QoS-aware Web Service Selection by a Synthetic Weight

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Abstract

The selection of web services according to different quality of service (QoS) is one of the most important decision issues for which complex considerations are involved. In many cases, the values for the qualitative QoS criteria are often imprecisely defined or acquired. Moreover, it is also not easy to accurately quantify the weight of each QoS criterion since human judgments including preference are often vague. In this paper, we apply the fundamental principles in the fuzzy set theory and model the decision making problem as Fuzzy Multiple Criteria Decision Making (FMCDM). The main contribution of this paper is to balance the subjective weight which reflects human rating and objective weight which represents reliability of evaluation criteria to form a synthetic weight. The detailed analysis of the synthetic weight for QoS-aware web service selection application is also presented.

1. Introduction

Web service [1] framework brings in a new revolution in traditional computing. Through using service oriented architecture (SOA) [2] based on web service technologies, enterprises can now address platform interoperability problems and therefore grasp ever changing business challenges and opportunities. However, most research papers on web service do not focus on quality of service (QoS) [3] issues, which only have been identified as an important factor in web service selection recently. It is not hard to imagine that service requestors will face a large number of choices of services that can provide the similar function.

QoS is a key indicator for web service nonfunctional quality criteria, which can be used to differentiate web services with the same function. Menasce presents an overview of current QoS based research situation [3]. Ran establishes a set of metrics to quantify each QoS category and their associated models for their representation [4]. Perryea and Chung group web services into several communities to help users match nonfunctional requirements [5]. Ardagna and Pernici discriminate global and local QoS constraints [6]. Zeng et al propose a QoS aware middleware for web services composition [7]. Their modeling method can be used as a general approach for global optimization in term of linearly formulated QoS criteria. All the methods stated above are based on the concept of accurate measurement and crisp evaluation of QoS criteria.

In general, the selection of a web service from a group of service alternatives on the basis of two or more QoS factors is a multiple criteria decision making (MCDM) problem [8]. However, when building the system evaluation model, the traditional multiple criteria programming is not flexible enough. There are two reasons. a) Under many situations, the values for the qualitative QoS criteria are often imprecisely defined or acquired. A web service is operating under a dynamic heterogeneous environment so that the runtime quality is also fluctuating with variation of the related component and/or hardware resource configuration of web service and the network connection status. b) It is also not easy to precisely quantify the weight of each QoS criterion since human judgments are often vague. A probable way to solve the problems above is to apply fuzzy numbers or linguistic variables.

In recent years, several researchers have applied the fuzzy sets theory and technique to develop and to solve the web service selection problems. For example, Liu and Jin propose fuzzy analytic hierarchy process to define the weight factor of QoS [9]. Zhang et al design a user preference model based on linguistic variable and apply a hierarchical fuzzy logic evaluation [10]. Chen et al adopt Fuzzy Multiple Criteria Decision Making (FMCDM) approach to capture how customers make their evaluation of services more effectively [11]. Huang et al presents a moderated fuzzy web service discovery approach to model subjective and fuzzy opinions, and to assist service consumers and providers in reaching a consensus [12]. Mon applies entropy weight to model objective significance of the criteria by fuzzy analytic hierarchy process [13]. These studies [3-13] motivate the research work presented in this paper.

Besides modeling the web service selection problem as FMCDM, in this article, we introduce a synthetic weight which combines both the subjective and objective weights. For subjective weights defined by human preference, we apply linguistic variables and fuzzy numbers. For objective weights, we investigate entropy concepts to improve the judgment consistency. A synthetic parameter is introduced to balance the two weights.

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The rest of the paper is organized as follows. In section 2, the definitions of triangle fuzzy number and entropy concepts are presented. The methodology to model web service selection as FMCDM is proposed in section 3 while the algorithm to select web services by a synthetic weight is presented in section 4. Then a real example is shown in section 5 to certify the validity of the methodology. Synthetic weight related discussion and comparison are presented in section 6. Finally, section 7 concludes the paper.

2. Basic concepts

2.1. Fuzzy theory and triangular fuzzy number

The fuzzy set theory proposed by Zadeh [14] is introduced to handle uncertain fuzzy problems through fuzzy information that is expressed in vague and imprecise terms. Triangular fuzzy numbers are widely used to present fuzzy information. We assume that a reader is familiar with the basic triangular fuzzy numbers [14]. The following definition is used.

