 doi:10.20944/preprints201807.0539.v1

ONTOLOGY-BASED CONTEXT MASHUP MODEL FOR CONTEXT-AWARE SERVICES IN INTERNET OF THINGS ENVIRONMENTS

[1]**YONGGOO CHOI**, [2]**ILKYEUN RA**

[1]Department of Computer Information, Dong Seoul University, Seongnam 13117, Republic of Korea

[2]Department of Computer Science and Engineering, University of Colorado Denver, Denver, Colorado 80204, USA

E-mail: [1]ygchoi@du.ac.kr, [2]Ilkyeun.Ra@ucdenver.edu

ABSTRACT

In an open and dynamic IoT (the Internet of Things) environment, a common context information model is essential for active things to share common knowledge, reason their situations, and support adaptive interoperability with each other. There have been many studies on the IoT context information models based on semantic technology, but most of them have assumed a static situation based on a service-oriented information model suitable for specific applications of the IoT. In the case of applying their models to an open and dynamic IoT environment, two issues have been observed: Most of the models ignore (a) the mashup of the open-world semantics of context information generated by multiple context sources and (b) the reconciliation of the semantic relationships between multiple context entities under dynamic situation changes. Therefore, in this paper, we propose a context information model that is flexible enough to express complex and diverse semantic relationships between context information generated from a variety of context information sources in the IoT. The main background of this proposal is to propose an adaptive context model that can effectively mash up various context classes that use ontology in open and dynamic IoT environments. In this paper, we also show the effectiveness of the proposed model through an adequate verification model and a practical example.

Keywords: *Ontology Model, Context Mashup, Context Type, Context Awareness, Internet of Things (IoT)*

1. INTRODUCTION

The ultimate vision of science and information technologies is to create a better world for human beings. As a key task for realizing this vision, smart things around human beings should manage the overall matters related to human activities with minimum human intervention. Since the Internet of Things (IoT) [1] becomes completely integrated into the everyday life of people in order to realize such a vision, it depends on dynamic technical innovation in a number of significant fields. IoT is able to provide people with context-aware services based on context information in an "anytime, anywhere, anything, and anyone" fashion. Therefore, in open and dynamic IoT environments, active and intelligent things on the IoT must be able to share common knowledge, reason their situations, and support adaptive interoperability with each other. Nowadays, IoT has brought up significant issues for a paradigm shift in the rapid changes as well as a new direction in overall human activities beyond these simply technical issues.

The IoT information system should enable intelligent things to not only provide an adaptive context-ware service for their interoperability, but also to give a decision-making service for insight interactions by reasoning and analyzing in their overall situations. These services should be supported by well-designed context models and logical reasoning skills. However, the model has a highly complicated aspect because it has to accommodate the context information generated by heterogeneous and mobile devices in the IoT. For instance, let us suppose that a patient is measuring his blood pressure, and is then given alert sounds in case the patient's blood pressure exceeds a certain level. The following factors show how to get blood pressure information for the patient:

- It can be caught in real time from wearable

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 27 July 2018 doi:10.20944/preprints201807.0539.v1

blood pressure sensors on the patient,

- It can be retrieved from the patient's medical records into a healthcare database,
- Or it can be obtained from combining and computing results from both the patient's sensor data and their recording data.

Since a crucial role of the IoT is to typically work in context-aware services, the core value of the IoT depends on context information created from multiple devices and their platforms in the IoT environments. However, the context information is very heterogeneous and imperfect because there are many various context sources in the IoT. For this reason, turning this context information into contextual knowledge schema remains significantly challenging in IoT information technology fields. There are many approaches for developing effective context models, but most of them are not capable for knowledge sharing and context reasoning in highly dynamic situations. Therefore, ontology modeling technology [2] has clear advantages in semantically representing complex relationships between heterogeneous contexts, and in soundly reasoning for context awareness. Nevertheless, developing a full-fledged model based on ontology is still not an easy task in the open and dynamic environment of the IoT.

There have been many studies on IoT context information models based on semantic technology so far, but most of them have assumed a static situation based on a service-oriented information model suitable for specific applications of IoT. In the case of applying their models to an open and dynamic environment, two issues have been observed: Most of the models ignore (a) the mashup of the open-world semantics of context information generated by multiple context sources and (b) the reconciliation of semantic relationships between mobile entities under dynamic situations. Therefore, in this paper, we propose a context information model that is flexible enough to express complex and diverse semantic relationships between situational contexts from multiple sources.

