Future Generation Computer Systems 57 (2016) 42–55

Contents lists available at ScienceDirect

Future Generation Computer Systems

journal homepage: www.elsevier.com/locate/fgcs

Cloud-FuSeR: Fuzzy ontology and MCDM based cloud service selection

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HIGHLIGHTS

- Discuss why Cloud service selection problem is important.
- Design a fuzzy ontology for Cloud service selection problems.
- Identify proper time points and approaches for operating fuzzy variables.
- Consider the functional similarity and QoS performance simultaneously by distinguishing compositions of service functions.
- Combine user preferences and expert perceptions on service functions and their evaluation properties.

ARTICLE INFO

Article history:
Received 10 July 2015
Received in revised form
21 November 2015
Accepted 27 November 2015
Available online 11 December 2015

Keywords:
Multi-criteria decision-making
Fuzzy AHP
Fuzzy TOPSIS
Fuzzy ontology
Cloud service selection

ABSTRACT

With the rapidly growing number of available Cloud services, to fulfill the need for ordinary users to select accurate services has become a significant challenge. However, as a Cloud service environment encompasses many uncertainties that may hinder users to make sound decisions, it is highly desirable to handle fuzzy information when choosing a suitable service in an uncertain environment. In this paper, we present a novel fuzzy decision-making framework that improves the existing Cloud service selection techniques. In particular, we build a fuzzy ontology to model uncertain relationships between objects in databases for service matching, and present a novel analytic hierarchy process approach to calculate the semantic similarity between concepts. We also present a multi-criteria decision-making technique to rank Cloud services. Furthermore, we conduct extensive experiments to evaluate the performance of the fuzzy ontology-based similarity matching. The experimental results show the efficiency of the proposed method.

1. Introduction

With the proliferation of a range of Cloud services over the Internet, efficient and accurate service selection based on user-specific requirements has become a significant challenge for decision makers and Cloud consumers [1]. Various decision-making methods are applied to help service users to find the most appropriate services [2]. However, a service selection environment may encompass many uncertainties, which may hinder the ability of decision makers to make sound decisions.

Consider a Cloud service selection scenario [3] in which a service user is looking for an online Cloud storage service with high security requirements. In the Cloud market, two types of storage services meet the user's requirements: normal storage services without an encryption function and secured storage services with advanced encryption tools. There are three options for the user to choose from: (a) a standard storage service without extra data encryption, (b) a standard storage service with an encryption service from another service provider (e.g. TrueCrypt [4]), and (c) a secured storage service (e.g. Spideroak [5]). Option *a* may be priced the lowest but have the worst security guarantee. Option *b* may provide the highest level of security but be the most costly and the easiest to use (because the user has to configure the security service and encrypt the data himself). Option *c* may support a lower level of security than Option *b*, but can be used in a more convenient way. It is difficult for the user (especially a non-professional) to compare such options in this multi-criteria scenario of vague expressions and un-quantified evaluation factors

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http://dx.doi.org/10.1016/j.future.2015.11.025
0167-739X/

(e.g. high security and greater convenience). Therefore, an efficient and accurate decision-making approach is highly desirable to guarantee that the chosen services work well in all possible cases, given the uncertainty [6]. We analyze the fundamental problems that need to be resolved in designing such a Cloud service selection system as below:

Problem 1. Why should we study the problems of Cloud service selection?

Web service selection has been explored for over 10 years. Some Web service selection techniques are being applied to the Cloud service area. However, can we say that it is worthless studying Cloud service selection given the mature techniques of Web service selection?

To select a service, service users are usually concerned with service functions and Quality of Services (QoS). Web services are software services [7]. For a set of Web services with similar functions, service requestors choose services based on their QoS ratings. Compared with Web services, the process of Cloud service selection is more complicated due to the following reasons: (a) Cloud services include not only software services (SaaS), but also IaaS and PaaS [8]. When selecting services for a service composition task, Cloud service selection techniques should consider both the composition between services at the same level (e.g., SaaS) and the composition between services at different levels (e.g., SaaS and PaaS); (b) A company user may need to choose the right deployment model (i.e., private, public and hybrid) to adapting the size and the usage purpose of the organization. Business objectives may be a deterministic factor for a company user making decisions on using Clouds; (c) Compared with Web service selection, balancing benefits and risks is much more difficult for a Cloud user composing services from different providers based on a hybrid deployment model; (d) Other than the common QoS (e.g., availability and throughput), Web and Cloud service users focus on different service evaluation dimensions. For example, a Cloud user should be concerned more with the interoperability [9] of a Cloud service to enable flexible data management among heterogeneous hardware; (e) As most Cloud users (especially enterprise users) expect a long-term and stable relation with a Cloud service provider, rating factors of Cloud providers should also be defined, such as financial stability, experience and technical expertise of the service provider [9]. □

From the above discussion, the problems faced by a Cloud selection system vary greatly from the problems to be solved by Web service selection techniques.

