A Context Information Ontology Hierarchy Model for Tourism-oriented Mobile E-commerce

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***Abstract*—with the development of e-commerce, it has become a study focus as how to get mobile service timely and accurately, as well as how to realize the context information management of users. In this paper, it takes mobile tourism for example to classify and describe context information firstly ,then extract scene features to construct a quality restriction system and eventually build up a self-guided ontology-based mobile information management model for the context. It also cites West Lake Self-help guide as an example to verify the validity of above model in this paper.**

***Index Terms*—context-aware, context modeling, fuzzy rough sets, ontology hierarchy**

I. INTRODUCTION

With the rapid development of "anytime, anywhere" access to information and services in mobile e-commerce, how to meet the requirements of dynamic and uncertain services in mobile environment, achieve context-aware in pervasive computing, and provide personalized services in mobile environment has become a hot topic of current research [1].

Context-aware computing takes in charge of managing, coordinating and scheduling the elements in the computing environment including device, context and physical environment building the interoperability of entity objects and providing unified API for applications and development [2]. In this paperthe “context is defined to describ the physical environment and objects representation characterization information, such as time, location and task, and then to judge and decide what kind of service the user object need. .

Context-aware service consists of context-achieve (context-aware), context information processing and inductive reasoning into applications. First, the physical status associated with the users and the tasks are collected by sensors. Secondly, the context model is built based on analyzing and processing the collected information. ,Finally, what kind of services should be provided can be figured out by context reasoning [3]. The goal of context-aware is to select and provide appropriate business services based on the context information of users and tasks. Context-aware service is provided with automation, 24-hour full service, real-time/ intelligence and personalized customization, which is more prominent in mobile self-help guide.

Now, there are a lot of researches and applications based on the context-aware services combined with the tourism industry, most of which are Context-aware tour guide, and mostly focused on the mechanism of tourismguide service recommendation for the application and development of tour guide system. Rakotonirainy have studied the extend of tour experience in museum based on the context information of user's interest and knowledge level [4]; Da-Jung Park have took Seoul Deoksugung tourism for example to design POA based tour supported application [5]; Gulliver researched the context tour guide system in groups from the standpoint of usefulness, and discovered that it’s faster and more efficient on accomplishing the assigned task than general tour guide system, and it usually got better satisfaction [6]. Tan Peiqiang etc. proposed a context-aware system service model [7].

In China, tThe study of context modeling focus on context-achieve and inference algorithms, which is usually for single-process [8], but pay less attention to quality control of the context information and context modeling itself. Strang. T and Linnhoff-Popien carried out a comparative study of five context modeling methods [9], and Razzaquem [10] discussed classification and quality control problems of context information. Henricksen and Indulska [11] studied the molding problem in context management structure, and the modeling method based on location of mobile environment was studied in details by Chen and Kotz [12]. While Tao Gu [13] proposed the specific context models after studying the perception and modeling in

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smart home environment. However, in these studies, specific interpretation and comparative data is not enough, and the redundant attribute of context information is not considered sufficiently.

Therefore, we proposed an ontology-oriented context information hierarchy model. It describes context by OWL languageand paid attention to the control of the usefulness of context information by quality constraint, which is defined by the theory of soft constraints. By this way, the personalized tour service were achieved by using the DLRL ontology-rule reasoning scheme. Additionally, the model held the ability of dynamic adaptation according to the change of context.

II. THEORY REVIEW

Wherever Times is specified, Times Roman or Times New Roman may be used. If neither is available on your word processor, please use the font closest in appearance to Times. Avoid using bit-mapped fonts if possible. True-Type 1 or Open Type fonts are preferred. Please embed symbol fonts, as well, for math, etc. The current studies of context-aware systems focus on pervasive computing. Wu Zhaohui, the Professor of Zhejiang University, considered that context-aware system research should include the context information acquisition, context information modeling, context information management and context reasoning [14]. Nanjing University Professor Lv Jian raised that context-aware system development and deployment could be supported by a distributed, service-oriented software infrastructure [15]. Currently Gaia, ACAI, CAPpella, CAPNet, SOCAM, CASM, CASA, ACF, and Jena and so on are the common context aware framework. These frameworks have focused on the description and information processing of context, especially on the context modeling and reasoning.