The main background of this proposal is to propose an ontology-based context information model that can effectively mash up various types of context information that can be adapted into a context information schema in an open and dynamic IoT environment. In this paper, we also show the effectiveness of the proposed model through an adequate verification model and a practical example.

In this paper, we will also present how to integrate heterogeneous context information from multiple context information sources by using ontology-based context modeling schemes for user-friendly context awareness in IoT environments. Since understanding how to acquire context information for context-aware performances is important, we present ways to categorize context types and use context-reasoning techniques. These ways efficiently retrieve very diverse context information from multiple context sources and soundly reason new and meaningful context information under complex situations of the IoT.

The paper structure is as follows. Chapter 2 discusses the current approaches of the IoT context model and IoT mashup model. Chapter 3 proposes the ontology-based context mashup model by presenting a context mashup ecosystem, ontology context classes, a universal ontology mashup model, and a global ontology mashup rules. The context-aware model is addressed in Chapter 4 by showing its impact on context information types and context-aware adaptation. Finally, Chapter 5 presents the conclusion.

2. RELATED WORKS

2.1 IoT Context Models

For the IoT information system, the context information model is a well-defined format that can realistically accommodate a concrete subset of diverse context information from multiple context sources such as sensors, applications, and users. According to this definition, the notion of the context always refers to any information that can semantically abstract a situation of active entities in a specific domain [3]. Since context-aware services employ context models in a unified and coherent way, they explicitly should specify in the IoT computing systems. As context information sources things on the IoT can be characterized into four categories: *Subjects* (or *Users*), *Objects*, *Webs*, and *Applications* (Figure 1).

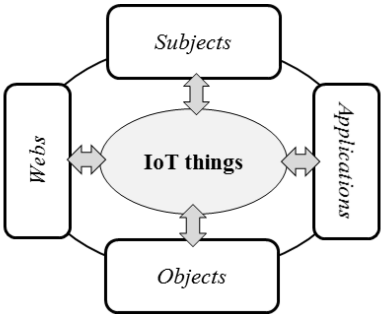

Figure 1: Framework of Tings on the IoT

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 27 July 2018 doi:10.20944/preprints201807.0539.v1

To achieve their inherent goals, such things all are connected to the Internet and communicate with each other by their acting automatically on behalf of humans. However, they are very heterogeneous due to structural diversities in both their semantic levels and update cycles. Despite this complexity of the IoT information system, a well-defined context model can make it easy to enable the context-aware services. Moreover, a formal representation of context information within a model is easy to check consistently for governing context information as well as its ability to provide sound reasoning for discovering knowledge that is more meaningful.

The concept of the context information model has been surveyed in several studies [4] [5] [6] with their own strengths and weaknesses based on application domains. These approaches can be classified into key-value models and makeup models [4]. The key-value models formulate context information with simple key-value pairs that consist of attributes and their values. JSON (JavaScript Object Notation) [7] is well-known as a standard format of the key-value expression in the practical fields. Although this format can easily express context information, it lacks capabilities for semantic knowledge representation in order to exchange context information efficiently and reason soundly. To improve the key-value modeling technique, markup models with semantic markup tags have been widely applied for many application domains in order to clarify context information representation. XML (extensible markup language) [8] with the semantic markup tags has been recognized as a flexible context modeling format for effectively representing and exchanging knowledge. These XML modeling technologies have led to a wide interest in the *Semantic Web* [9] [10], which is an extension of the current web enabling web applications to understand the meaning of various information resources on the web and to search for them intelligently.

An important basis for many developments in the semantic web is RDF/RDFS (Resource Description Framework/RDF Schema) and OWL (Ontology Web Language), which provides some modeling schemes for representing metadata on the web resources [9]. While RDFS provides taxonomic relationships between web resources, ontology is more expressive for defining entities and their semantic relationships with richer vocabulary. Therefore, ontology [10] is a very promising methodology for modeling context information. Despite the large number of proposed contextual models for context-aware applications, ontology-modeling methodologies for the IoT information system are still vague and general.

2.2 IoT Mashup Models

Context information from multiple sources is extracted, transformed, and loaded into one centralized warehouse and can be queried with a single schema [11]. Therefore, a context mashup is a process that brings together a variety of context information from multiple sources and combines them in a way that clarifies or enhances reasoning and context awareness. The goal of the context mashup is to create more meaningful context information from ordinary context information for a more high-level context awareness. In the IoT environments, context mashups usually combine physical sensor information with each other or with context information retrieved from numerous web-content sources. Therefore, context information sources in the IoT information systems have been broadly classified into the following components [4]: *Physical* (including *Sensor*), *Virtual* (including various *Web Contents* and *Legacy Data*), and *Logical* (including *Applications*) (Figure 2).

