A QoS-Aware Web Service Selection Method Based on Credibility Evaluation

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Abstract—There exist so many web services that share same or similar functional properties; so it is often a challenging effort to select a credible and optimal web service based on their various history QoS records. In view of this challenge, in this paper, a novel QoS-aware web service selection method is put forward, based on credibility evaluation associated with negotiated QoS dimensions. More specifically, the historical empirical data, i.e., execution logs of a service, are used for evaluation purpose. At last, a case study is employed for illustration purpose, and the evaluations are presented to demonstrate the feasibility of our method.

Keywords—web service; QoS; service selection; credibility evaluation; execution log

I. INTRODUCTION

Service oriented architecture (SOA) [1] has emerged as a fundamental architectural model that supports the overall paradigm of service computing from architecture perspective, and the web service technology is a popular technique to realize the SOA model. Briefly speaking, web service is a software application accessible to the user over the web, which overcomes the limitation of traditional middleware on the B2B (business to business) integration [2]. Although the current web service architecture supports registry, discovery, and consumption of web services, how to effectively select a web service which satisfies a user’s requirement remains to be a challenge, as there are so many services that share similar functionalities.

QoS (quality of service, QoS) has been studied a lot and is applied effectively in service contracting [3], service discovery [4], service selection [5, 6] and service composition [7]. Generally, QoS could be utilized to discriminate multiple functional equivalent web services, and the best one would be selected and returned to the user. However, in most web service selection methods, it is often assumed that the QoS information offered by providers is fixed and trusted, which may not be practical in certain situations. For example, the execution time of a service is undetermined until the service finishes its execution. So for the purpose of flexibility, the execution time of a service may be advertised with a value range, e.g., [1s, 5s]. In this situation, if all the functional qualified candidates are advertised with the same range of execution time, e.g., [1s, 5s] (here, only one criterion execution time is considered for simplicity), then it would be difficult to evaluate all the functional qualified alternatives. Furthermore, the trustworthiness of the QoS information advertised by service providers may not be assured, as some providers are apt to advertise inauthentic QoS information, in order to attract more potential end-users. In this situation, how to cope with these fraud cases is still a challenge. In view of these challenges, a new criterion named credibility is proposed in this paper, to evaluate the actual quality of a service. For each functional qualified candidate, its credibility is calculated, and the candidate that achieves the largest credibility is selected finally.

The rest of this paper is organized as follows. In Section2, the preliminary knowledge is presented, including QoS specification and the credibility of web services. A QoS-aware web service selection method based on credibility evaluation is specified in Section3. In Section4, a case study is investigated to demonstrate our web service selection method. Evaluations are presented in Section5 to validate the feasibility of our proposal. Finally, the conclusions and our future works are presented in Section6.

II. PRELIMINARY KNOWLEDGE

In this paper, the credibility evaluation is based on the QoS information from execution logs and users’ QoS constraints. The specification of QoS information in service requests and execution logs are presented in Section2.1. While in Section2.2, the credibility of web services is analyzed.

A. QoS Specification

The QoS dimensions could be classified into the following two categories, i.e., negotiable dimensions and nonnegotiable dimensions [3].

--Negotiable dimensions. The value of a negotiable dimension may vary at runtime according to the service requestor’s requirements.

--Nonnegotiable dimensions. The value of a nonnegotiable dimension of a service is determined by its historical execution records and cannot be modified by the provider.