Definition 1: A triangular fuzzy number defined on R is a fuzzy set $\tilde{S}=(L,M,U)$. The membership function of $\tilde{S}$ is defined as

$$u_{\tilde{S}}(x)=\begin{cases}(x-L)/(M-L) & \text{if } L\le x\le M\\ (U-x)/(U-M) & \text{if } M\le x\le U\\ 0 & \text{otherwise}\end{cases}$$

Definition 2: Suppose that $\tilde{S}$ is a fuzzy set defined on R and $0\le\alpha\le 1$. The $\alpha-cut$ $S(\alpha)$ of $\tilde{S}$ consists of points x satisfying $u_{\tilde{S}}(x)\ge\alpha$, i.e., $S(\alpha)=\{x\mid u_{\tilde{S}}(x)\ge\alpha\}$.

Definition 3: Suppose that $\tilde{S}$ is a fuzzy set defined on R and $0\le\alpha\le 1$. The $\alpha-cut$ of $\tilde{S}$ is $S(\alpha)=[S_L(\alpha),S_U(\alpha)]$. Then, we have

$$\tilde{S}=\bigcup_{0\le\alpha\le 1}\alpha S(\alpha)$$

Definition 4: For any x and $0\in R$, define the signed distance [15] from x to 0 as $d(x,0)$.

Definition 5: Suppose that $\tilde{S}$ is a fuzzy set defined on R. The signed distance of $\tilde{S}$ to $\tilde{0}$ is

$$d(\tilde{S},\tilde{0})=\frac{1}{2}\int_0^1(S_L(\alpha)+S_U(\alpha))\mathrm{d}\alpha$$

For the triangular fuzzy number $\tilde{S}=(L,M,U)$, the $\alpha-cut$ of $\tilde{S}$ is $S(\alpha)=[S_L(\alpha),S_U(\alpha)]$, $0\le\alpha\le 1$, where $S_L(\alpha)=L+(M-L)*\alpha$, $S_U(\alpha)=U-(U-M)*\alpha$. The signed distance of $\tilde{S}$ to $\tilde{0}$ is

$$d(\tilde{S},\tilde{0})=\frac{1}{2}\int_0^1(S_L(\alpha)+S_U(\alpha))\mathrm{d}\alpha=\frac{1}{4}(L+2*M+U)$$

2.2. Entropy weight

Definition 6: The entropy $E(p_1,p_2,...,p_n)$ where p_i is a relative frequency has the unique form if it satisfies the following three reasonable and compatible conditions:

(1) $E(p_1,p_2,...,p_n)\le E(\frac{1}{n},\frac{1}{n},...\frac{1}{n})$

(2) $E(p_1,p_2,...,p_n)=E(p_1,p_2,...,p_n,0)$

(3) $E(PQ)=E(P)+E(P\mid Q)$

Definition 7: A balanced judgment matrix for n candidates under m criteria is $A=(a_{ij})_{m\times n}$, where $0\le a_{ij}\le 1$.

Definition 8: The entropy for the ith criterion is defined as $E_i=-e*\sum_{i=1}^{n} f_{ij}\ln f_{ij}$, where $e=1/\ln n$ and $f_{ij}=a_{ij}/\sum_{j=1}^{n} a_{ij}$

The total entropy can be calculated as $H=\sum_{i=1}^{m} E_i$.

Definition 9: The entropy weight for the ith criterion is $1-E_i$.

Definition 10: The balanced entropy weight for the ith criterion is $Ew_i=\frac{1-E_i}{\sum_{i=1}^{m}(1-E_i)}=\frac{1-E_i}{m-H}$.

When candidates have the same value on a specific criterion, from Definition 8, the entropy reaches the maximum value of 1. Therefore, the entropy weight for this criterion is 0, which means that this criterion does not provide any helpful information for decision making. Since the larger the entropy value, the lower the information express quantity, the entropy weighting is an effective measurement for the average essence of information quantity. Thus, it can represent actual objective weighting of criteria.

3. Modeling web service selection as FMCDM

Every functionality of a service can be evaluated by several QoS properties. The QoS property of a web service is defined by the measurements of its QoS criteria. Ran sorts the QoS criteria into runtime, transaction

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support, configuration management and cost, and security related ones [4]. Each is made up of several metrics and submetrics. Runtime related QoS is an indicator for web service concurrent performance, which may include scalability, capacity, response time, latency, throughput, reliability, availability, robustness, flexibility, accuracy, etc. Transaction support related QoS mainly concerns the web service integrity, which includes atomicity, consistency, isolation and durability. Configuration management and cost related QoS includes regulatory, stability, change cycle, completeness, etc. Security related QoS addresses the web service trustworthiness, e.g., authorization, confidentiality, traceability and auditability.