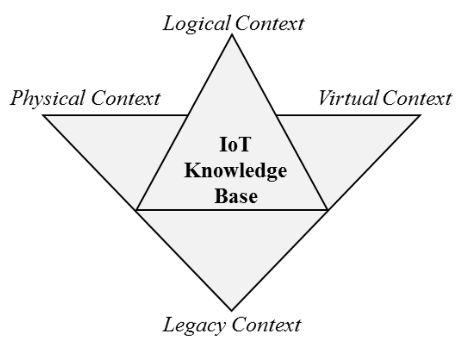

Figure 2: Context Mashup Components for the IoT Knowledge Base

Physical context information generated from physical sensor devices is less meaningful and imperfect due to its dynamic and heterogeneous nature. To make more meaningful context information, it is sometimes combined with other context components. The virtual context information typically collects the context information from distributed web sources such as web contents, calendar, email, Twitter, and online opinions. While the physical devices typically provide context information with real-time velocity, the virtual devices more rarely access context information. Therefore, in order to develop an efficient context model, it is important to understand their semantic levels, update rats, and context stems.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 27 July 2018 doi:10.20944/preprints201807.0539.v1

On the other hand, logical context information is acquired by mixing and/or computing with the physical context, the virtual context, legacy context, and application logics. The reason for such manipulation is to create more meaningful context information or to excavate new context knowledge for high-level reasoning and business intelligence. For instance, meteorological information is a sort of logical context, which is obtained from a result of combining and processing thousands of physical sensor contexts and virtual contexts related to various weather situations.

For context-aware services in the IoT information systems, the context information from multiple context sources should be represented as an aggregated structure in a common model. In the IoT information systems, it is not easy to express the heterogeneous context information into a common model. Therefore, finding out more attainable techniques for developing a context model is very important. It also depends on expression powers, validation constraints, reasoning techniques, and performance costs.

3. ONTOLOGY-BASED CONTEXT MASHUP MODEL

3.1 Context Mashup Ecosystem

The context mashup refers to the mixing of heterogeneous context components generated from multiple context sources to provide the things with a single unified view. In IoT information technology, this context mashup combines physical sensor contexts with virtual sensor data to create more meaningful context information. Therefore, the context mashup model can be explicitly specified as a formal mashup ecosystem that represents the context composition in the IoT information systems (Figure 3).

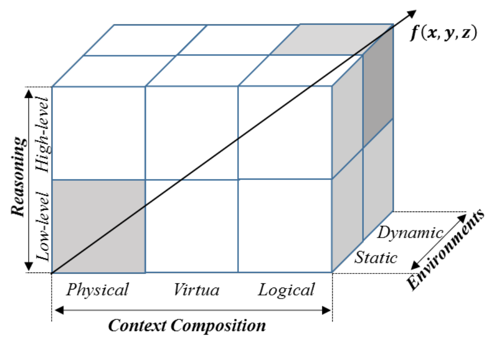

Figure 3: Mashup Ecosystem for the Context Composition

According to the IoT application environments, the context models can be classified as static or dynamic schema. While static model schema has a predefined set of context information that is collected and stored, dynamic model schema changes a data structure in order to be adapted to new platform configurations. In fact, the context compositions are made up of physical, virtual, and logical contexts from multiple context sources. The results of context reasoning are generally classified as low-level or high-level context information based on the semantic levels of their application fields.

The context mashup model based on ontology is a mixing format that contains three reflective dimensions as semantically relative domains. Therefore, in the mashup ecosystem, context reasoning can be determined as a function of the independent variables of these components in the domain of interest. For instance, a function of a context-aware domain can be expressed as

$$f(x,y,z) = \lim_{i,j,k=n} \sum_{t=1}^{\infty} (x_i \cdot y_j \cdot z_k), \qquad (1)$$

where x is context components, y is reasoning levels, and z represents the environments according to time t. Therefore, a full-fledged model for the IoT information system should be flexible enough to effectively represent in combination with such mashup components in open and dynamic situations.