For instance, price is a negotiable dimension, as a user may accept a higher price for higher quality of service, e.g., less execution time or higher availability. On the contrary, the successful execution rate and reputation of the service are nonnegotiable, as their values can not be determined by
TABLE II. CATEGORIES OF TYPICAL QoS DIMENSIONS

<table>
<thead>
<tr>
<th>QoS Dimension</th>
<th>Category</th>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>negotiable</td>
<td>negative</td>
</tr>
<tr>
<td>Execution time</td>
<td>negotiable</td>
<td>negative</td>
</tr>
<tr>
<td>Reputation</td>
<td>nonnegotiable</td>
<td>positive</td>
</tr>
<tr>
<td>Successful rate</td>
<td>nonnegotiable</td>
<td>positive</td>
</tr>
<tr>
<td>Availability</td>
<td>negotiable</td>
<td>positive</td>
</tr>
</tbody>
</table>

the service provider. Besides, from the perspective of a user, QoS dimensions can be classified into positive dimensions and negative dimensions. For positive dimensions, the higher the value is, the higher the quality is; while for negative dimensions, the lower the value is, the lower the quality is. TABLE I gives a simple description of five frequently-used standard QoS dimensions, as well as their categories and properties.

It is supposed in this paper that there are $N$ nonnegotiable QoS dimensions, i.e., $q_i (1 \leq i \leq N)$, and $M$ negotiable QoS dimensions, i.e., $q_m (N+1 \leq m \leq N+M)$. $q_i$ is referred to as a generic QoS dimension, where $1 \leq i \leq N$ and $1 \leq m \leq M$. In the actual service selection, users are more accustomed to expressing their QoS requirements as a range, rather than a precise value.

**Definition1 (Service Request on QoS: RQ).**

$RQ=(r_{q_1},..,r_{q_N},..,r_{q_M})$, where $r_{q_i}$ represents the constraints on $q_i$ in service request. The admissible values of $r_{q_i}$ are denoted by a value range, i.e., $r_{q_i}=[q_{i,\text{min}},q_{i,\text{max}}](1 \leq i \leq I)$, where $q_{i,\text{min}}$ and $q_{i,\text{max}}$ are the lower and upper bounds of the closed interval respectively.

For example, a user may expect the service price in the range of [10, 15], the successful execution rate in range [0,0.9, 1]. The execution log is used to record the execution history of a service. It is assumed that each execution of a service produces a piece of record of definite QoS information. The execution records are formalized as follows:

**Definition2 (Execution Log on QoS: EL).**

$EL= \langle \text{nonneg. neg. timestamp} \rangle$, where

- $\text{nonneg.}=(q_{v_1},..,q_{v_N})$, $q_{v_i}$ represents the value of nonnegotiable dimension $q_{i}$ of a service execution;
- $\text{neg.}=(q_{v_{N+1}},..,q_{v_{N+M}})$, $q_{v_m}$ represents the value of negotiable dimensions $q_{m}$ of a service execution;
- $\text{timestamp}$ records the time when the execution happened.

For example, the successful execution rate is a nonnegotiable dimension, and its value in $EL$ is true or false. The value of price in $EL$ is a specific value which expresses the result of negotiation between the service provider and a user before execution. The timestamp in $EL$ denotes the required time period of execution log that a user is interested in.

**B. Credibility**

As mentioned above, it is usually hard to determine the quality level of a certain web service before its execution. However, execution log offers useful information to evaluate a service’s overall quality. In this paper, a metric named credibility proposed in [8] is recruited, for evaluating the quality of a service by mining its execution log. Since the **credibility** of a service is computed based on its historical execution log, it is relatively more credible than the QoS information advertised by service providers.

The credibility of a QoS dimension describes the quality and the degree of a user’s satisfaction on this dimension. As mentioned in Section 2.1, we have classified QoS dimensions into two categories, which are nonnegotiable dimensions and negotiable dimensions. From a user’s perspective, nonnegotiable QoS dimensions are independent with each other. So, a higher quality of a nonnegotiable dimension often means a higher satisfaction degree for the user. While for negotiable dimensions, they have correlations with each other. Namely, the change of a QoS dimension may influence another dimension. In the next section, the different calculation manners of credibility are proposed for different categories of QoS dimensions.

