs is the same, that is an audio play. Then the “play” is the very function concept extracted from the needs. Hence we would extract concepts of function from various needs by eliminating the contexts which the needs rely on, then organize the concepts according to layers of function denoted by Maslow’s hierarchy of need. Figure 4 gives a portion of function concepts.

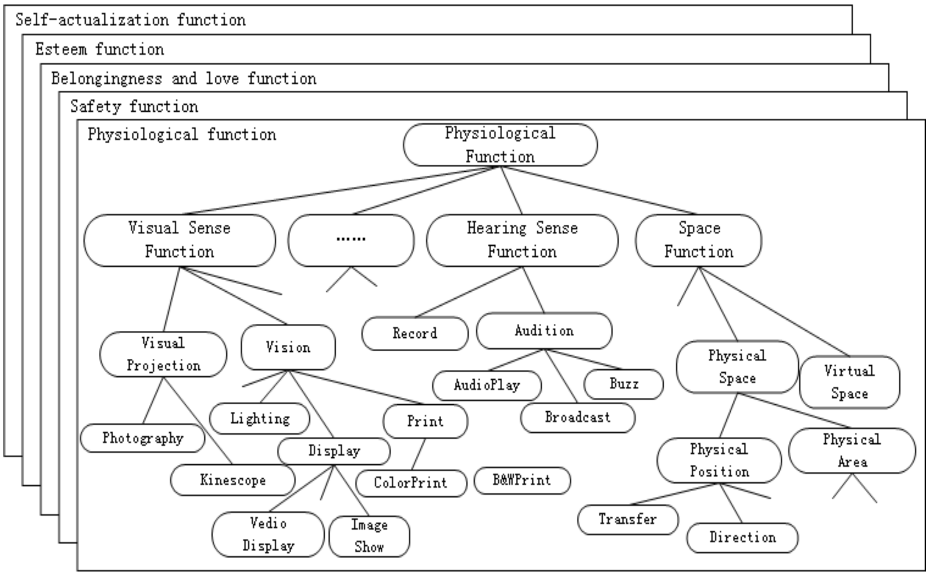

Fig. 4. Part of Function Concept Ontology

2.4. Context Concept Ontology

According to the former sections analysis, function presents the intention of need and the goal of service. It bridges the need and the service. By annotating service with the concepts in Function Concept Ontology, candidate services could be automatically retrieved for need. Then to decide which service would finally be invoked, there exist numerous rules, such as utility rule, cost rule, etc. Among the various rules the essential principal and the least constraint rule is that the context should offer all the contents that the service requires. So for a service invocation we should check whether the context offers suitable contents that could be operated by service. Therefore analyzing the elements of the context and expressing them with formal language to provide semantic information for context would assist automating service invocation.

Figure 1 shows that the boundary of the smart home model is device which would interact with user and nature environment. Consequently Home Service would communicate with device, user and nature environment only, and then the content that Home Service operates could only be derived from above three sources either. Consulting relative domain ontologies of other literatures, we construct the Context Concept Ontology by extracting concepts from device, user and nature environment. Figure 5 shows portion of the ontology and the hierarchy of concepts. With the Context Concept Ontology annotation, whether the least constraint rule is satisfied could be inferred automatically.