A. Fuzzy rough set

The obtain context information need preparation by screening and analysis. Rough set theory can dig out the information hidden in the knowledge in the form of rules [16].

Suppose U and W as limited field of non-doctrinaire, R is the fuzzy relationship from W to U, the triples (U, W, R) is called general fuzzy approximation space. Arbitrary $X \in 2^w$, the lower approximation $\underline{R}(X)$ and upper approximation $\overline{R}(X)$ of X on the approximation space (U, W, R) is the fuzzy sets of U, the functions which they are subject to are defined as,

For arbitrary $x \in U$,

$$\underline{R}(X)(x)=\bigwedge_{y\in W}[(1-R(x,y))\vee X(y)]=\min\{1-R(x,y)\mid y\notin X\}, x\in U$$

$$\overline{R}(X)(x)=\bigvee_{y\in W}[(1-R(x,y))\wedge X(y)]=\max\{R(x,y)\mid y\notin X\}, x\in U$$

$(\underline{R}(X),\overline{R}(X))$ is general fuzzy rough sets [17].

Considering the sources of context information in tour mobile e-commerce are complex and varied; while properties of the context information are equally important, and even some are redundancies, we adopt the fuzzy rough set theory to realize the context information classification, to maintain the context information classification ability staying the same with deleting unimportant or redundant properties, and retain the important properties related to user preferences.

B. Context Modeling

Context modeling is the basis of context reasoning, and the core of context-aware system framework. It's also the Gordian technique of context-aware services. Context modeling is to define, store and signify context by a machine understandable form. Context model has six categories, key-value pair models, markup scheme models, graphical models, object oriented models, logic based models and ontology based models.

The first three models describe context intuitively by symbols, graph and number, such as CML, a kind of graph-based modeling language [18]. These methods have strong man-made factors, and lack of a unified format to support context interaction, so the reciprocal model appeared. It can gain simple, intuitive context information by terminal equipment or sensor, and some abstract and complex context can be reasoned based on the simple context. So McCarthy defined context as a series of events, formulas and rules, and rule logic support context reasoning [19].

The mainstream modeling method is ontology-based modeling. Ontology has strong ability to express, and it support logical reasoning. It's easy to understand by machine [20]. Reusing and sharing knowledge is also an advantage of it. Ontology based model, in a consistent way to describe the core concepts, is not only suitable for describing and defining contexts and the relationship between them, but also to facilitate analysis and reasoning by computer [21].

C. Context Reasoning

Acquired context data usually required for further processing. According to the relationship associated with other context information, we should decide the values, and get the information value of context which can not be obtained directly by the sensor layer, then get the current complete customer context. This process is called context reasoning. Currently, according to the difference of context models, the primary reasoning method is divided into rule-based methods and ontology-based method.

Rule-based reasoning is divided into two types according as rules and reasoning are separated or not. Now using logic rules and inference engine to achieve a common reasoning is widely adopted. Separation of the rules and reasoning can cope with different situations by rules' definition and modification [22]. Ontology-based reasoning defines context, relationships between them and inference rules in terms of ontology, their attributes and constraints by ontology language, and the reasoning of the context is realize by the reasoning of ontology. Considering advantages of ontology-based representation and developments of ontology reasoning tools, it's very convenient for using ontology reasoning.

Integrating rule-based reasoning into ontology reasoning can abstract modified and extended ontology inference rules, so the ontology-rule reasoning mechanism can combine the advantages of the two methods.

