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An agility-oriented and fuzziness-embedded semantic model for collaborative cloud service search, retrieval and recommendation

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HIGHLIGHTS

- An agility-oriented and fuzziness-embedded cloud computing ontology is proposed.
- The collaborative ontology evolves as users contribute their own knowledge.
- A tool facilitates effective cloud service search, recommendation and retrieval.

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ABSTRACT

Cloud computing enables a revolutionary paradigm of consuming ICT services. However, due to the inadequately described service information, users often feel confused while trying to find the optimal services. Although some approaches are proposed to deal with cloud service retrieval and recommendation issues, they would only work for certain restricted scenarios in dealing with basic service specifications. Indeed, the missing extent is that most of the cloud services are "agile" whilst there are many vague service terms and descriptions. This paper proposes an agility-oriented and fuzziness-embedded cloud service ontology model, which adopts agility-centric design along with OWL2 (Web Ontology Language) fuzzy extensions. The captured cloud service specifications are maintained in an open and collaborative manner, as the fuzziness in the model accepts rating updates from users on the fly. The model enables comprehensive service specification by capturing cloud concept details and their interactions, even across multiple service categories and abstraction levels. Utilizing the model as a knowledge base, a service recommendation system prototype is developed. Case studies demonstrate that the approach can outperform existing practices by achieving effective service search, retrieval and recommendation outcomes.

1. Introduction

Cloud computing revolutionizes the world's ICT with on-demand provisioning, pay-per-use self-service, ubiquitous network access and location-independent resource pooling. Its reliable, scalable and elastic computational services and resource provision can adapt rapidly and effectively to nearly all kinds of needs for all major industry sectors [1,2]. As considerable efforts are made to drive and enhance the interoperability and composition of cloud services/resources [3–5], significant research gaps are found among the proposed service reference frameworks and models. On the other hand, along with the rapid development in the field, the number of cloud services continues growing whilst the market becomes increasingly complex. Cloud service consumers (CSCs) thus, may need to dig deeply to find the optimal services, by researching on a large number of service descriptions, characteristics, properties, service level agreements (SLAs), etc. Furthermore, regarding the services' features, functionalities, customizability and interoperability, etc., existing cloud service providers (CSPs) offer a diversity of interfaces, standards, policies and SLA parameters, which result into numerous difficulties in service information retrieval, interpretation and analysis [6,7]. Consequently, these impose urgent needs and great challenges on the specification and retrieval of cloud services, whereas an effective cloud service recommendation system is in demand for a variety of CSCs.

Recently, as a series of cloud computing/service semantic models propagate [4,8–12], they suffer from certain limitations. Firstly, the majority of the existing models cannot maintain com-

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prehensive service information across multiple abstraction levels (i.e. Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS) and Software-as-a-Service (SaaS)). These models fail to reveal the various agile interactions among cloud services and resources of such matrix structure (e.g. SaaS services can be deployed on PaaS platforms whilst PaaS services may rely on IaaS resources). Secondly, a limited number of models can effectively present the diverse full and potential service functions and features; none of them clarifies the range of connections or cooperation among cloud services and companies who have (hidden) relationships (e.g. some cloud services can orchestrate with others whilst some CSPs have certain industry relationships). Thirdly, most of the cloud services are "agile", i.e. adaptable at run time in their functions, interfaces, capacity, etc. Yet, such agility aspects are often ignored or poorly disclosed in existing models. Consequently, the lack of these critical aspects would cause ineffectiveness while implementing service search, discovery, retrieval, and recommendation tasks.

To eliminate the above limitations, a novel semantic model is proposed, notably the agility-oriented and fuzziness-embedded cloud service ontology (AoFeCSO). It adopts an agility-centric design and maximally utilizes the full range of OWL2 specifications. Moreover, AoFeCSO is deployed as a fuzziness-embedded model that stays active. It comprises fuzzy weighted service specifications to present inexplicit/controversial facts. The fuzzy weights can be collected from CSCs, CSPs and cloud service brokers (CSBs), through the form of "collaborative service specification fuzzy ratings", i.e. users can collaborate to rate the service specification applicability. Compared with the conventional ontology building and managing processes executed by limited number of field experts, the novel collaborative ratings make AoFeCSO more resourceful as well as more credible. This would bring much more cloud computing knowledge than any single group of experts does alone.