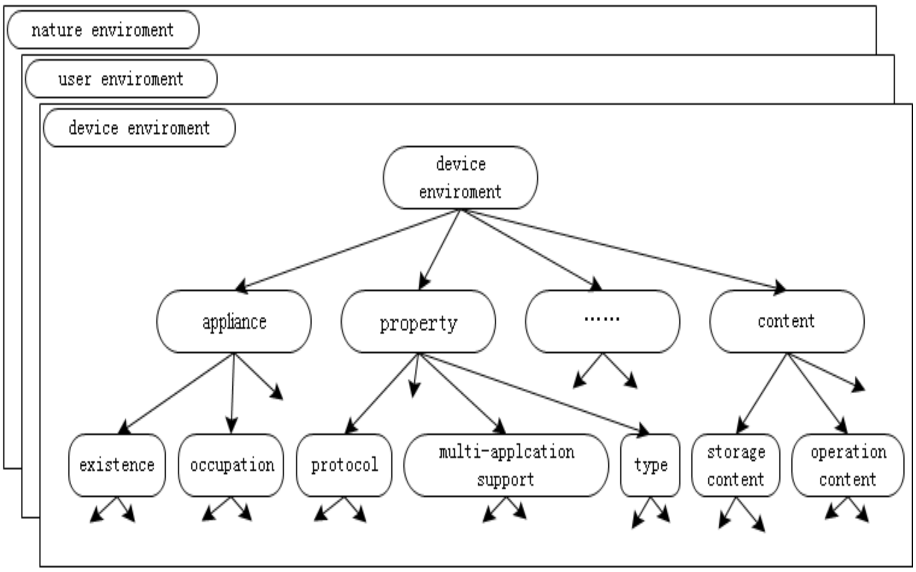

Fig. 5. Context Concept Ontology

2.5. Ontology-Based Home Service Model

Above three sections present three ontologies respectively: Home Service Ontology, Function Concept Ontology and Context Concept Ontology which would be scattered into two different layers. These three ontologies in conjunction with top-level ontology, rules and service repository compose our Home Service Model. Figure 6 represents the framework of the model.

As shown in figure 6, the Home Service Model has 5 layers.

The first layer is top-level ontology which is similar to other ontology-based models such as Eco-ontology [28], SWEET [29], MMI [30], etc. The top-level ontology defines the concepts like time, space, matter, energy, etc.

The second layer of Home Service Model is domain upper ontology which is used to formalize the concepts extracted from the smart home field. It provides theoretical support for the following layers. The ontologies in the first two layers are used to clarify the fundamental of the field of smart home.

