

Context Aware System based on Bayesian Network driven Context Reasoning and Ontology Context Modeling

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Abstract

Uncertainty of result of context awareness always exists in any context-awareness computing. This falling-off in accuracy of context awareness result is mostly caused by the imperfectness and incompleteness of sensed data, because of this reasons, we must improve the accuracy of context awareness. In this article, we propose a novel approach to model the uncertain context by using ontology and context reasoning method based on Bayesian Network. Our context aware processing is divided into two parts: context modeling and context reasoning. The context modeling is based on ontology for facilitating knowledge reuse and sharing. The ontology facilitates the share and reuse of information over similar domains of not only the logical knowledge but also the uncertain knowledge. Also the ontology can be used to structure learning for Bayesian network. The context reasoning is based on Bayesian Networks for probabilistic inference to solve the uncertain reasoning in context-aware processing problem in a flexible and adaptive situation.

Key Words : Context Aware, Context Reasoning, Context Modeling, Context Awareness Middleware, Bayesian Network, Ontology

1. Introduction

Context-awareness takes an important role in the pervasive computing [1]. Most important concept of pervasive computing is the ‘anytime, anywhere’ computing by decoupling users from smart, intelligent device and viewing applications as entities that perform tasks instead of user [2]. To realization of pervasive computing, we must consider about uncertainty of context data that it is acquired from pervasive computing environment. Uncertainty of context data is an unavoidable factor in any context-aware applications [3]. This is mostly caused by the imperfectness and incompleteness of sensed data.

To prevent of waste from uncertain result of context awareness, first of all, we define the context and fundamental concepts of context-aware computing. And we propose a novel approach to modeling method of the uncertain context by using ontology and context reasoning based Bayesian Network in this paper.

The organization of this paper is follows: Section 2 introduces the related works about general research of the context awareness and applications. And Section 3 and Section 4 propose the ontology based context modeling method and fusion context reasoning process. Netica based Simulation about

context awareness is presented in Section 5, and Section 6 presents its conclusion.

2. Related Works

2.1 Definition of Context and Context Awareness

There has been research in addressing the issue of context awareness. These researches are inspired by the ubiquitous computing and lots of institutes investigate the subject. One challenge of context awareness computing is to exploit the changing environment with a new class of applications that are aware of the context in which they are run [4].

Generally context is the information about user and applications that relate with the connection between user and ubiquitous computing environment. Three important aspects of context are: where user is, who user is, and what resources (device, service etc) are nearby. Context includes lighting, noise level, network connectivity, communication costs, communication bandwidth, and so on. In this article we define that the context is information about ubiquitous environment that the user is part of.

General point of view about context awareness is focus on the change of physical environment, computing system circumstance, interaction of user-system in the ubiquitous computing environment and the purpose of context awareness is that the u-environment uses the context to infers a service correspond to defined circumstance . Generally technique of context awareness is divided into two parts: development of context aware middleware, and context aware application service. In this paper, we focus on the development of

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context aware middleware. And such context-aware computing process adapts according to the location of use, the collection of nearby people, and accessible devices, as well as to changes to such things over time.

2.2 Fundamental concepts of Ontology

Ontology is a formal representation of a set of concepts within a domain and the relationships between those concepts. It is used to reason about the properties of that domain, and may be used to define the domain. Ontology is used in artificial intelligence, the semantic web, software engineering, biomedical informatics, library science, and information architecture as a form of knowledge representation about the world or some part of it. Common ontology has component of likes included following Table 1 [5].

Table 1. Common components of ontology

Components	Contents
Individuals	instances, objects
Classes	sets, collections, concepts, type of objects
Attributes	properties, features, parameters that classes can have
Relations	ways that classes and objects can be related to one another
Function terms	complex structures formed from certain relations that can be used in place of an individual term in a statement
Restrictions	formally stated descriptions of what must be true in order for some assertion to be accepted as input
Rules	statements in the form of an if-then sentence that describe the logical inferences that can be drawn from an assertion in a particular form
Axioms	"axioms" include the theory derived from axiomatic statements.
Events	the changing of attributes or relations

Ontology offers a way of incorporating structured syntactic and semantic knowledge into context awareness work (Fig. 1). In order to do context aware computing we use ontology. Because we can structure model about context by use of ontology and it can manage about context from semantic access.