Generally, there are two kinds of QoS criteria, i.e., cost and benefit. For cost ones, i.e., the higher the value, the lower the quality. These include criteria such as response time and latency. Other criteria are benefit, i.e., the higher the value, the higher the quality. These include criteria such as availability and stability. Some of the QoS criteria can be measured quantitatively as follows

Table 1. QoS criteria and measures used for evaluating candidate web services

QoS criteria	Measures
Cost	The fee to be paid by a service requestor for invoking the web service.
Latency	The interval time between the service request arrives and the request is being serviced.
Availability	The attribute for evaluating an immediate availability of a web service. It can be computed as the ratio of the service accessible time to the total time of observation.
Capacity	The maximum concurrent connections the service can support with guaranteed performance.

Since web service is operating in a highly varying environment, the QoS criteria and measures for candidate web services fluctuate continuously. For example, the cost of web service is related to the market trend and the latency of web service is closely correlated with runtime throughput. We use a fuzzy number $\tilde{S} = (L, M, U)$ to represent the fuzziness of a QoS criterion, where the parameter M gives the most possible value of this criterion and the parameter L and U indicate the lower and upper bounds of this criterion.

Besides the QoS criteria that can be measured quantitatively, there are also QoS criteria that can be only measured qualitatively. For example, the robustness reflects the degree to which a service can function correctly in the presence of invalid, incomplete or conflicting inputs. The security, reliability and maneuverability of web service are also hard to be measured quantitatively. For these criteria, we employ linguistic expression set *L1={VP, MP, P, M, G, MG, VG}*, where *VP=Very Poor, MP=Medium Poor, P=Poor, M=Medium, G=Good, MG=Medium Good, VG=Very Good*. For example, linguistic variables for the preference of robustness and security are shown in Tab. 2.

Decision maker's subjective perception for important weights of criteria is also hard to precisely grasp. We also use linguistic expression set $L2 = \{VL, L, M, H, VH\}$ for the importance of each criteria, where *VL=Very Low, L=Low, M=Medium, H=High, VH=Very High*.

4. Methodology and algorithm

We propose a systematic approach for the selection of web services in this section. The steps to be taken are described below.

Algorithm: (Web service selection using FMCDM with a synthetic weight)

Step 1 Construct judgment matrix.

Step 1.1 Select m QoS criteria and n candidate web services, i.e., WS_{1-n} for evaluation.

Step 1.2 Construct a fuzzy judgment matrix $\tilde{A} = (\tilde{a}_{ij})_{m\times n}$ for m criteria and n candidates. $\tilde{a}_{ij}$ is a triangular fuzzy number $\tilde{a}_{ij} = (L_{ij}, M_{ij}, U_{ij})$.

Step 1.3 Normalize the fuzzy judgment matrix $\tilde{A} = (\tilde{a}_{ij})_{m\times n}$ to obtain a balanced fuzzy judgment matrix $\tilde{B} = (\tilde{b}_{ij})_{m\times n}$. For cost and benefit criteria, values are balanced according to (1) and (2), respectively.

$$\tilde{b}_{ij} = (L_i^{min} / U_{ij}, L_i^{min} / M_{ij}, L_i^{min} / L_{ij}) \quad (1)$$

$$\tilde{b}_{ij} = (L_{ij} / U_i^{max}, M_{ij} / U_i^{max}, U_{ij} / U_i^{max}) \quad (2)$$

where

$$L_i^{min} = Min(L_{ij}), 1 \le j \le n$$

$$U_i^{max} = Max(U_{ij}), 1 \le j \le n$$

Step 1.4 Defuzzify $\tilde{b}_{ij}$ using the signed distance method to obtain a balanced judgment matrix $A = (a_{ij})_{m\times n}$, where $a_{ij} = d(\tilde{b}_{ij}, \tilde{0})$.

Step 2 Obtain the synthetic weights for m QoS criteria.

Step 2.1 The decision maker uses the linguistic weighting variables shown in Tab. 3 to assess the importance of m criteria and obtain a fuzzy weight vector $\tilde{V}_{Sw} = (\tilde{S}w_i)_{m\times 1}$.

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Step 2.2 Defuzzify $\tilde{S}w_i$ using the signed distance method to obtain subjective weight vector $D_{Sw} = (DSw_i)_{m\times1}$, where $DSw_i = d(\tilde{S}w_i, \tilde{0})$.

Step 2.3 Normalize the weight vector $D_{Sw} = (DSw_i)_{m\times1}$ to obtain a balanced subjective weight vector $V_{Sw} = (Sw_i)_{m\times1}$ where $Sw_i = \frac{DSw_i}{\sum_{i=1}^{m} DSw_i}$.