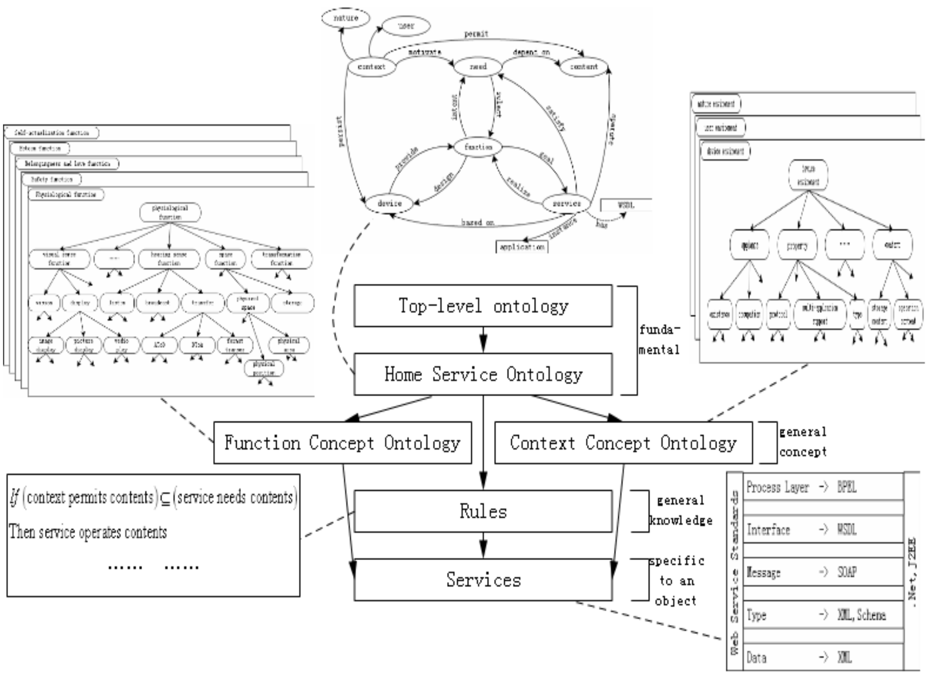

Fig. 6. Home Service Model

In the third layer there are two domain ontologies: Function Concept Ontology and Context Concept Ontology. They provide general concepts for the field from different facets. The Function Concept Ontology is constructed with the guidance of Maslow's hierarchy of needs, and the function concepts in it present the goals of services. With the annotation of Function Concept Ontology, the service could be automatically retrieved for need. Then for automating Home Service invocation, the Context Concept Ontology is constructed. It extracts concepts from device, user and nature environment. With the annotation of Context Concept Ontology, whether the context offers compatible content for service operation could be inferred.

The rules in the fourth layer which is maintained by user express user's general knowledge and exhibit user's preference. Initially the set of rules in Home Service Model provides just one default rule that is the least constraint rule, the formal expression of the rule is shown as Rule-1. Then users could customize rules set by appending new rules according to their preference.

$$IF \quad (\text{context offers contents}) \supseteq (\text{service requires contents})$$

Rule-1

$$\text{THEN service operates contents}$$

Finally the service repository in the bottom layer is labeled with criterions from SOA (Service-Oriented Architecture) which is a well adopted architecture for Web Service organization. For instance the interface of Home Service is described by WSDL (Web Services Description Language) and the communication protocol uses SOAP (Simple Object Access Protocol). With these universal criterions the Home Services in our repository could be invoked by other users with other models.

3. Home Services Analysis

Before demonstrating the usage of the model, we discuss the types of Home Services first, and then give one scenario for each type to simulate the solution.

As shown in figure 1, in HAN model there are two kinds of bandwidths: high bandwidth and low bandwidth and two kinds of devices: simplex device and duplex device. The HAN could be classified into 3 categories logically according to bandwidths and devices. The first one is Control Net. The devices in this kind of net just receive instructions from residential gateway, therefore the bandwidth required is very low. Light and alarm bell are such devices that are used in Control Net. The second category is Information Net. The devices in Information Net exchange a little information with the gateway, consequently the bandwidth is not high. The devices like sensor, ammeter are used in Information Net. They have to response the query from the gateway. The third category is Service Net. The devices in Service Net would exchange large amounts of data with the gateway, thus the bandwidth is very high. Such as VOD (Video On Demand) application, the TV has to receive large amounts of video data from the gateway.

According to the categories of network, the service could be classified into two types. First the services implemented in Control Net concentrate on controlling home appliances rather than content operation, so we call this type of services Control Service. Second the services implemented in Information Net or Service Net not only control devices but also operate contents, so we call this type of services Content Service. Table 1 presents the relations among service type, network, bandwidth, device and content.

Table 1. Service Type

Service type	Network	Bandwidth	Device	Require content
Control Service	Control net	Low	Simplex device	N
Content Service	Information net	Low	Duplex device	Y
	Service net	High	Duplex device	Y

4. Scenarios

As last section analysis, the Home Services could be classified into two types: Control Service and Content Service according to property of HAN. In this section we would display two scenarios for above two types of services respectively. The scenarios show the entire process from need generation to service invocation to demonstrate the usage of the Home Service Model.

4.1. Scenario for Control Service

This subsection presents a scenario that displays the process of solution of Control Service. The essential service that smart home should supply is security service. The model should inform the insecurity when dangerous affairs occur. Figure 7 displays the scenario to simulate the solution.