III. A QoS-AWARE SERVICE SELECTION METHOD BASED ON CREDIBILITY EVALUATION

As mentioned in Section 1.2, the QoS information advertised by service providers is prone to be uncertain and dubious, which blocks the fair service evaluation. In this step, a novel QoS-aware service selection method is proposed, which takes the candidates’ credibility into consideration. As QoS dimensions are classified into negotiable dimensions and nonnegotiable ones, the calculation manners of credibility should be exploited respectively. Our selection method mainly consists of the following four steps as in Fig. 1.

**Step1:** Data preparation. Get the constraints and preferences of QoS from the service requestor and extract the QoS information from the execution log of each candidate service.

**Step2:** Calculate the credibility of nonnegotiable QoS dimensions for each candidate service.

**Step3:** Calculate the credibility of negotiable QoS dimensions for each candidate service.

**Step4:** web service selection based on credibility evaluation. According to the calculation results in Step2 and Step3, synthesize the final credibility of each candidate service, and select a candidate service with largest credibility.

![Fig.1 Four steps of the proposed web service selection method](image-url)

**Step1:** Data preparation
As the evaluation is mainly based on the execution log, the QoS data should be extracted from the execution logs of candidate services and be pooled in matrix format according to Def1. Also, users’ requests on QoS play an important role in service selection, so the QoS constraints should be acquired based on Def2. Besides, the preferences for QoS dimensions are acquired from users’ requests. However, for simplicity, it is assumed that the weights of different QoS are equal in our method. In detail, all the data used for evaluating the credibility of a candidate service can be expressed as
The credibility of other values of reputation are the times that the service has been successfully completed; of dimensions, but also the quality of the executions that fall satisfying the user’s constraints over all Negotiable dimensions. From an overall perspective, the method considers not only the quantity of execution records, the service’s quality and reputation are categorized into positive and negative dimensions. For example, if the successful execution rate $\geq 95\%$ in a request constraint, while the value of a candidate service’s successful execution rate $= 90\%$, then the service will be discarded. The credibility of each nonnegotiable QoS dimension is computed using formula (1):

$$
C_{\alpha} = \left( \frac{1}{K} \sum_{i=1}^{K} g_{i,n} - q_{\text{max}} \right) \left( q_{\text{max}} - q_{\text{min}} \right),\quad q_{\text{max}} = q_{\text{min}}
$$

where $1 \leq n \leq N$, $K$ represents the number of execution records, $x_{i,n}$ represents the value of QoS dimension $q_n$ in execution log $E_{i}$, $q_{\text{max}}$ and $q_{\text{min}}$ represents the best value and the worst value for $q_n$ in the set of admissible values, respectively. Obviously, the value of $C_{\alpha}$ is in range $[0, 1]$.

Next, we take successful execution rate and reputation for example. $C_{\text{rate}} = T/K$, where $C_{\text{rate}}$ represents the credibility of successful execution rate of a candidate service; $T$ denotes the times that the service has been successfully completed; $K$ represents the total number of invocations. If the admissible values of reputation are in the set of $\{0, 1, 2, 3, 4, 5\}$, the credibility of reputation is calculated using formula: $C_{\text{rep}} = \left( \sum_{i=1}^{N} x_{i,\text{rep}} / K \right) / 5$. The credibility of other nonnegotiable QoS dimensions can be computed in the similar way. If the value of any nonnegotiable QoS dimension fails to satisfy a user’s QoS constraints, then the candidate will be abandoned directly and there’s no need for further computation.

**Step 2: The credibility of nonnegotiable QoS dimensions**

For a nonnegotiable QoS dimension, the average value of execution records [6] appropriately describes its credibility. In other words, if the average value cannot satisfy the user’s constraints, the service will be abandoned, so there’s no need for further computation of negotiable dimensions. For example, if the successful execution rate $\geq 95\%$ in a request constraint, while the value of a candidate service’s successful execution rate $= 90\%$, then the service will be discarded. The credibility of each nonnegotiable QoS dimension is computed using formula (1):

$$
C_{\alpha} = \left( \frac{1}{K} \sum_{i=1}^{K} g_{i,n} - q_{\text{max}} \right) \left( q_{\text{max}} - q_{\text{min}} \right),\quad q_{\text{max}} = q_{\text{min}}
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where $1 \leq n \leq N$, $K$ represents the number of execution records, $x_{i,n}$ represents the value of QoS dimension $q_n$ in execution log $E_{i}$, $q_{\text{max}}$ and $q_{\text{min}}$ represents the best value and the worst value for $q_n$ in the set of admissible values, respectively. Obviously, the value of $C_{\alpha}$ is in range $[0, 1]$.