Step 2.4 Calculate the entropy weight for the *i*th criterion in $A = (a_{ij})_{m\times n}$ and obtain the balanced entropy weight vector $V_{Ew} = (Ew_i)_{m\times1}$.

Step 2.5 Suppose that the synthetic parameter for subjective and objective weights is λ. Then we gain the final weight vector $W = (w_i)_{m\times1}$, where $w_i = \frac{(1-\lambda)*Sw_i+\lambda*Ew_i}{\sum_{i=1}^{m}((1-\lambda)*Sw_i+\lambda*Ew_i)}$.

Since $\sum_{i=1}^{m}((1-\lambda)*Sw_i+\lambda*Ew_i) = (1-\lambda)*\sum_{i=1}^{m} Sw_i + \lambda*\sum_{i=1}^{m} Ew_i = 1$, we have $w_i = (1-\lambda)*Sw_i + \lambda*Ew_i$.

Step 3 Compute the overall quality score $Score(\lambda)_{WS_j}$ for each candidate WS_j.

$$Score(\lambda)_{WS_j} = \sum_{i=1}^{m} a_{ij}*w_i$$

The greater the total value $Score(\lambda)_{WS_j}$, the more preferred the alternative WS_j. Through comparing $Score(\lambda)_{WS_j}$ of all candidate web services, we can choose the optimal web service.

5. Case study

We adopt the algorithm to evaluate five candidate web services. We establish the evaluation model of the web services as in Fig. 1. The evaluation is based on six QoS criteria, i.e., cost, latency, availability, capacity, robustness and security.

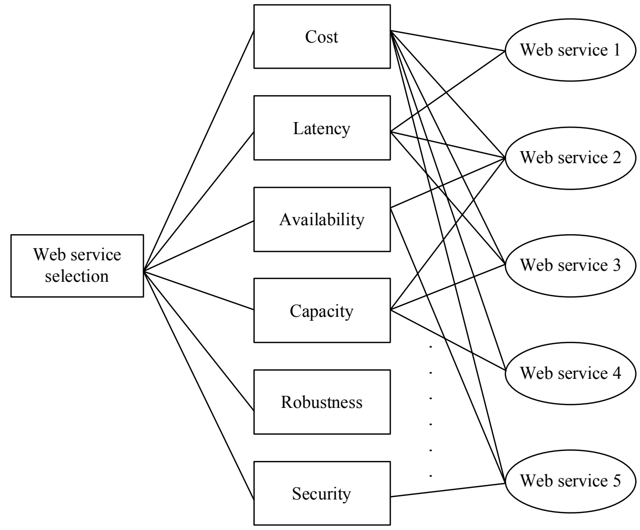

Figure 1. The evaluation model of the web services

We follow the algorithm. We establish a fuzzy judgment matrix $\tilde{A} = (\tilde{a}_{ij})_{6\times5}$ for six criteria and five candidates in Tab. 4.

The subjective weights of QoS criteria are shown in Tab. 5. After executing Step 2.2 and 2.3, we obtain the balanced subjective weight vector as

$$V_{Sw} = [0.1573\ \ 0.1573\ \ 0.1910\ \ 0.0899\ \ 0.1910\ \ 0.2135]$$

The entropy weights are also calculated and normalized to obtain the balanced entropy weight vector as

$$V_{Ew} = [\ 0.3039\ \ 0.4037\ \ 0.0954\ \ 0.1462\ \ 0.0169\ \ 0.0339]$$

Suppose that the synthetic parameter $\lambda = 0.4$. Then we gain the final weight vector as

$$W = [0.2159\ \ 0.2559\ \ 0.1528\ \ 0.1124\ \ 0.1214\ \ 0.1416]$$

Finally, the overall quality score for each candidate web service WS_j can be calculated as

$$Score(\lambda)_{WS_{1-5}} = 0.5510, 0.6559, 0.6468, 0.5684, 0.6662$$

Thus, the ranking of the web services from the best to the worst is 5, 2, 3, 4, 1.

6. Discussion and comparison

In order to show how the alteration in synthetic weights leads to different selection of web services, we suppose that the synthetic parameter λ varies between 0 and 1. We can then obtain the overall quality score of web services as shown in Fig. 2.