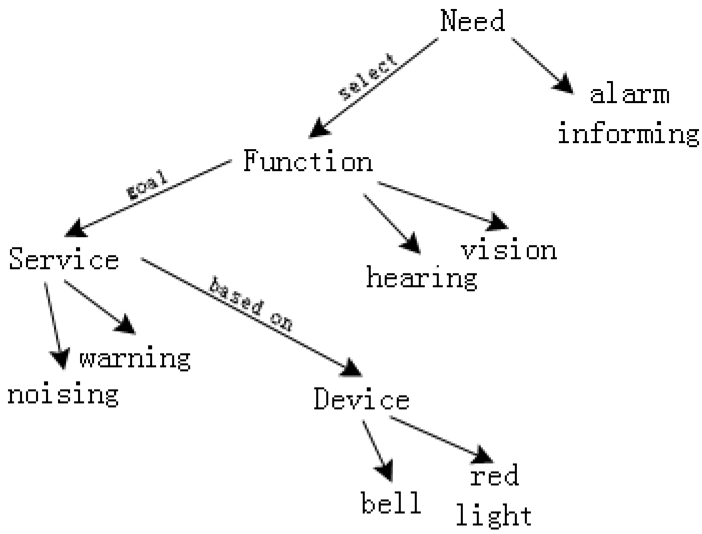

Fig. 7. Scenario for Control Service

It is obvious that insecure affairs would motivate “alarm informing” need. The model could select “vision” function and “hearing” function for the intention of the need. Then according to annotation of Function Concept Ontology, the “warning” service for “vision” goal and “noising” service for “hearing” goal could be retrieved. Afterward the model would reason Context Concept Ontology to check whether the devices “bell” and “red light” which implement two services separately are offered by the context. Finally the need could be satisfied, if the context does offer at least one device.

4.2. Scenario for Content Service

This subsection presents a scenario that displays the process of solution of Content Service. In smart home besides the security related services, the entertainment services should also be provided. After busy working, people may listen to the music for relaxation. Figure 8 displays the scenario to simulate the solution.

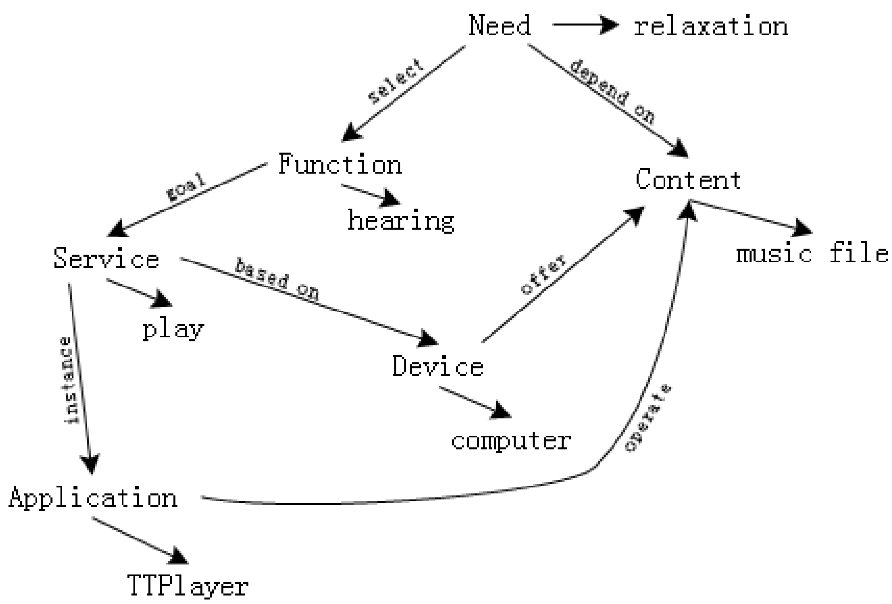

Fig. 8. Scenario for Content Service

It is obvious that the need in the scenario is “relaxation”. The intention could be achieved by “listen to music”. Thereby the selected function is “hearing” and the corresponding content is “music file”. Then the model may get “play” service for the “hearing” goal according to annotation of Function Concept Ontology. The model would locate the device “computer” which implements the “play” service by reasoning Context Concept Ontology, and then check whether the required content is offered by the device. If the device does store the content “music file”, the model may use “TTPlayer” which is an application of “play” service to operate the content.