OWL, an ontology language, excel in express meaning and semantic [23], and OWL DL as its sublanguage, except with all these advantages, can complete the knowledge representation in limited time, and has a certain ability of automatic calculation and classification reasoning. Considering the requirements of this paper, OWL DL is the right choice as ontology description language, while SWRL is used as the language of rule design. SWRL is rule description language based on OWLDL, OWLLite and RuleML, which can drive the rules to combine with OWL knowledge base, and achieve the perfect combination of rules and knowledge. SWRL use highly abstract syntax to express knowledge described by OWL, which make the design of rules easier. And the syntax of SWRL can be described by XML and RDF, so the knowledge and rule which are expressed by SWRL give better sharing and reusability.

OWLDL can build a better hierarchy for ontology, while ensure that the definitions produced by ontology not in conflict with each other. SWRL can achieve context reasoning based on ontology knowledge combined with ontology-based rules.

II. Ontology-Based Context Information Hierarchy Modelof Context Information

The context information management model for tour mobile e-commerce get the context information from context providers and context reason engines. Then on the one hand we determine the natural properties of information based on the acquired way; the other hand, it construct the quality constraint model based on soft constraint in satisfactory optimization theory, which can find out the basic information and useful information. Finally, the fuzzy rough set theory was proposed to achieve ontology classification of information, where the type of information category was identified by mutual information values, and ultimately we build the multilevel model of context sub-ontology. The specific steps are shown in Fig.1:

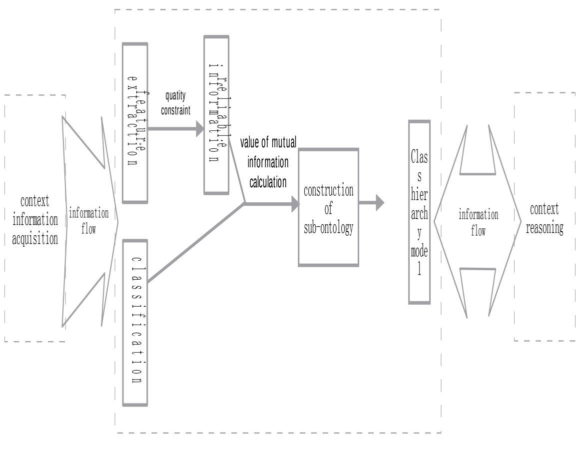

Figure 1. flow chart of modeling

A. Context Modeling

1) Classification and description of context information

After obtaining context information, we determined the natural properties of information based on the acquired way for acquiring the systems representation and unified naming convention of information, which can make the context model describing the different entities will have semantic interoperability.

We divided the context information into two main categories, direct context and indirect context, shown in Fig..2. Direct context can be obtained from the source provider directly, and it can be can be further classified into sensed context from physical sensors and defined context which is typically defined by a user. Indirect context is obtained by integration and reasoning of direct context.

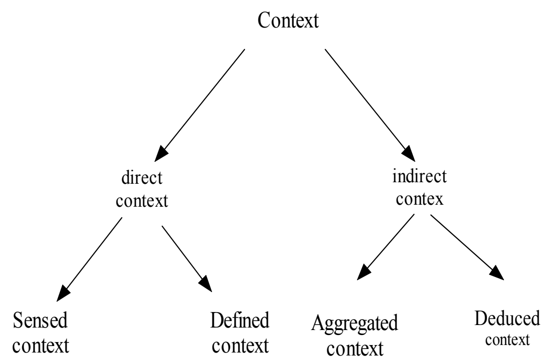

Figure 2. classification of context information

To describe context classification information in our context, we introduced property element - owl: classifiedAs in property restrictions. This element can capture related properties about data types and object in the context classification. The values of the property element are Sensed, Defined, Aggregated or Deduced. As follows, we described the classified information -Defined on the ObjectProperty - Mtransportation, which is the limited information about means of transport based on the spot position.

```
<owl:Class rdf:ID=”sspots”>
  <owl:Restriction>
  <owl:onProperty rdf:resource=” Mtransportation”/>
  <owl:to Class rdf:resource=”# Scenery-spot”>

<owl:classifiedAsrdf:resource=”http://www.zjgsu.edu
/owl/classfication# Deduced”/>
  </ owl:Restriction>
</owl:Class>
```

After determining classification of property, considering the interdependence between context information, we further analyse the characteristics of context information.