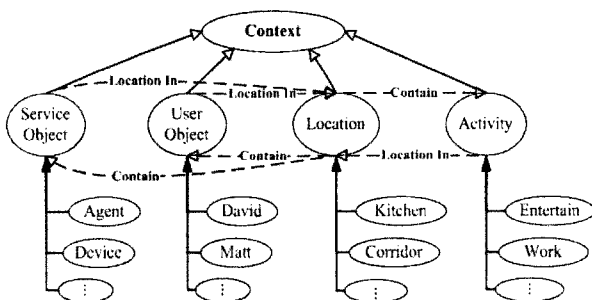


Fig 1. Example of Hierarchy Construction of Ontology

2.3 Fundamental concepts of Bayesian Network

There are several models that are used to represent uncertainty, such as fuzzy-logic, Bayesian Network(BN), etc. Generally, a BN of n variables consists of a DAG (Direct Acyclic Graph) of n nodes and a number of arcs.

Nodes X_i in a DAG correspond to random variables, and directed arcs between two nodes represent direct causal or influential relations from one variable to the other. The uncertainty of the causal relation is represented locally by the CPT (Conditional Probability Table). $P(X_i | pa(X_i))$ associated with each node X_i , where $pa(X_i)$ is the parents set of X_i . Under the conditional independence assumption, the joint probability distribution of $X_i = (X_1, X_2, \dots, X_n)$ can be factored out as a product of the CPTs in the network, namely, the chain rule of BN(Fig. 2): $P(X) = \prod_i P(X_i | pa(X_i))$. With the joint probability distribution, BN support, at least in theory, any probabilistic inference in the joint space [6].

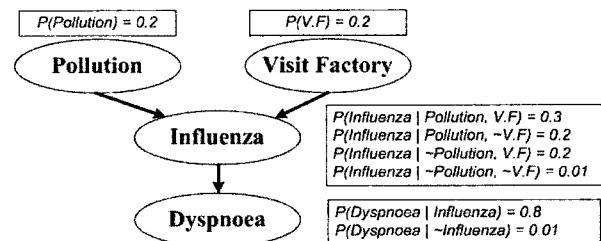


Fig 2. Example of Bayesian Network Construction

Recently, using Bayesian networks to model and reason about the uncertain contexts was received much attention by context-aware research community. Tao Gu et. al. [7] represented a particular Bayesian networks in the OWL-based ontology and then translates into a Bayesian network for reasoning.

However, these approaches have imperfect property about uncertain result of context awareness problem and none of them consider the issue of reusing the uncertain knowledge captured by Bayesian network even though ontology was used. Apparently, the knowledge captured by a particular Bayesian network is fixed and distinctive for a particular application so that it is unable to share and reuse between applications. Additionally, in similar domain-specific applications, reusing and sharing of Bayesian network will make the ontology more compact and unique [8].

3. Context Modeling

Most important thing in the context awareness processing is a modeling of context in that user's point of view. It is impossible that structure considering all case of context model, so we need efficient and economical method to modeling of context about target service.

In this paper, we propose that context modeling method is based on ontology. Ontologies represent a description of the concepts and relationships. Therefore, ontologies are a very promising instrument for modeling contextual information due to their high and formal expressiveness and the possibilities for applying ontology reasoning techniques. Various context-aware frameworks use ontologies as underlying context models [9].

We can hierarchy classify contexts into much categories via the context modeling. It is necessary process for offer higher grade concept information about context to context aware application. The basic context model can be extended to form a complex context or a set of contexts by combining the predicate and Boolean [2]. There is a need for supports to construct the context model. It is a common context model can be shared by all devices.

Ontology is a formal explicit description of concepts in a domain. It provides a vocabulary for representing domain knowledge and specific situation information. We can use this feature and supply to context modeling. Based on the context model, we can build context ontology for a specific type of domains. This context ontology model not only provides the vocabulary for representing structural and relational knowledge in the domain but also represents the probabilistic knowledge which can be used for context reasoning.

OWL is modeled through an object-oriented approach, and the structure of a domain is described in terms of classes and properties. From a formal point of view, OWL can be seen to be equivalent to description logic (DL), which allows OWL to exploit the considerable existing body of DL reasoning including class consistency and consumption, and other ontological reasoning. We believe that Web ontology and other Semantic Web technologies can also be employed in modeling and reasoning about context information in pervasive computing environments [10].