In a word, in the Home Service Model, Home Service Ontology formally represents the whole process from need motivation to service invocation by explicating the relations among fundamental concepts. The relations in the ontology are defined by object properties of which domain and range connect two concepts respectively. Therefore by object property reasoning in DL (Description Logic), the model could automatically progress the phases of process. Then for various highly abstract concepts in the process, we reify them with the concepts from two domain ontologies to annotate the semantics of service.

5. Ontology-Based Home Service Search

Last section has shown two scenarios about how to accomplish process with the guidance of Home Service Model roughly. In this section we would give more details about the process of service search.

As figure 1 shown, the residential gateway controls all the appliances in the smart home, and it is the center of HAN. Therefore we embed Home Service Model into the gateway to manage Home Services.

5.1. Home Service Register

When the Home Services are deployed into smart home, they should also be registered to Home Service registry which lies on the residential gateway. The current service registry of residential gateway stores a table-based representation of the Home Service. Then in service discovery phase, the residential gateway would search services by matching the keyword with service name syntactically. For appending addition semantic information to service, the service registry should be expanded as shown in figure 9.

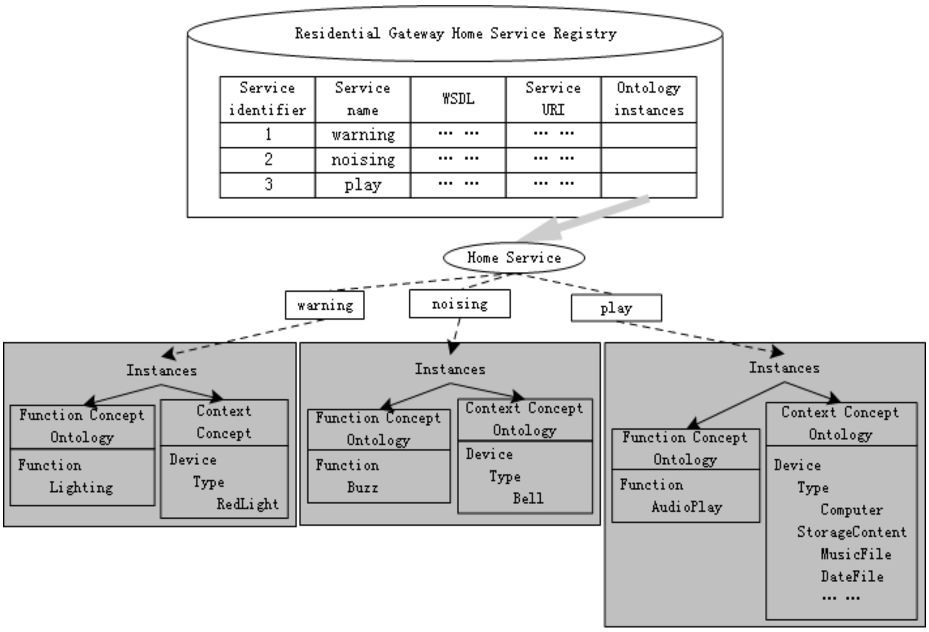

Fig. 9. Instances of Ontology

We add Ontology instances item to the service registry. The new item which stores the instances of the concepts provides the semantic information for service. Figure 9 declares three instances for the services which are mentioned in the scenarios of last section. Referring to the Function Concept

Ontology, the function of “warning” service is annotated by “Lighting” concept, and the functions of “noising” service and “play” service are respectively annotated by “Buzz” concept and “AudioPlay” concept which are two sub-concepts of “Hearing” concept. That is declaring instances for the relevant function concepts. The function instances are declared as follow:

<Lighting rdf:id=” Lighting_WarningService ”/>

<Buzz rdf:id=”Buzz_NoisingService ”/>

<AudioPlayrdf:id=” AudioPlay_PlayService”/>

Then, as figure 9 shown, instances of Context Concept Ontology are declared to present the device information for services. For example the device type of “play” service is annotated with “Computer”, and the storage content is annotated with “MusicFile”, “DataFile”, etc.