3.2 Ontology Context Classes

Context classes are a sort of semantic elements in the context model that describe various context information. They have identifiers, attributes, and values, as well as collections of properties for describing specific characteristics. In addition, they have semantical relationships between three context classes from the root *Things*: *Physical*, *Virtual*, and *Logical* (Figure 4).

Specifically, the logical context class in the IoT computing system is derived from mixing the physical context classes with virtual context classes. The ontology relation properties of these context classes are defined as *isDerivedFrom* in an ontology mashup model. The context-aware processes dynamically change and adapt to the object's behaviors based on context information derived from the context classes. This ontology relation property can provide a clear determination of context information sources for an ontology reasoning process.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 27 July 2018 doi:10.20944/preprints201807.0539.v1

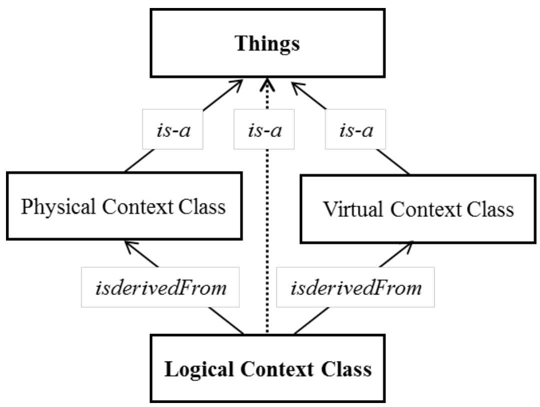

Figure 4: Ontology Relationships between the Context Classes

In this reasoning process, each attribute and its value should be searched in the context information mashup model to determine the context-aware information. The context mashup model based on ontology in the IoT information system may have the same attributes and values from different ontology context types. For example, let us recall the example presented in the introduction section. In this case, the attribute of the same meaning related to a blood pressure value may exist in the physical context class, the virtual context class, and the logical context class. In order to deal with the inconsistency problems of the context ontology attributes in the reasoning process, the context mashup model distinguishes each of them with the XML namespace [8] (Table 1) and with the multiple ontology properties of the same semantics (Figure 5).

Table 1. Example of an XML Namespace for Distinguishing Multiple Context Classes

```
<?xml version="1.0" ?>
<Ontology
      xmlns="http://www.w3.org/2002/07/owl#"
             ....
      <Ontomash
  xmlns:phy="http://www.young.org/Physical
         xmlns:vir="http://www.young.org/Virtual
xmlns:log="http://www.young.org/Logical
....
     </Ontomash>
</Ontology>
```

With this approach, an integrated view that is provided to context-aware applications is not only a context model that accommodates the various context information from multiple sources, but is also a semantically rich description of the relevant context classes in a domain of interest. These context classes should be fully coherent in context ontology schema in order to be adapted to context-aware applications.

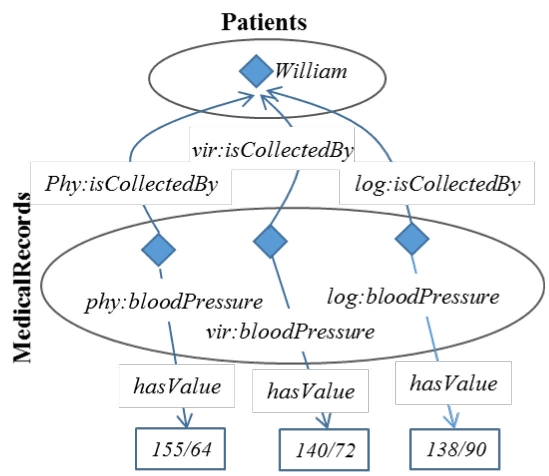

Figure 5: Example of the Multiple Ontology Classes of Same Semantics

3.3 Universal Ontology Mashup Model

The notion of an ontology model is to formalize the context information types with a more high-level organization to establish a common understanding of their terms and meanings. According to an abstract level of knowledge concepts, ontology can be divided into upper-level ontology and lower-level ontology in a broad sense [12]. Since the upper-level ontology deals with basic and universal concepts applicable to various application domains, it is not dependent on a specific domain and situation. On the other hand, the lower-level ontology aims to specify a specific domain and situation in the real world without pursuing universality. First, this paper will focus on an upper-level ontology to discuss the conceptual schema of a context mashup model.