To describe restraint in context information by OWL, we introduced property element - rdfs：dependsOn in object properties and data attributes, which is to capture attribute dependence between data types and object. For example, in self-help guide, the visitor's tour plan (Plan) depends on the user's location (locatedAt) and expected weather (weatherCond).

```
<owl:ObjectProperty rdf:ID="feasible">
<rdfs:domain rdf:resource="Plan"/>
<rdfs:classifiedAs rdf:resource=http://b.zjgsu 。edu/owl/classification#Defined"/>
<rdfs:dependOn rdf:resource="locatedAt"/>
<rdfs:dependOn rdf:resource="weatherCond"/>
…
</owl: ObjectProperty >
```

2) Quality constraint

Considering highly dynamic nature of pervasive computing systems and imperfect sensing technology led to information inconsistency at different levels, we constructed quality constraint, an extensible ontology for quality of information, as indicators describing authenticity of context information.

Quality constraint is associated with a number of quality parameters, which capture the dimensions of quality relevant to the attributes of entities and relationships between entities. Each parameter is described by one or more appropriate quality metrics, which defines how to measure or compute context quality with respect to the parameter. Besides a value, a metric contains a type and a unit.

For different type information focused on the difference, and fuzzyness can not be ignored in the defined information, we have defined four types of quality parameters, accuracy, resolution, certainty and timeliness of the four types of parameters as the basic quality criterias of context information .

Shown in Figure 3, we have defined four types of quality parameters: accuracy - range in terms of a measurement, which is different calculation indoor and outdoor; resolution - smallest perceivable element; certainty - the probability to describe the state of being certain and timeliness - production time and average lifetime of a measurement. The resolution is positive correlated with accuracy; resolution, accuracy is to some extent negative correlated with timeliness; certainty is associated with the classification property of the information.

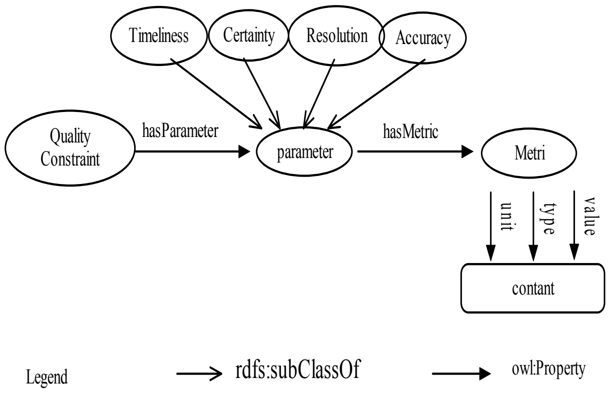

Figure 3. ontology-orient model of quality constraint

Quality constraint is a set of parameters which is used to judge the credibility of the information. Considering ambiguity information and possibility of the parameters boundary adjustment, using soft constraint build the constraint condition of the quality of information [24], the steps:

Step 1: The number of performance index of information quality is n, and $P_j^{\min}$ is the lower limit of j th index, and $P_j^{\max}$ is the upper limit, and the information quality constraint is:

$$P_j^{\min} \leqslant fj(x1,x2\dots xk) \leqslant P_j^{\max}\ ,\ j=1, 2,3\dots n \tag{1}$$

fj(x1, x2, ⋯, xk) is the linear function which describes the relationship between j th indicator and other indicators, it is signifying the value of proportion, a certain index in overall indexes