5.2. Home Service Retrieval

In current service retrieval phase, the residential gateway searches Home Service registry by syntactically comparing keyword with service name. If there are some services matched, then the gateway returns the URI addresses where the services are deposited. However, the keyword-based approach would encounter synonyms and homonyms problems. For instance there is another service whose name is “play” and the function is to play video. Unfortunately the keyword-based approach could not distinguish two “play” services because of the same service name. Accordingly both “play” services would be retrieved by the keyword “play”, and apparently the video related service is improper service for user’s intention.

By enhancing residential gateway with Home Service Model, above syntactical problems could be solved by the appended semantic information. As figure 9 shown, each service in the registry is annotated with a function concept, namely an instance of specific function is declared to present functional information for the service. Therefore in our semantic approach the residential gateway would search services by reasoning the instances of the function which user requests.

For example when registering above video “play” service to Home Service registry, an instance of “VideoDisplay” concept would be declared for the service according to the Function Concept Ontology shown in figure 4. Then if an audio “play” service is wanted, the gateway would reason the instances of “AudioPlay” concept in Function Concept Ontology. All the services which are annotated with “AudioPlay” concept could be retrieved, and above video related “play” service which is declared as instance of “VideoDisplay” concept could be expelled.

In addition in DL instance reasoning the instances of sub-concepts are also instances of parent concept. As shown in figure 4 and figure 5, one function of two scenarios proposed in last section is “hearing”. Consulting Function Concept Ontology, “Buzz” concept and “AudioPlay” concept are two sub-concepts of “Hearing” Concept. Therefore by reasoning instances of “Hearing” concept both of “noising” service and “play” service could be retrieved. The names of above two retrieved services are such different and the functions are similar to some degree, which could hardly be achieved in keyword-based approach. Similarly "warning" service could be retrieved by reasoning instances of "Vision" concept.

Afterwards by searching Home Service registry, the URI addresses of retrieved services could be returned.

5.3. Home Service Invocation

Once candidate services are retrieved, the residential gateway should invoke the proper services automatically. As former sections analysis, the least constraint rule for service invocation is that the context should offer all the contents that service requires. Therefore the residential gateway has to check whether the device, user and nature environment are suitable for services invocation. That is to examine the compatibility between the instances of Context Concept Ontology and specific context.

For example both of "noising" service and "play" service could be retrieved by reasoning the instances of "Hearing" concept. The gateway should invoke proper service for specific context. As figure 7 for the first scenario depicted, the insecurity context requires "bell" device to inform alarm. Then the gateway would reason the relative instances of retrieved services. According to figure 9, the Device Type of "noising" service is annotated by "Bell". It means that the "noising" service is compatible with the insecurity context, and then the gateway would invoke "noising" service to satisfy "alarm informing" need. Similarly with the first scenario, by reasoning Device Type instance and StorageContent instance for the second scenario, it can be drawn that the "play" service is compatible with the entertainment context and could be invoked to satisfy "relax" need.

6. Related Work

6.1. Research of Home Service Model

In Home Service invocation related field, several researchers have proposed several approaches for smart home. Choonhwa Lee et al. [31] propose using OSGi (Open Services Gateway initiative) as an infrastructure for integrating various devices and sensors to provide pervasive computing environments. However, they don't resolve the service search and invocation problems. Dobrev et al. [32] tackle these two problems directly, but not from a semantic perspective. They import services from and export them to Jini and UPnP technologies using OSGi to bridge multiple discovery protocols. Tao Gu et al. [11] represent ontology-based context model. The model presents contextual information that can be used by context-aware applications. However it dose not describe physical effects by services execution. Daniel Retkowitz et al. [12] construct context model by extracting concepts from user and nature environment. The model ignores the information produced by devices. Diaz Redondo. et al. [13, 14] propose OWL-OS for Home Service by extending OWL-S, in their model the approach could discover, select and invoke services semantically.