In the IoT environments, the context mashup model based on ontology has several kinds of vocabulary for expressing ontology classes and their relevant properties that are related to *Subjects*, *Objects*, *Contexts*, *Services*, and *Resources* (Figure 6). First, in the context mashup model, the *Resource* class is used to distinguish the other context types clearly. Thus, to enhance a search performance for reasoning, this class should be located in the top level of an ontology-based mashup model. The terminology of the relation property between this class and the others is *isDrivedFrom*.

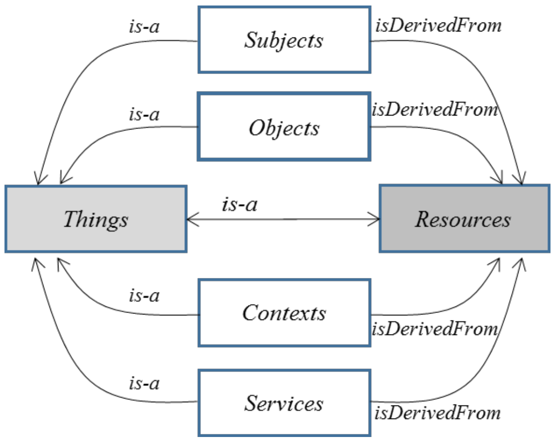

Figure 6: Upper-Level Ontology Model for the IoT Context Mashup

- *Objects* are physical devices such as sensors and actuators in the IoT systems. They can interact with one another through communication channels. The sensors are used to observe the status of physical devices, and the actuators are used to control or operate intelligent computing devices. They have context information types such as name, time, location, status, owner, and so on.
- *Subjects* are users who can own the objects or define the context-aware services in needs. They have personal information, context awareness information, service definition information, security information, and so on.
- *Contexts* are any information type that can be used to characterize the situation of subjects, objects, places, or services. For interoperability through the reasoning process, the context class is used to share or reuse the things in the IoT.
- *Services* provide information and any behaviors requested by the subjects or objects through a context-aware process. Service classes have service conditions and service behaviors. The service condition defines the criteria for determining the situation and the conditions to provide the service. A service process defines an action to be provided with the object's state or function.

The ontology-based universal model is widely referred to as a well-defined aggregation format that is related to multiple context classes and their relevant properties. With this approach, a context information model not only merely has a context structure to accommodate the various context from multiple context resources with ontological semantics [13], but a semantical relationship between such classes. Each class in the model is able to make a synergistic effect through organically mutual combinations with each other. A reference model of the ontology class is depicted in Figure 7.

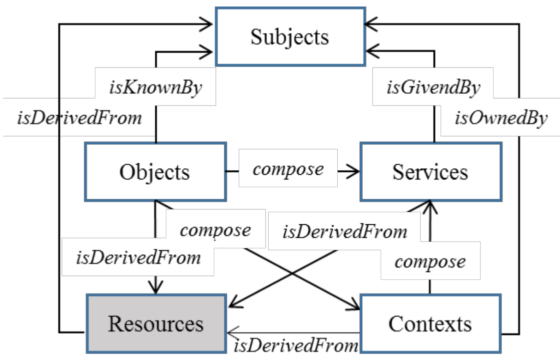

Figure 7: Reference Model of IoT Ontology Classes

In the reference model of IoT ontology classes, *Objects*, *Subjects*, *Contexts*, and *Services* all are derived from a *Resources* class. *Objects* are owned by *Subjects*, and they compose a class of *Services* and *Context*. *Contexts* is composed of *Services* and are known by *Subjects*. *Service*s are given by *Subjects*. In the reference model for the IoT ontology class, each of the class components is modeled into a lower-level ontology to be suitable for a specific domain and application in the IoT environments.

3.4 Global Ontology Mashup Rules

In order to apply the dynamic IoT information system to a high-level context awareness, it is necessary to integrate upper-level ontology into the lower-level ontology. This integrated ontology refers to global ontology [14] [15]. The global ontology is made up of upper-level ontologies (UO) and lower-level ontologies (LOs) [14] for a unified and coherent reasoning. The *UO* specifies the semantic representation of common concepts and their semantic relationships of things such as objects, users, context, services, and so on. On the other hand, the *LO*s are a semantic representation of the entity classes and their relationships in an interest domain for any specific goal in the IoT information systems [15]. A global ontology is comprehensive of repetitive blocks of the lower-level ontologies based on the upper-level ontology schema rules.