Step 2: Introducing n logical variables $\delta_{(m)}^{\min}$ $\delta_{(m)}^{\max}$ and intermediate variables $\mu_{(m)}^{\min}$ $\mu_{(m)}^{\min}$:

$$P_{(m)}^{\min}(1-\delta_{(m)}^{\min})+\delta_{(m)}^{\min}\cdot\mu_{(m)}^{\min} \le f_{(m)}(x) \le P_{(m)}^{\max}(1-\delta_{(m)}^{\max})+\delta_{(m)}^{\max}\cdot\mu_{(m)}^{\max} \tag{2}$$

Step 3: Seeking minimum and maximum of adjusted constraint:

$$\min f_{(d)}(X)=f_{(d)}(x_1,x_2,\dots,x_k)$$
$$s.t.\begin{cases} P_{(M)}^{\min}(1-\delta_{(M)}^{\min})+\delta_{(M)}^{\min}\cdot\mu_{(M)}^{\min} \le f_{(M)}(x) \\ f_{(M)}(x) \le P_{(M)}^{\max}(1-\delta_{(M)}^{\max})+\delta_{(M)}^{\max}\cdot\mu_{(M)}^{\max} \\ M=\{m \mid m<d\} \end{cases} \tag{3}$$

Step 4: Initializing parameters and computing after assigning values to $\delta_{(d)}^{\min}$ $\delta_{(d)}^{\max}$.

In step 2, m is reality-based constraints' adjustment priority, and the value of it has positive correlation with the willingness of adjustment, so the formula $P_{(m)}^{\min} \le f_{(m)}x \le P_{(m)}^{\max}$ can describe different context. In step 3, based on the priority level, select d (d ≤ p and d ≠ 1) as target function of marginal adjustment from low to high level. That level is below d is still retained as the set of constraint condition, M = {m | m <d}, until all priority levels are completed. It can achieve the boundary values' adjustment of quality constraint in different context information.

3) Building of hierarchy ontology

With the complexity of context information and context ontology considered, we divided the context ontology into Person sub-ontology, Scenery-spot sub-ontology, and S-content sub-ontology based on trigonal structure, then delaminate category feature of sub-ontology and use the reliable information constructing it. The key is determining value of mutual information, and we calculated it by formula :

$$\mathrm{MI(ti)}=\sum_{j=1}^{s}\mathrm{K_{tj}}\bullet p(c_j)\left|\log\frac{p(t_j|c_j)}{p(t_i)}\right|=\sum_{j=1}^{s}\frac{\max\{\mathrm{n}_{t_k}(i)\}}{\mathrm{n}_{t_k}(j)}\bullet p(c_j)\left|\log\frac{p(t_j|c_j)}{p(t_i)}\right| \tag{4}$$

t_i is the feature item of information, and the occurrence frequency of t_i and category c_j is $p(t_i,c_j)$.

$p(t_i)$ signify the frequency which t_i occurs in the information, and $p(c_j)$ is the probability that the information belongs to category c_j . $K_{t_k j}$ is modifying factor, which means the tendency that t_k vary with the numbers of information in category c_j .

As determined sub-ontology, we built the sub-ontology by vocabularies provided by ontology-based domain. Context ontology defines a common vocabulary to share context information in a pervasive computing domain; and include machine-interpretable definitions of basic concepts in the domain and relations among them.

The context ontology should be able to capture all the characteristics of context information. As the pervasive computing domain can be divided into a collection of sub-domains which would be easy to specify the context in one domain in which a specific range of context is of interest. Our context ontology are divided into upper ontology and domain-specific ontology. The upper ontology is a high-level ontology which captures general context knowledge about the physical world in pervasive computing environments. The domain-specific ontology are a collection of low-level ontology, Which define the details of general concepts and their properties in each sub-domain. The low-level ontology in each sub-domain can be dynamically plugged into and unplugged from the upper ontology when the environment is changed.