Some initiatives have addressed the research issues of ubiquitous computing and user modeling for the ontological description of the smart home. Harry Chen et al. [15] describe a shared ontology called SOUPA - Standard Ontology for Ubiquitous and Pervasive Applications to represent intelligent agents with beliefs, desires and so on, and discuss the application in intelligence space. Dominik Heckmann et al [16, 17] present General User Model Ontology (GUMO) for the distributed user models in intelligent Semantic Web enriched environments.

The drawback of the models mentioned above is that the function concept and the need concept are confused. They annotate the functional semantic of service with need. The needs are diverse with various contexts. Accordingly in their model for different contexts one service could have multiple semantics, which would hinder service retrieval. In this paper we differentiate function from need, and adopt function as the functional semantic of service. The function is context-independent concept and is fixed for different contexts. Therefore annotating the service with function could facilitate service retrieval semantically.

6.2. Research of Function Concept Ontology

The Home Service Ontology discussed in Section 2 defines the concept of functionality strictly from the need-centered viewpoint. We extract function concepts by eliminating context factors from needs. Such definition is done intended to prescribe guidelines to functional modeling. We focus on purpose function rather than device function. Other types of function, however, still remain to be investigated. Consulting function categories proposed by Yoshinobu Kitamura [37] as shown in figure 10, this section discusses descriptive definitions of other kinds of function. Note that figure 10 shows an "is-a" hierarchy only for readability, because some distinctions are independent from each other.

Firstly, environmental function which represents changes outside of the device boundary is related to users or user actions. For example an electric fan performs cooling function for human body as environmental function where the cool-down effect by wind is on human body and thus outside of the system boundary. The environmental function could divide into physical environmental function and interpretational function. The physical environmental function represents physical changes of the environment in which device works, while an interpretational function sets up one of necessary conditions of human's cognitive interpretation. Chandrasekaran and Josephson [33] discuss a similar kind of function called environment function as effect on environment. They conceptualize “mode of deployment”, which is configuration of device and environment. Some researchers distinguish purpose from function [34, 35], where the purpose represents human-intended goal in the similar sense to the environmental function or interpretational function. Hubka [36] distinguishes the purpose function as effects from the technical function as internal structure. Rosenman and Gero [18] investigate purpose in socio-cultural environment. The situated FBS framework treats change of requirements [19]. Our function is kind of interpretation function, and we have differentiated function from need.

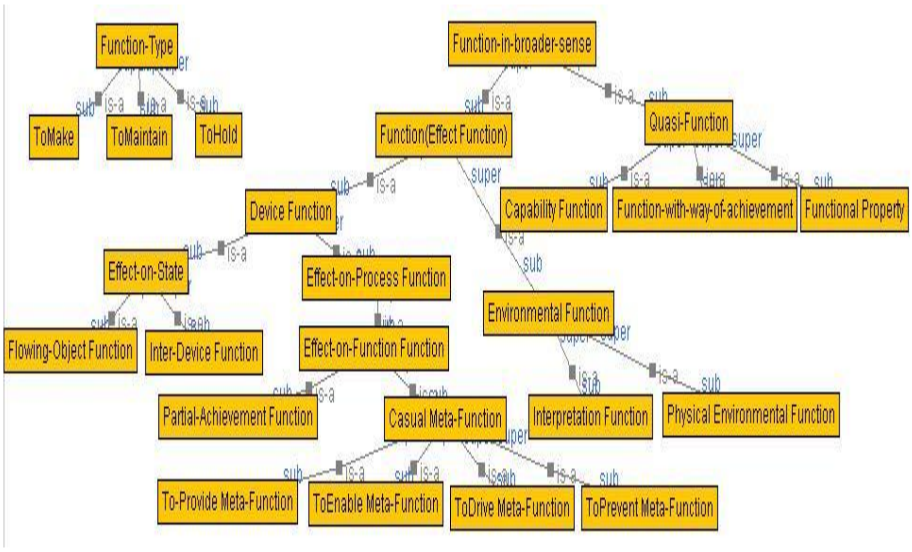

Fig. 10. Descriptive Categories of Function

Secondly, contrary to environmental function, device function considers changes within the device boundary. One of device function is effect-on-state function which focuses on temporal changes of physical attributes. The flowing-object function [37, 38] refers to temporal changes of physical attributes of objects which flow through the device and inter-device function [39] refers to changes of another device.