Definition 1 (Global ontology structure): When a global ontology (GO) is made up an upper-level ontology (UO) and several lower-level ontologies (LOs), it can be expressed as follows:

$$GO = UO \propto \sum_{i=0}^{m} \sum_{j=0}^{n} LO_{ij}, \qquad (2)$$

where i is the number of a specific ontology domain, and j is the number of a ontology block in the block i. According to equation 2, a global ontology is shown as $GO = \{ UO \propto \{ \{ LO_{11}, LO_{12}, ..., LO_{1n} \}, ..., LO_{ij}, ..., LO_{mn} \} \}$, where LO_{ij} is the ontology blocks in global ontology, and each LO_{ij} has seamlessly semantic relationships with each other based on *UO* schema rules.

Definition 2 (Context integration and integrity constraints of a global ontology): The global ontology should preserve (a) context integration that completely converges the lower-level (or domain) ontologies to share the global ontology among the things in the IoT, and (b) context integrity that entirely contains all of the essential context information pertaining to context reasoning.

Lemma 1(New-fashion placing): If an ontology transaction intends to access a target ontology block in the global ontology, the access point should be placed in the most recently inserted ontology block in a time sequence.

Proof) The IoT applications are typically based on prompt interoperability that uses context information generated in a real-time fashion from various context sources on the IoT. Let's recall Definition 1. Suppose that the lower-level ontology sets $\{ LO_{11}, LO_{12}, ..., LO_{1n} \}$ in a global ontology are listed in chronological order, and $LO_{11} > LO_{12}$ in time sequence is established. If an ontology transaction intends to traverse an ontology block LO_{1j} for context reasoning, the LO_{11} always becomes the target ontology block. In the same manner, if an ontology transaction intends to insert a new ontology block from local ontology repositories, it is inserted into the front of LO_{11}. This new-fashion placement follows a stack data structure that has a "last-in, first-service (LIFO)" fashion.

4. CONTEXT-AWARE SERVICE MODEL

4.1 Context Information Types

The context awareness refers to situational reorganization around the subjects and the objects. In fact, a definition of context awareness has been widely referenced in many studies and described as "A system is context-aware if it uses context to provided relevant information and services to the user, where relevancy depends on the user's tasks [16]". Simplifying this definition, context awareness can streamline the context's applications to provide some context-aware services to any subject or object. It is necessary to decide how to retrieve context information from a large amount of context information sources. For the sake of context awareness, understanding context information acquisition for context-aware performances is important. Therefore, it depends on how to categorize context information types and apply context-reasoning techniques.

A categorization of the context types will be useful in reasoning processes and context awareness for fast exploration in a common context model. The important aspects of the context types are to determine "where you are, who you are with, and what resources are nearby [5]". In the IoT information system, there is a wide variety of context information from multiple context sources. According to semantic levels for context awareness, the context types are divided into primary context and secondary context [17]. Primary context is any information retrieved without using existing context, whereas the secondary context is any information that can be retrieved or computed using primary context. For example, if we want to collect the blood pressure level of a patient, it is important to know the information of the identifier, location, time, and status related to the patient. This information is important for collecting the blood pressure level of the patient.

A quick and easy way to retrieve a large amount of context information in the IoT depends on how to formalize this primary context in a model. Even though primary context types are very controversial in research, we only define the primary context as *Identifier*, *Location*, *Time*, and *Status* (Figure 8).

For a context-aware service in the partial *Petri Nets* [18], the IoT information system first finds the *Identifier* of an entity in state S_1 at time t_1 to figure out adaptive context information. In the IoT information system, an entity is always a subject or an object. If there is an entity in a static IoT environment, the IoT information system directly retrieves the *Status* of the entity in the state S_4 at time t_2, and then the secondary context will be retrieved in the system. On the other hand, if there is a dynamic IoT environment, it retrieves the

Location and *Time* of the entity in state S_2 and state S_3 at time t_2. Afterwards, the IoT information system finds out their status information in state S_4 at times t_3 and t_4 each, and then the secondary context will be retrieved. These procedures are repeatedly executed in a real-time or sequence fashion based on a context-aware process.