Using AoFeCSO as a central interacting knowledge base, a collaborative cloud service search, retrieval and recommendation system (CSR) prototype is developed. With its built-in fuzzy rating management and ontology evolution mechanism, CSR facilitates automatic and dynamic model evolution without interrupting concurrent service retrieval actions. The paper's contributions are: (1) an agility-oriented and fuzziness-embedded cloud service semantic model that maintains comprehensive and in-depth service information; it ultimately comprises a diversity of cloud service descriptions, service resource aspects, characteristics and features, plus their interactions, as a single retrievable knowledge source; (2) a cloud service recommendation system that is deployed on top of the model, allowing system users to not only search and retrieve cloud services flexibly and effectively, but also participate in model contents updates, which ultimately drive dynamic model evolution.

The rest of the paper is organized as follows: Section 2 introduces the background concepts and knowledge. Section 3 defines the architecture design of the proposed semantic model. Section 4 describes the adopted fuzzy OWL2 extension technique and ontology fuzzy assertion management. Section 5 illustrates the prototype implementation and component interactions. Section 6 uses a case study to demonstrate how the proposed model captures cloud service specifications and how the relevant prototype features for cloud service search, recommendation and retrieval are provided. Section 7 evaluates the model using state-of-the-art ontology evaluation approaches. Section 8 discusses the related research regarding web/cloud service semantic model, service recommendation system and ontology fuzzy extension. Finally, Section 9 concludes the paper with summaries and future work.

2. Background

In recent years, Web Ontology Language (OWL) [13] has been widely adopted for web service semantic specifications [14,15]. The formal entity specification and reference framework can enable the integration of a wide range of aspects, e.g. context information [16], user requirements [17], business processes [18]. Accordingly, this would assist service design, development, invocation and composition tasks in pervasive environments [6].

In fact, unlike web services and many other domains, cloud computing involves many vague and imprecise descriptions, terms, categorizations, etc. This may incur several issues during specification process. For instance, according to the majority of literature, "availability" and "security" are two separate service properties, yet some [19,20] argue that availability is a sub category of security. For those diverse service models and characteristics, should Amazon S3, Dropbox and Google Drive be regarded as SaaS, PaaS, IaaS or Storage-as-a-Service? Do they have the same extent (degree to the capability) towards scalability, reliability, interpretability? Indeed, conventional OWL/OWL2 modeling techniques cannot handle the above scenarios effectively, since they are designed to clarify explicit knowledge with concrete axioms, either true or false [6]. Fundamentally, this is due to the formal description logical (DL) consistency requirement which does not support such fuzziness [21,22].

Fuzzy logic (FL) is a well-known extension to DL that has been used widely in many fields. It includes two theories, known as fuzzy set [23] and fuzzy relationship [24]. The former describes vague subsumption between classes and their members, whereas the latter specifies uncertain relationships between individuals and classes. On the other hand, probabilistic logic network [25] (PLN) is another theory for uncertainty representation and inferences. It extends the existing fuzzy theories and their reasoning applicability to a great extent: the FL's fuzzy membership theory is further divided into a number of detailed scenarios (e.g. degreed belonging, chanced belonging, sharing partial properties and overall weighted judgment). The FL's fuzzy relationship theory is extended with higher-order and N-ary logical relationships.

While traditional OWL modeling techniques cannot handle and express uncertainties, FL and PLN theories are able to provide extended logic (reasoning) support for fuzzy specifications. AoFeCSO adopts OWL2 fuzzy extensions on the ground of these theories. This significantly enhances the accuracy of the model specification and expression with the most appropriate facts. More specifically, as an ordinary ontology axiom can only clarify a definite fact, a fuzzy-extended axiom can describe the fact along with "a truth degree". The degree of truth, usually a float of interval (0, 1), is viewed as the fuzzy weight of the axiom. With such weighted assertions, AoFeCSO is able to clarify a variety of vague specifications. For instance, a service owns certain "partial" properties. A service works "closely" with another service. A service is sometimes but not always regarded as what it is being specified.

3. AoFeCSO model architecture design

This section presents the design of the proposed cloud service ontology. Firstly, it introduces the loosely-coupled and agility-centric ontology design features. Subsequently, the design of the object property, data property and annotation property constructions are revealed respectively. Finally, it discusses the ontology design patterns adoption and application.