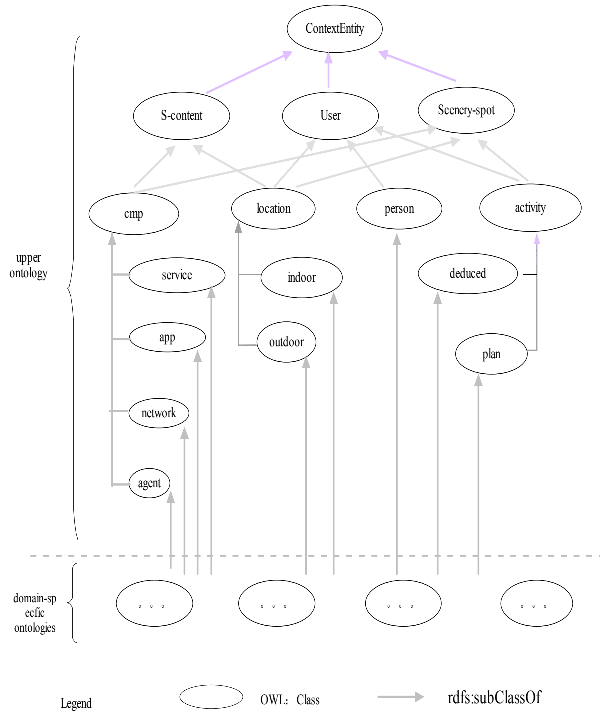

Figure 4. Class hierarchy model for context ontology

The upper ontology defines the user, location, computing and activity the four basic concepts of entities as shown in Figure 5, and it uses the four basic concepts to build the three sub-ontology. Context ontology provides a reference starting point to the upper ontology and one instance of ContextEntity exists for each distinct user, each instance of ContextEntity presents User, S-content and Scenery-spot. The details of these basic concepts are defined in the domain specific ontology which may vary from one domain to another.

DLRL reasoning scheme

In this scheme, we use OWLDL reasoning combined with SWRL reasoning, which ensure reasoning efficiency, and make reasoning have more rationality and decidability.

Reasoning by OWL DL can build better hierarchy ontology, and ensure that no conflict happen between definitions. Knowledge and reasoning based on ontology-rule relies on rule-based reasoning of SWRL. The construction pattern is shown in Figure 5,

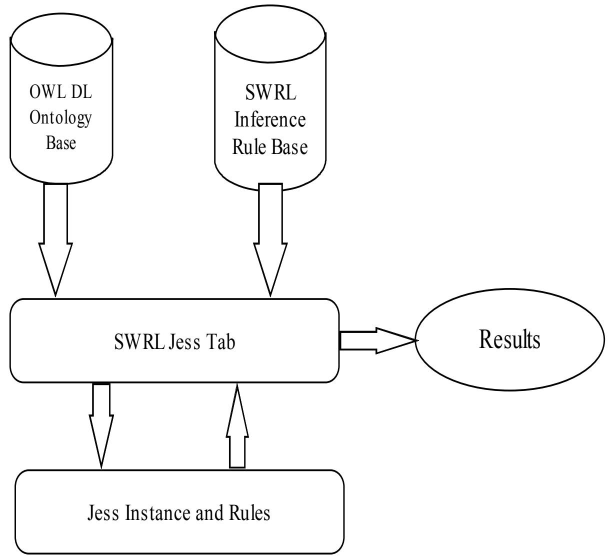

Figure 5. Structure chart of inference scheme

After standardizing terms of definitions, we define various properties in accordance with the requirements of OWL. Subsequently, use OWL to represent ontology model, and introduce ontology knowledge in the description logic inference engine. Then, combined with the particularity of established ontology and reasoning rules, we use SWRL represent reasoning rules. Jess rule engine can afford a format conversion method between SWRL and OWL, which can transform ontology knowledge and rules into the format supported by Jess inference engine. Then we import converted knowledge base and rule base conversion into Jess rules engine and run this engine. The results of reasoning will be returned to users in Jess knowledge.