Table 2. Partial OWL serialization of the upper ontology

```

<owl:Class rdf:ID="Context"/>
<owl:Class rdf:ID="User Object">
  <rdfs:subClassOf rdf:resource="#Context"/>
</owl:Class>
<owl:ObjectProperty rdf:ID="Age">
  <rdf:type rdf:resource="FunctionalProperty"/>
  <rdfs:domain rdf:resource="User Object"/>
  <rdfs:range rdf:resource="xsd:Integer"/>
</owl:ObjectProperty> ...
<owl:Class rdf:ID="Bed Room">
  <rdfs:subClassOf rdf:resource="#Location"/>
  <owl:disjointWith rdf:resource="#Study Room"/>
  <owl:disjointWith rdf:resource="#Living Room"/> ...
</owl:Class>
<owl:ObjectProperty rdf:ID="Location In">

```

```

<rdf:type="owl:TransitiveProperty"/>
<rdfs:domain rdf:resource="#Entity"/>
<rdfs:range rdf:resource="#Location"/>
<owl:inverseOf rdf:resource="#contains"/>
</owl:ObjectProperty> ...

```

Figure 3 shows the upper context model (the partial OWL serialization is show in Table 2). The context model is structured around a set of abstract entities, each describing a physical or conceptual object including *User Object*, *Activity*, *Computational Entity (CompEntity)* and *Location*, as well as a set of abstract sub-classes. Each entity is associated with its attributes (represented in *owl:DatatypeProperty*) and relations with other entities (represented in *owl:ObjectProperty*). The built-in OWL property *owl:subClassOf* allows for hierarchically structuring sub-class entities, thus providing extensions to add new concepts that are required in a specific domain. And figure 3 shows a partial definition of specific ontology for a disabled domain.

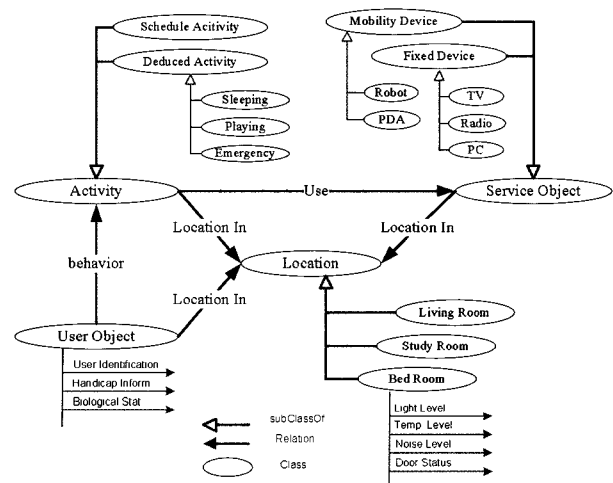


Fig 3. Example of Ontology-based approach for modeling

4. Context Reasoning

4.1 Context Reasoning Method

There are lots of methods for context reasoning. We want to execute the context reasoning without use existing middleware context awareness or reasoning method. So we propose the context reasoning process based two type of context reasoning method are mixed Bayesian Network.

The first method is the ontology-based context model. It is responsible for checking class consistency and implied relationship, asserting inter-ontology relations when integrating or switching domain-specific ontology [2].

The other method is based on Bayesian Network as probabilistic inference model. It is useful in expression the

uncertain context or situation data.

Each reasoning methods have a problem to expect the high performance of inference about context, but if we fuse Bayesian Network with ontology-based reasoning method then the performance of reasoning model will be improve. Besides the power of probabilistic reasoning provided by Bayesian Network themselves, we are attracted to Bayesian Network in this work for the structural similarity between the DAG of a Bayesian Network and activity graphs of context model: both of them are directed graphs, and direct correspondence exists between many nodes and arcs in the two graphs. Moreover, Bayesian Network can be utilized to represent the uncertainty visually, provide inference effectively and facilitate human understanding of context models. Considering the advantages of Bayesian Network, we apply Bayesian Network to represent the uncertainty in context model.

Eventually context reasoning is inference process by 5W1H (Where, When, What, Who, Why, How) factor.

So, if we want to develop the context model, we must define a domain about specify class that is related with given environments. It means that we define a list of service and activity about context as included notions.

