Context Oriented Semantic Model for the Internet of Things

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Abstract. This paper presents a context-oriented approach for architecting the Internet of Things(IoT) applications using ontology mechanism. Considering the abstraction which is necessary for IoT real-time intelligent information decision making, we define two kinds of semantic description information: context information and meta-information, to describe service resources. A context ontology model is proposed to describe the inheritance relationships of context. And a meta-information ontology mode is designed to introduce dynamic description logic to describe the premise and result of executing service. The analysis indicates that the approach effectively realizes decision supporting for context awareness oriented applications in IoT.

Introduction

The IoT is the network of physical objects embedded with electronics, software, sensors, and network connectivity, which is an important part of a new generation of information technology. IoT connects anything with Internet through the information sensing device, such as radio-frequency identification, infrared sensors, global positioning system and laser scanning, according to agreed communication protocol. And its purpose is to achieve intelligent recognition, monitoring, object tracking, positioning and management of the object[1,2]. Currently, the devices in IoT can only respond to users with accurate and complete information. However, a task of IoT is often an abstract task which is described by high-level semantics. Meanwhile, IoT includes a large number of heterogeneous sensing systems. Therefore, for IoT real-time intelligent information decision making, it’s difficult to directly translate decision information described by high-level semantics into information query which is oriented to sensing nodes. Based on the above requirements, we construct a semantic model of IoT application development. The model provides a high-level semantic view to consolidate all kinds of IoT resources. According to the view, each entity in IoT can communicate with each other through the high-level semantics based information.

Context is defined as any information that can be used to characterize the situation of an entity. Context-oriented architecture refers to the idea that devices can both sense, and react based on their environment[3,4]. Ontology is a formal definition and naming of the types, properties, and interrelationships of the entities that exist for a particular domain. With its standardization, formalization, rich semantic expression ability and excellent reasoning ability, ontology is recognized as one of the promising technologies in the field of context aware computing[5,6].

In view of the above analysis, an approach, for modeling ontology-based context-aware IoT application, is presented. The main characteristics of the model include three aspects. Firstly, we define two kinds of semantic description information: context information and meta-information, to describe service resources. Secondly, we construct context ontology, and describe the inheritance relationships of context. Finally, we construct meta-information ontology, and introduce dynamic description logic to describe the premise and result of executing service.

Semantic Modeling for IoT

The semantic modeling for IoT is mainly aimed at the semantic modeling of various types of services in IoT. In service entities of IoT, there are a lot of resource-constrained embedded devices, such as sensor nodes, embedded network managements, etc. Due to the constraints of limited computing power, limited energy storage and other factors, Web-based SOAP services aren't suitable to be used to encapsulate these entities. Currently, a lot of research works construct service platforms based on Restful service architecture, so we also use Restful service architecture to model the service entities in IoT. Restful service architecture defines a style of building Web services. Principles of Restful include: a resource-centric approach, all relevant resources are addressable using URIs, uniform access using http-get, post, put, delete, all services are described as resources, the service interoperability is realized based on http, and so on.

Service resources are mainly composed of sensor devices with sensing functions. The contexts of service resources determine the availability of services. This context includes spatial and temporal characteristics of service resource, and current status of sensor. In addition to context information, it is also needed to understand self-describing information about resource, that is, meta-information about resource. Based on resource meta-information, we can understand service type, service interface, specific meaning of delivery message. According to the above analysis, we provide two kinds of semantic description information, such as context information and meta-information, to describe Restful service. These two types of resources are corresponding to two ontology files, can be accessed through unique URIs. Among them, the context ontology describes the state of the resources, including space-time state and energy state, the meta-information ontology describes some attribute information related to service. By combining context ontology with meta-information ontology, we can query semantic information of IoT service resource, and realize the following functions, such as service discovery, service matching and service combination.