Another device function is effect-on-process function [40] which represents effect on a process or its changes. Behavior as basis of function can be regarded as a kind of a process. Thus, as a subtype of the effect-on-process function, effect-on-function function represents a role of a function for another function. It includes partial-achievement function and causal-meta function. The former is performed by a method function for a goal function in the is-achieved-by relation. The latter represents a role for another method function

Thirdly, we recognize the following three kinds of quasi-functions. Although the authors do not consider them as kinds of function, it is found that a quasi-function is confused with a function. Firstly, a function-with-way-of-achievement implies a specific way of function achievement as well as a function. Its examples include washing, shearing, adhering (e.g., glue adheres A to B). Because meaning of this type of function is impure, we regard it as quasi-function. Secondly, a functional property represents that an artifact (usually material) has a specific attribute-value which directly causes functionality. This is found in material science domain where a material whose function is dependent on its electronic, optical or magnetic property is called functional material [41]. For example, if an electrical conductivity of a material is high (i.e., it has high conductivity property), the material can perform the “to transmit electricity” function. There is direct relationship between the high-conductivity property and the transmitting function. Lastly, a capability function represents that an entity can perform an activity which is not effect on others. For example, people say that “a human has walking function”.

7. Conclusion

This paper presents an ontology-based Home Service Model which contains 5 layers for automatically progressing the phases of the process from need motivation to service retrieval and invocation. The model presents a domain upper ontology to clarify the relations among the concepts, and two domain ontologies to provide semantic information for service annotation from different facets. With assistant of above three ontologies, the model could retrieve and invoke feasible services automatically. Considering personality the model also offers a layer for rules which are customized according to user’s preference. Finally two scenarios, which are displayed for two types of services, are given to demonstrate the usage of model.

All the services discussed in this paper are atomic services. Along with the complication of task, several atomic services should be composed to satisfy one need. So in the future work we will research how to compose the services by functions. For this purpose we will adopt function decomposition tree to organize the functions in complex tasks.

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Moji Wei, born in 1981, received the B.E. and M.E. degrees in Information Management and Information System from Shandong Economic University, China, in 2005 and 2008 respectively, and the Ph.D. degree in Department of Computer Science from Ocean University of China in 2011. His current research interests are knowledge representation, ontology theory and application, smart home. (weimoji1981@126.com)

Jianliang Xu, born in 1969, received the B.E. and M.E. degrees in software engineering from Shan-Dong University, China, in 1991 and 1994 respectively, and the Ph.D. degree in system engineering from Yamaguchi University in 1998. He is presently a professor in the Department of Computer Science and Technology, Ocean University of China. His research interests include automata theory, computational complexity and semantic web. (xjl9898@gmail.com)

Hongyan Yun, born in 1971, Ph. D. candidate in Department of Computer Science, Ocean University of China. Associate professor of the College of Information Engineering, Qingdao University. She graduated from North West University (Xi'an, China) in 1993 with a Bachelor Degree in computer software, and then she earned a Master Degree in computer software and theory from North West University in 2000. Her current research interests are Semantic Web, knowledge representation and reasoning, ontology engineering and intelligent information system. (yunhongyan@gmail.com)

Linlin Xu, born in 1989, MS. candidate in Department of Computer Science, Ocean University of China. She graduated from Inner Mongolia Finance and Economics University in 2010 with a Bachelor Degree in computer science and technology. Her current research interests are Semantic Web and semantic-based web serivices discovery and compostion.(gxl0216 @gmail.com)

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