As shown in the following Table 2, we show the environment about disabled as user and define the related service, activity, and the other context.

Table 3. Definition of context for disabled

Context	Definition	Context property
Object (who, what)	User : Disabled Service Devices: Intelligent Robot, Home-net system ...	: User Identity (Name, Sex, Age, Disabled Information) : Service Devices spec
Location (Where)	Information of Object Location (Living Room, ...)	: Coordinate inform of User, Service Devices : Name about Location of Object
Activity (How)	Information of User's Actions, Service Device response	: Real Activity of Object : Activity React
Time (When)	Time information (date, hour, ...)	: Current time and date : Occurrence time of Activity : Service offer time

4.2 Bayesian Network structure based Context Model

It is necessary that we construct a context model for context reasoning. In this article, we propose a fusion context model for context reasoning. First, we use ontology-based reasoning method to develop the hierarchy semantic structure of context. Because of this structure is similar to aspects of Bayesian network structure, it can be applied to Bayesian Network structure learning process. The Bayesian Network learning task

has traditionally been divided into two parts: structure learning and parameter learning. Structure learning determines the dependence and independence of variables and suggests a direction of causation.

Context awareness will be possible by using this Bayesian Network structure including the User Activity and predefined context in the Table 4. For this reason, Bayesian Network has to execute structure learning in the forgoing context model based on ontology. Structure learning of Bayesian Network is a definition of causal relation between the Bayesian Network nodes. This process has a following rule.

[Service-Activity rule :

(?a type Service) //if there is a Service

(?b type Activity) //and an Activity

(?a ?c ?b) //that is in relation with this Service

→ //then

(?b behavior ?a) //the relation is a type of behavior

] //end

Table 4. Example of Service and Activity of groups of disabled information

User Info	Activity	Corresponded Service
Blind	- Moving - Searching - Reading	- Alarm about Crash - Information about Location - Text:Speech Translate
Deaf	- Calling - Danger - Emergency	- Message Display - Light, Shock Alarm - Warning by Image
Dementia	- Danger activity - Lost Way - Amnesia	- Information about Location - Information Circumstance - Warning Danger - Calling Guardian

Also, we need to execute the parameter learning. Parameter learning determines the conditional probability table at each node, given the link structures and the data.

Upon completion of this learning proceeding, we can structure the Bayesian Network to execute the context awareness computing.

Fig. 4 is example of Bayesian Network structure based context model by using Bayesian network and ontology-based context model and conditional probability table of the each node are fulfilled with initial value and it written by author. It is structured by Bayesian Network structure tool: Netica application and API and Netica does parameter learning.

5. Simulation of Context Aware

In this paper, we use the Netica API, Netica Application software to structure Bayesian Network. For the simulation, we

assume that the sensor data about user and location information are early given. And if there are happen some kinds of change, for example further adding user or change of location then we can restructure Bayesian Network by adding a node to the given Bayesian network. Because of corresponding belief about CPT of Bayesian Network are related with parameter learning of Bayesian Network, we need to more research about learning algorithm such as ANN(Artificial Neural Network), Reinforcement Learning, Counting, Gradient descent, EM(Expectation Maximization), etc.

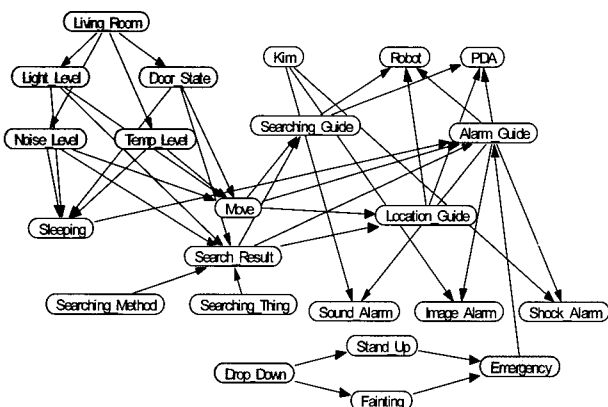


Fig 4. Example of Bayesian Network based context model

There are three types of algorithms that Netica can use to learn CPTs: Counting, Gradient descent, EM(Expectation Maximization). Of the three, "counting" is by far the fastest and simplest, and should be used whenever it can. It can be used whenever there is not much missing data or uncertain findings for the learning nodes or their parent nodes. In this paper, we execute the learning the CPT of a node by counting

Fig 5 is shown Bayesian Network structure to reason activity that user can takes in the given circumstance.