Problem 2. How to find Cloud services with the user-expected functions given the fuzzy expressions of user requirements?

In the Cloud area, it is more difficult for decision makers to make informed decisions on service usage because of the diversification of service types and the lack of service-publication standards [10]. Defining a common ontology with high extensibility has been widely accepted as a reasonable approach to solve this kind of problems [11]. Ontology is a conceptual framework that models domain knowledge into a format that is both human- and machine-readable [12]. Crisp ontology cannot represent uncertain information or process uncertain reasoning. Several fuzzy ontologies for different domains have been proposed [6,13,11]. Nonetheless, little attention has been paid to fuzzy ontology for Cloud service selection. Based on a rigorous survey in this area, we conclude that it is necessary to build a fuzzy ontology to support Cloud users' needs: (a) compared to Web services, Cloud services are more heterogeneous, e.g., a variety of terms are used by different providers to describe the same concepts; (b) there is no normalization of Cloud service descriptions serving different kinds of users; (c) there is usually limited concern for the interdependency of criteria (e.g., compensation and dominance [14]) in the Cloud service selection area. □

Another key issue for service selection is that the candidate services are generally evaluated by multiple criteria [15], e.g., Quality-of-service (QoS), provider reputation, and service price. Multi-criteria decision-making (MCDM) techniques are proposed to handle MCDM problems [16]. The analytic hierarchy process (AHP) [17] and the technique for order performance by similarity to ideal solution (TOPSIS) [18] are two of the most widely applied MCDM approaches.

Problem 3. How to combine the MCDM techniques with the fuzzification and defuzzification techniques to rank Cloud services based on the fuzzy information of the performance of the service non-functional performance and the fuzzy information of user preference on the non-functional properties?

To handle fuzziness, fuzzy AHP and fuzzy TOPSIS have both been studied and applied to various domains. However, there are still problems in this area that require further study. Three key points are identified here: (a) Different defuzzification techniques are usually employed to simplify the inference process, where linguistic variables are defuzzified before complicated operations are conducted (e.g. Eigenvector calculation in AHP). In this way, computational efficiency can be enhanced. Nevertheless, a large amount of information used to capture the uncertainty will be lost and the rationality of defining fuzzy variables is therefore reduced [19]. (b) In contrast, there are also approaches [20,21] that retain the fuzziness of fuzzy variables in the whole inference process, which can provide results with fuzzy rating values. The techniques of ranking fuzzy variables are emphasized in this situation. One of the problems encountered by this kind of approach is that enclosing a wide range of fuzzy information in complicated computational steps (e.g., fuzzy number multiplication) may cause the exaggerated support of a fuzzy number [22], which can result in reduced accuracy in decision-making. Also, Chen et al. [23] have stated that it is highly time-consuming to perform complicated fuzzy number arithmetic operations and linguistic approximations. (c) The risk attitude of decision makers can greatly affect the decision-making results. The subjective judgement and preference of decision makers can significantly influence the ranking results [24]. □

Against the above problems, we propose a **F**uzzy **U**ser-oriented **Cloud SeR**vice Selection System (Cloud-FuSeR) that is capable of dealing with fuzzy information and rating Cloud services by considering three aspects: (1) the similarities between user-required functions and the service functions provided by Cloud providers, (2) the performance of the non-function properties, and (3) the user preference on different properties.

This work is an extension of our previous work [25], which is extended mainly from four main dimensions: (1) we introduce detailed definitions and examples of the fuzzy Cloud storage ontology; (2) we compare our Euclidean-based fuzzy AHP and TOPSIS framework with the Non-Euclidean fuzzy calculation procedure, and prove that the performance of the Euclidean fuzzification procedure is better than that of the Non-Euclidean procedure; and (3) we extend the past experiment with a larger simulated datasets; (4) we give a practical example of the Cloud storage service selection based on the proposed fuzzy ontology and multi-criteria decision making framework. Overall, this work has the following distinctive contributions:

- We build a fuzzy Cloud ontology to support the functional similarity calculation, which defines the concept taxonomies of Cloud services and the properties of Cloud services, and quantifies the relations among concepts and between concepts and properties;