Definition 1. Context reasoning is a mapping Φ, which is between the value v_{cxt} of context information cxt and the value set, $V_{CXT} = \{v_{cxt1}, v_{cxt2} \ldots v_{cxt\,n}\}$, of associated context information aggregate, CXT = {cxt1, cxt2, …,cxtn}. $v_{cxt} = \Phi(V_{CXT})$

Mapping is represented by reasoning rules, which comprise terms described by ontology, including value condition cv and relation condition cr.

Definition 2. Value condition cv = 〈obj , cx t , V cxt〉, relation condition cr = 〈obj , relation , obj〉,

(1) obj is object,

(2) cxt is context information,

(3) V cxt is the value of context information,

(4) relation is the relation between objects.

Obj, cxt and relation are ontology or attribute of ontology. Vcxt can be ontology or numeric type, such as character string, integer.

Definition 3. The inference rule of mapping Φ is 1Φ= 〈A , S〉 , and

(1) A is the set of precondition,

(2) S is,

(3) A and S satisfy the following constraint,

①for arbitrary A , if A $\neq\varnothing$, there is cv ∈A ;

②for arbitrary S , if S $\neq\varnothing$, there is no cr ∈S .

Value condition and relation condition make up the set of precondition A, and value condition is necessary, while the set of post condition just include value condition. For example, if a user is in a room of hotel at night, and the lamp of room is turn off, then can deduce that the user is asleep. User, Room, Hotel, Lamp, Time, Location are ontology, and User, Hotel and Lamp are obj, Room is the sub-concept of Hotel. Time, Location and state are cxt of people, turn off is the state of lamp, located is the relation between lamp and room. We can use reasoning rule represent this example as follow,

1Φ= 〈A , S〉

A = {〈User, Location, Room〉,〈Lamp, located, Room〉,

〈Lamp, on/off, off〉,〈User, Time, Night〉}

S = {〈User, State, Sleep〉}

In this example, use night, a context subdivision value, as context information time. The mapping, t ∈ ∅ , discretize continuous type context information.

III. Applied Example And Analysis

We have taken the West Lake of Hangzhou for example to illustrate the application of the model. User M shares information with guide system as well as RFID, GPS by PDA. GPS and RFID get the location of users in the outdoor and indoor, and use the wireless network to return the information to the user's PDA and guide system. Then provide personalized services to users by context reasoning through integrating information in guide system, requirements and preference of user. The implementation process is as follows:

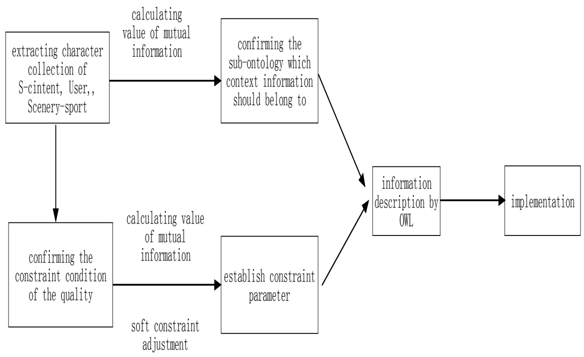

Figure 6. Procedure for implementation

Discernibility matrix extracts knowledge feature characteristic set, which contains time, place, activity as the basic dimension, and different range of dimension weighted value corresponding to different sub-ontology. Finally, the value of mutual information calculated by(4) can correspond to relevant context information. The figure below shows the correspondence of three sub-ontology and context information:

Table I
Sub-Ontology And Relevant Context

Name of Subclass	Classfy of Info	context
Person	Deduced; Sensed; Defined;	Personal information; Location; Plan; Preference
Scenery-spot	Sensed; Aggregated;	Geographic information; Landscape; Ancillary facility
S-content	Deduced; Sensed; Aggregated;	Device; Network; Service; Application

By setting the highest priority of different context information, using adjustment methods in section 3.2 assigned $\min f_{(d)}(X)$ and $\max f_{(d)}(X)$, then calculated the range of context information quality constrains.