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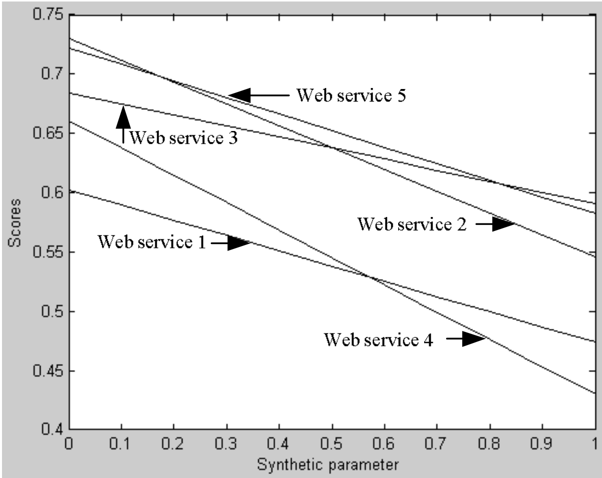

Figure 2. The variation of web service ranking with different synthetic parameters

From Fig. 2, when we only consider the subjective weight, i.e., $\lambda = 0$, Web service 2 is the best choice while the ranking from the best to the worst is 2, 5, 3, 4, 1. When we only consider the objective weight, i.e., $\lambda = 1$, Web service 3 is the best choice while the ranking is 3, 5, 2, 1, 4.

Since $Score(\lambda)_{WS_j} = \sum_{i=1}^{m} a_{ij} * w_i = \sum_{i=1}^{m} a_{ij} * ((1-\lambda) * Sw_i + \lambda * Ew_i)$, we have $Score'(\lambda)_{WS_j} = \sum_{i=1}^{m} a_{ij} * (Ew_i - Sw_i)$, where $Score'(\lambda)_{WS_j}$ denotes the first derivative of function $Score(\lambda)_{WS_j}$. We can compute $Score'(\lambda)_{WS_{1-5}}$ = -0.1281, -0.1841, -0.0928, -0.2308, -0.1399 respectively. The negative property of the slopes of all the functions $Score(\lambda)_{WS_{1-5}}$ is coincident with the curves in Fig. 2.

7. Conclusion

Web service framework brings in a new revolution in traditional computing. Through selecting and deploying suitable web services under SOA, enterprises can now address platform interoperability problems and therefore grasp ever changing business challenges and opportunities. However, most of the recent works are focused on meeting the functional requirements, while we put emphasis on service selection on nonfunctional criteria and propose an FMCDM approach in this paper. Firstly, triangular fuzzy numbers and linguistic values characterized by triangular fuzzy numbers are used to describe QoS criteria. Secondly, the fuzzy subjective weighting method and the entropy weighting method are jointly used to form a synthetic weight. Finally, the best alternative web service is chosen and relative analysis on the synthetic weight is presented.

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Table 2. Linguistic variables for the preference of robustness and security

QoS criteria	*VP*	*MP*	*P*	*M*	*G*	*MG*	*VG*
Robustness	(0,0.1,0.6)	(0.5,0.6,0.8)	(0.7,0.75,0.8)	(0.8,0.85,0.9)	(0.86,0.88,0.9)	(0.88,0.9,0.92)	(0.90,0.95,1)
Security	(0,0.1,0.5)	(0.5,0.6,0.7)	(0.66,0.68,0.7)	(0.7,0.75,0.8)	(0.76,0.78,0.8)	(0.8,0.85,0.9)	(0.9,0.95,1)

Table 3. Linguistic variables for the subjective weights of QoS criteria

Linguistic variables	*VL*	*L*	*M*	*H*	*VH*
Triangular fuzzy numbers	(0,0.1,0.2)	(0.2,0.4,0.6)	(0.6,0.7,0.8)	(0.8,0.85,0.9)	(0.9,0.95,1)

Table 4. QoS criteria fuzzy values for five candidate web services

QoS criteria	WS_1	WS_2	WS_3	WS_4	WS_5
Cost (₵)	(3,4,5)	(4,6,10)	(9,10,15)	(7,7.5,8)	(3,5.5,8)
Latency (ms)	(50,80,90)	(22,40,60)	(15,20,50)	(32,50,60)	(32,34,40)
Availability	(0.5,0.55,0.6)	(0.9,0.95,1)	(0.5,0.8,1)	(0.6,0.7,0.8)	(0.8,0.88,1)
Capacity	(100,390,500)	(300,450,700)	(420,600,800)	(200,350,430)	(480,500,600)
Robustness	*P*	*VG*	*G*	*MG*	*M*
Security	*M*	*G*	*P*	*VG*	*G*

Table 5. The subjective weights of the QoS criteria

QoS criteria	Cost	Latency	Availability	Capacity	Robustness	Security
Subjective weights	*M*	*M*	*H*	*L*	*H*	*VH*

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