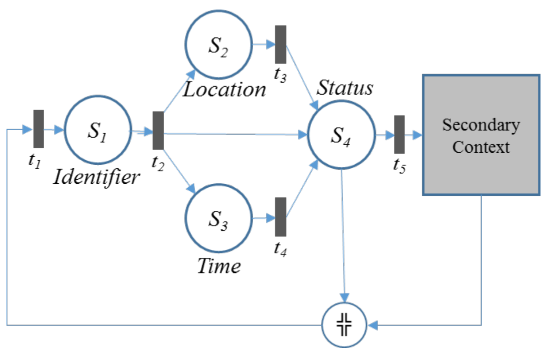

Figure 8: Partial Petri Nets for Search Sequence Using Primary Context Types

4.2 Context Awareness Adaptation

In the IoT information system, a context awareness application typically monitors in real time whether there are situation changes to the things that use context information from multiple context sources. The reasoning process makes a decision on whether any service is adequate to the changes. The reasoning processes are applied for inferring higher context information or new knowledge from the ontology context model.

The context reasoning procedure consists of analyzing the ontology context model in order to infer adaptive context information. This context reasoning procedure consists of the following steps [19]:

- *Reasoner*: Allows new situational inferences from relevant context properties based on defined semantic relations and inference rules.
- *Adaptation*: Defines each process associated with each action in the reasoning results.
- *Repository*: Stores a new context information or behavior status in the reasoning results of the context model.

For example, in a context mashup model based on medical care, the discrete behavior of each diagram's component is usually defined through finite state mechanisms. The reasoning process can be simply defined with the following transitions (Figure 9).

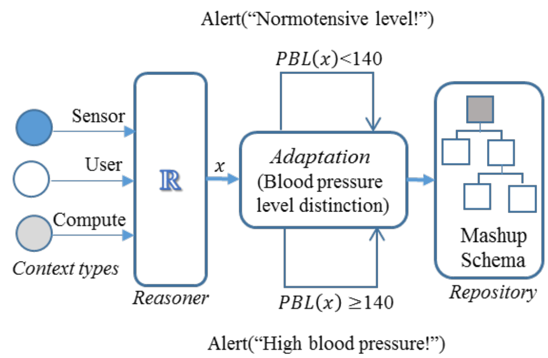

Figure 9: State Transition Diagram of Context Reasoning

In Figure 9, we depict the state transition diagram of context reasoning for a medical care system. The reasoning process inputs multiple context types such as sensor contexts, user contexts, and compute contexts, and then outputs context information after adaptive reasoning processes based on their predefined axiom. The event function determines the patient's blood pressure level based on the results of context. If it is less than *140*, then a message of normal blood pressure will be indicated. If not, an alarm sound will start.

In this way, if there are multiple context types in the ontology model, the adaptive result can be reasoned by applying an appropriate selection pattern in the reasoning process. According to the system configuration of the IoT, the reasoning pattern can be set by the user or by the IoT computing system through a machine learning process. Let us recall the partially ontology mashup model depicted in Figure 5. In the model, an ontology axiom that can retrieve the logical context of *William*'s blood pressure level is as follows:

$$\begin{aligned} &WilliamBloodPressureLevel \cong Identifier.William \sqcap \\ &\quad \forall\, isDerivedFrom.Logical \sqcap \\ &\quad \forall\, Status.Active \sqcap \\ &\quad \exists\, hasLocation.(Room123 \sqcap AbcHospital) \sqcap \\ &\quad \exists\, hasTime.2017\text{-}05\text{-}20\text{-}T10{:}22{:}12 \sqcap \\ &\quad \exists\, hasBloodPresureValue.138/90 \end{aligned}$$

To retrieve *William*'s blood pressure level, the IoT information system first creates a *William*'s partial ontology where the value of the attributes of the primary context identifier is *William*, and then creates a *William*'s logical ontology where the value of the primary context's attribute *Status* is *Active*. Afterwards, the system retrieves the value of property *BloodPresureValue* from *William*'s logical ontology where the value of the attribute Location is *Room123* and *AbcHospital*, and the value of the attribute Time is *2017-05-20-T10:22:12*. Finally, *William*'s blood pressure level can be detected as *138/90*.

The reasoning aspects for context awareness are often emphasized by an ontology axiom so that at least one situation must be active at one time. For organizing all possible situations, their relationships and transition courses have to include an ontology mashup model as particular cases in informal reasoning patterns as well as formal reasoning processes. This would provide a more abundant knowledgebase, better stable reasoning, and best performance for IoT information systems.