Step 1. Let m=1, d=2, $\delta_{(M)}^{\min}=\delta_{(M)}^{\max}$=0, $\mu_{(M)}^{\min}=\mu_{(M)}^{\max}$=0,

Step 2. Let $\delta_{(d)}^{\min}=\min f_{(d)}(X)$, then $\delta_{(d)}^{\max}=\max f_{(d)}(X)$,

Step 3. If $\mu_{(d)}^{\min}\geq P_{(d)}^{\min}$, $\delta_{(d)}^{\min}=0$, else , $\delta_{(d)}^{\min}=1$,

If $\mu_{(d)}^{\max}\leq P_{(d)}^{\max}$, $\delta_{(d)}^{\max}=0$, else $\delta_{(d)}^{\max}=1$,

Step 4. Let m=2, repeat step 1~3, until $m=4$,

Step 5. Let $M=M\cup\{d\}$.

Repeat steps 1 to 5, we can obtain the boundary value, and get the value range of context information quality constraint.

Reasoning machine determine user status and best route based on imported model. When the user M get to a scenery spot, the information about surrounding bus, shop, and public facilities will be displayed on their PDA, so does the recommendation based on the plan and preference. Combining with users' dynamic location information, the recommendation will have timely adjustments.

There are Jiuxiyanshu, Longjing Village and LinyinTemple in user's plan, and the system found the user hiking frequently by integration of information saved in PDA. Then calculate the value of spots in planned zone and selected eight scenery spots, finally generated the best route after adjustment based on relative orientation of spots and routes reference lines online. Then when user M was in Jiuxiyanshu, the best route is first to Li-An Temple, then to Longjing Village, Lion Ridge, Faxi Temple, Lingyin Temple and BeiGaoFeng, Laohe Mountain. And recommended activities focused on outdoor activities as shown in Figure 7 (a).

(a)

(b)

Figure 1. Mobile navigation

When user M takes a bus in Longjing Village, the system can infer the context state of trip mode according to the relationship of the users' locations following inference rules,

User (M), position (Pn), time (tn) is obj, located (located), time (Time), travel means (TrMeans) is cxt.

A={<M，located，Pn ><M，Time，tn >}

S={<M，TrMeans，Walk/Bus/Drive>}

The main reasoning ontology and rules as follows,

Ontology /Rules	Instance
M	PDA
Pn	P_1, P_2, …, P_n
t_n	t_1, t_2, …, t_n
Rules	(A={<M，located，P1 ><M，located，P2 ><M，Time，t1 ><M，Time，t2 >}，S={<M，TrMeans，Walk >}) (A={<M，located，P2 ><M，located，P3 ><M，Time，t2 ><M，Time，t3 >}，S={<M，TrMeans，Bus>}) (A={<M，located，P3 ><M，located，P4 ><M，Time，t3 ><M，Time，t4>}，S={<M，TrMeans，Drive>})

figure 8 the main inference ontology and rules

Then, recommendations would change with weather taken into consideration.

User （M）, scenery spot （Scenery-spot）,recommendation （RecomSpot） is obj, travel mode（TrMeans）, weather（Weather） and location (Location) is cxt.

1Φ=<A，S>

A={<M，TrMeans，Bus>< Scenery-spot，Weather，hot sun >}

S={< RecomSpot，Location，Indoor>}

Adjust the best route to the user travel mode and the weather, so it changed from hike to touring, and the surrounding recommended activities were also themed by sightseeing as shown in Figure 7. In this case, the adjustment of best route based on the change of user states, and the deducing of recommended scenery spots based on user states.

VI. Conclusion

Aimed at mobile services of self-help guide, this paper proposed an OWL-based formal and extensible context model, which can signify, operate and access context in mobile environments. Using OWL to represent context, classification, dependent information and quality information, realized to afford, "anytime, anywhere, anyway" guide information service based on different personal habits. This model is time-sensitive and position-sensitive.

The future work will focus on further abstracting and formalizing the relevant issues of context modeling, such as optimizing of ontology quality constraints, the development of context-aware framework and so on.

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