If each node has specified state variables, then result nodes are indicated by probabilistic values.

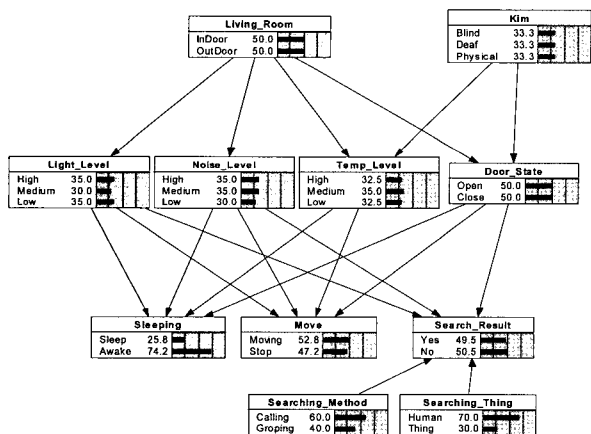


Fig 5. Bayesian Networks Structure for Activity Reasoning

Fig. 6 is shown result of Activity reasoning based on predefined Location and User information. For example, we specify the living room as the location nodes and select the deaf as the user nodes. And we specify the other condition of Bayesian Network node like following:

- Intensity of illumination = High
- Noise level = High
- Temperature = Medium
- State of the door = Open

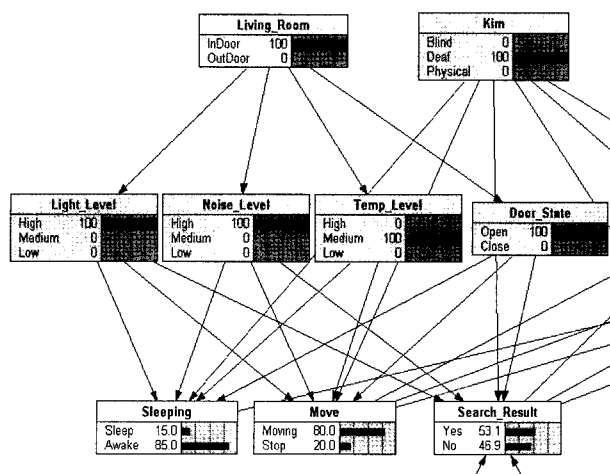


Fig 6. Location, User Information based on Active Reasoning

We can see that result of reasoning is following Fig 7. Result of reasoning is shown that Moving (80%) has largest probability. So In this environment condition, we may regard that user's activity is Moving.

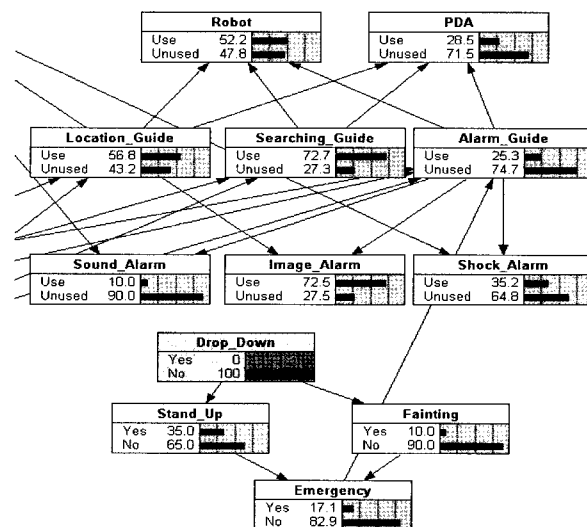


Fig 7. Result of Service Reasoning given Activity

6. Conclusion and Future Works

In this paper, we proposed a novel approach to model the uncertain context by using Bayesian Network and ontology-based context reasoning method.

Our context aware processing is divided into two parts: context modeling and context reasoning. The context modeling is based on ontology for facilitating knowledge reuse and sharing. Ontology facilitates the sharing and reuse over similar domains of not only the logical knowledge but also the uncertain knowledge and it can be used to structure learning for Bayesian network. The context reasoning is based on fusion context modeling for probabilistic and semantic inference to solve the uncertain reasoning in context-aware process.

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