Context Ontology Modeling

Context of IoT. Context is any information that is used to describe entity features. An entity may be a person, a place, or an object. There are association relationships between entities (objects, users, and applications). Various resource information represented in contexts can come from these entities, such as users, systems, environments, etc. Context is represented as a five-tuple Ctx=<CtxSour, Type, Cont, TimeStamp, Duration>, where CtxSour represents an entity that generates context; Type and Cont represent the type of context that can be identified and the content of context, respectively; TimeStamp and Duration indicate context generation time and validity date, respectively. Let Cont={<Ki, Vi>|i=l, 2,..., n}, where Ki represents a property name in a context; Vi is the value of the property.

Context plays an important role in IoT. An important function of IoT is as follows. First, continuously detect device context, user context and environment. Second, carry on the judgment, the inference and the decision-making by using cluster relevant knowledge. Third, provide services for organizations and individuals. Context of IoT has characteristics of diversity, concurrency, universality, dynamics and sociality. These characteristics are interpreted as follows. First, due to the diversity of IoT terminals, the contexts corresponding to the terminals are varied. Because there is no standard protocol for IoT, there is no common definition of the corresponding context. This leads to the diversity of context. Second, when users are using IoT devices, they also involved in other activities. After devices collect data from IoT, the data may be sent to multiple IoT services that subscribe to context information. The task that is currently performing work is interrupted by higher-priority tasks. These above circumstances lead to the concurrency problem of context processing. Third, context information comes from varied data sources with different structures, and there exist conflicts and uncertainties among these contexts. As a result, context is widely distributed in many heterogeneous networks. Fourth, context changes dynamically with time, environment, and other factors. This is mainly manifested in the continuous change of instance and the constant updating of concept. Finally, IoT provides services for individuals, businesses and society, its social nature have a significant impact on context information.

Context ontology. Sensor is a main object of providing IoT service. Therefore, we construct context ontology for IoT according to sensor context. According to application requirements, sensor context ontology is abstract description of the related concepts and their relationships. The concepts include observer, observation object, observation result, observation time, observation site, observation theme, and so on. Formally, sensor context ontology is represented as a five-tuple SCO=<C, R, F, A, I>, where C is a set of concepts; R is a relation set of concepts; F is a set of functions; A and I are the set of axioms and of ontology instances, respectively. Firstly, the concept is highly summary of all common property, such as sensor, observation value, observation property, observation situation, and application field. Concept is represented as a three-tuple Con=<G, M, K>, where G is a set of objects, M is a set of properties, K is a set of relationships between G and M. Secondly, the relation of concepts refers to the relationship among the classes in sensor context ontologies, which mainly includes subclass relationship and non-subclass relationship. Usually, we use subClassOf to represent subclass relationship, and use custom properties, such as ObjectProperty and Dataproperty, etc. to represent non-subclass relationship. Thirdly, function is a kind of special relation. In a relation, the first n-1 elements can determine the nth element of the relation. Fourthly, axiom is some tautology, and refers to the constraints and the rules which are defined on the concepts and the properties. We can use logical languages to represent axioms. In sensor context ontology, we generate new knowledge by defining constraints and rules. Finally, instance is basic element which belongs to concept or class.

Fig.1 shows inheritance relationships of context ontology model used in IoT. Context class is defined as object which shows inheritance relationships between contexts. The sub-classes of sensor context include interface, parameters, status, sensor ID, sensor data, service and component. Among of them, interface defines dynamic protocols for data exchange between physical sensors and network users. Parameter is an important data to describe the basic characteristics of sensor nodes. Status is used to describe the recent situations and the recent events of sensor nodes. Sensor ID consists of the following four parts: number, manufacturer, production time, and text description. It is used to identify sensor node. Sensor data describe not only the states of the environment, but also control commands. Service refers to the complete set of functions provided by sensor nodes, including system service, semantic service, etc. Component represents either module with certain functions in sensor nodes, or data set of important features of sensor nodes.