5. CONCLUSIONS

In this paper, a common modeling scheme for the diverse context mashup based on ontology was introduced to be adapted to open and dynamic IoT environments. The key point of this approach is an adaptive context model that can mash up various context classes that use ontology in open and dynamic IoT environments. This model is useful for supporting a context-aware process through multiple context types and reasoning processes under the model. For realizing this model, we presented semantic classes to represent various context entities from multiple context sources and clearly expressed semantic relationships between the classes. The proposed model has a common ontology common *Resource* that can distinguish the duplicated context properties from multiple context sources. This approach not only enables the model to accommodate various context information from multiple sources in a unified and coherent way, but also provides it with semantically rich relationships between the relevant context classes.

This paper also presented semantic levels in accordance with a context awareness scheme that governs context types and context reasoning. The reasoning aspects of context awareness are often emphasized by an ontology axiom so that at least one situation must be active at a time. To organize all possible situations, their relationships and transition courses are included in an ontology mashup model as particular cases in informal or formal reasoning processes. This provides a more abundant knowledge base, better stable reasoning, and best performance for the IoT information systems

Although the proposed model is adequate in an open and dynamic IoT environment, additional discussion is needed on how to prove validation and present a detailed implementation specification of the model based on an actual implementation situation. This is why context-aware services can be sensitively changed based on changes in IoT environments. In addition, the IoT information system is needed for synchronization schemes in concurrent access to a context information model at the same time. Despite the limitations of this research, these studies can become a useful reference model in a significant evolution for novel context models and efficient context-aware services.

REFERENCES:

[1] IStrategy, I. T. U., and Policy Unit. "ITU Internet Reports 2005: The internet of things." Geneva: International Telecommunication Union (ITU) (2005).

[2] Gruber, Thomas R. "A translation approach to portable ontology specifications." Knowledge acquisition 5.2 (1993): 199-220.

[3] Abowd, Gregory D., et al. "Towards a better understanding of context and context-awareness." International Symposium on Handheld and Ubiquitous Computing. Springer Berlin Heidelberg, 1999.

[4] Perera, Charith, et al. "Context aware computing for the internet of things: A survey." IEEE Communications Surveys & Tutorials 16.1 (2014): 414-454.

[5] Bettini, Claudio, et al. "A survey of context modeling and reasoning techniques." Pervasive and Mobile Computing 6.2 (2010): 161-180.

[6] Gu, Tao, et al. "An ontology-based context model in intelligent environments." Proceedings of communication networks and distributed systems modeling and simulation conference. Vol. 2004. 2004.

[7] Crockford, Douglas. "The application/json media type for javascript object notation (json)." (2006).

[8] W3C, Extensible Markup Language (XML), http://www.w3.org/XML.

[9] Berners-Lee, Tim, James Hendler, and Ora Lassila. "The semantic web." Scientific american 284.5 (2001): 28-37.

[10] Hachem, Sara, Thiago Teixeira, and Valérie Issarny. "Ontologies for the internet of things." Proceedings of the 8th Middleware Doctoral Symposium. ACM, 2011.

[11] Meng, Jian, and Jinlong Chen. "A mashup model for distributed data integration." Management of e-Commerce and e-Government, 2009. ICMECG'09. International Conference on. IEEE, 2009.

[12] Lenzerini, Maurizio. "Ontology-based data management." Proceedings of the 20th ACM international conference on Information and knowledge management. ACM, 2011.

[13] Jarrar, Mustafa, Jan Demey, and Robert Meersman. "On using conceptual data modeling for ontology engineering." Journal on data semantics. Springer Berlin Heidelberg, 2003. 185-207.

[14] Brena, Ramon F., and Hector G. Ceballos. "Combining Global and Local Ontology handling in a Multiagent System." FLAIRS Conference. 2004.

[15] Hachem, Sara, Thiago Teixeira, and Valérie Issarny. "Ontologies for the internet of things." Proceedings of the 8th Middleware Doctoral Symposium. ACM, 2011.

[16] Schilit, Bill, Norman Adams, and Roy Want. "Context-aware computing applications." Mobile Computing Systems and Applications, 1994. WMCSA 1994. First Workshop on. IEEE, 1994: 85-90.

[17] Chen, Harry, et al. "Soupa: Standard ontology for ubiquitous and pervasive applications." Mobile and Ubiquitous Systems: Networking and Services, 2004. MOBIQUITOUS 2004. The First Annual International Conference on. IEEE, 2004.

[18] Murata, Tadao. "Petri nets: Properties, analysis and applications." Proceedings of the IEEE 77.4 (1989): 541-580.

[19] Guermah, Hatim, et al. "An Ontology Oriented Architecture for Context Aware Services Adaptation." arXiv preprint arXiv: 1404.3280 (2014).