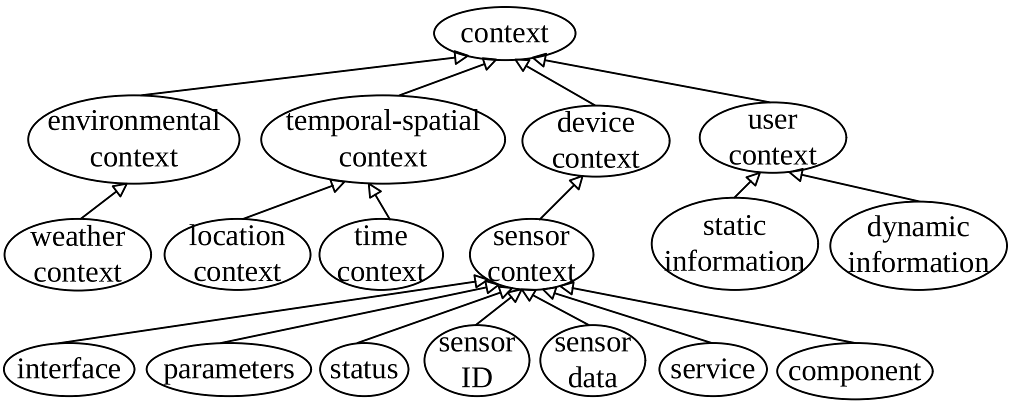

Fig.1. Inheritance relationships of context ontology model in IoT

Meta-information Ontology Modeling

By using OWL-S based meta-information ontology, we provide uniform service semantic. OWL-S consists of three parts: service profile, service process model, and service grounding. Among them, service process model is a main component that is adopted to describe the semantic information of service; it describes the following aspects about service: the service inputs, the service outputs, the preconditions for performing services, and the outcomes of services. The meta-information ontology modeling process mainly describes the following three types of data objects: IoT service, environmental entity, and user requirement. We describe IoT service from the following two aspects: functional behavior and QoS. Functional behavior includes two parts: static data and dynamic behavior. The static data describe perceived environment entities, related attributes and service interfaces. Dynamic behavior describes the state migration of service. QoS describes the properties and constraints of service action. Environmental entities refer to all identifiable entities in the physical environment, which have certain physical and/or virtual properties and can be perceived or controlled by services. In the physical world, environmental entity is the interactive object and function goal of IoT service. Each environmental entity includes both data description section and behavior description section. Data description emphasizes the entity's own attributes and organizational structure between entities. Behavior description emphasizes the dynamic nature of entity. User requirement describes which properties need to be met in the process of interaction between the physical environment expected by user and IoT service, and set constraints on the behavior of IoT service. User requirement is divided into two categories: functional and non-functional. Among them, Functional requirement describes the state migration of environmental entity, as well as the IOT service behavior that affect the migration. Non-functional requirement depends on functional requirement; it describes the QoS expected by user, and sets the constraints on the physical environment and the behavior of IoT service.

In order to support service matching and service composition reasoning effectively, we introduce dynamic description logic to describe, in a unified way, the premise and result of executing service. Dynamic description logic introduces the concept of action based on description logic, and adds an action set to the logic system. Dynamic Logic system includes two actions: atomic action and compound action. By the operators including sequence, choice and cycle, atomic actions can constitute a compound action. Based on dynamic description logic, the premise and the corresponding result for each service can be described as an action. Here, the premise and result of action correspond to the premise and result of service, respectively. Dynamic description logic can describe not only single IoT service but also service composition. Context ontology and meta-information ontology constitute the semantic model of IoT service resources. For any service resource that is labeled with URI, a service resource operation based on http’s get/put/post/delete operations is described as an action of dynamic description logic.

Conclusion

In this paper, we propose a context-oriented approach for architecting IoT applications using ontology mechanism. We derive conclusions of IoT context ontology model and meta-information ontology model from analysis, and introduce dynamic description logic to describe the premise and result of executing service. The results show that the approach effectively realizes decision supporting for context awareness oriented applications in IoT.

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