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**Step 3: The credibility of negotiable QoS dimensions**

According to the analysis above, we introduce a new method to compute the credibility of negotiable QoS dimensions. From an overall perspective, the method considers not only the quantity of execution records satisfying the user’s constraints over all Negotiable dimensions, but also the quality of the executions that fall into the user’s constraints. In the following discussions, for simplicity, only negotiable dimensions are referred in service request $RQ$, i.e., $(q_{N+1}, ..., q_{N+M})$.

In this paper, the TOPSIS (Technique for order performance by similarity to ideal solution, TOPSIS) method [9] is employed to calculate the credibility of Negotiable QoS dimensions. In TOPSIS, it is argued that the chosen alternative should have the shortest distance from the positive ideal solution (PIS) and the farthest one from the negative ideal solution (NIS). As the QoS dimensions are categorized into positive and negative dimensions in Section 2.1, in this step, the PIS and NIS employed in TOPSIS could be specified as follows:

**-- Positive ideal Solution (PIS):** The QoS value of this point achieves the user’s largest satisfaction degree based on the $RQ$. In PIS, the value of positive QoS dimension is the maximum one that meets the user’s QoS constraint, while the value of negative QoS dimension is the minimum one that meets the user’s QoS constraint.

**-- Negative Ideal Solution (NIS):** The QoS values of this point achieves the user’s lowest satisfaction degree based on the $RQ$. In NIS, the value of positive QoS is the minimum one that meets the user’s QoS constraint, while the value of negative QoS dimension is the minimum one that meets the user’s QoS constraint.

With the derived $PIS$ and $NIS$, the satisfaction degree of each candidate service could be calculated by $SD = (d^+ / d^-)$, where $d^+$ represents the distance between the service’s quality and $NIS$, $d^-$ represents the distance between the service’s quality and $PIS$. Thus the processes of computing the credibility of negotiable dimensions about a candidate $S$, could be specified as follows.

**i)** Compute the quantity of executions that a user concerns in execution log of service $S_i$. For each item of execution log, i.e., $E_{i}$ with $1 \leq i \leq K$, $TF(E_{i})$ is used to indicate whether a service can satisfy the user’s constraints on negotiable QoS dimensions. The value of $TF(E_{i})$ is true or false, and can be calculated by formula $TF(E_{i}) = \bigcap_{x_{i,n} = q_r} x_{i,n}$. If $TF(E_{i}) = \text{true}$, then mark this item of execution log and the value of Count increases by one. The variable Count presents the number of execution records that satisfy request $RQ$ and its initial value is 0. For comparing with other candidate services, the following formula is utilized to scale Count: $C_{\alpha} = Count / \max \{Count_1, Count_2, ..., Count_i\}$, where $L$ represents the number of candidate services.

**ii)** Evaluate the quality of the executions that a user concerns. The average QoS value of the marked items is calculated in execution log. Suppose that $AVG_{i}$ is expressed as the average value, then $AVG_{i} = (a_{q_{N+1}}, ..., a_{q_{N+M}})$, and $\text{Avg}_n = (\sum_{i=1}^{N} A_{i,n}) / \text{Count}$, for $TF(E_{i}) = \text{true}$ and $\text{Count} \neq 0$. In order to evaluate the degree that indicates how much the quality of average QoS values satisfies users’ constraints, the TOPSIS method is employed. With this method, the quality of ever occurred execution that the user concerned can be evaluated. Besides, the credibility can be
scaled into the range of [0, 1]. According to the descriptions and calculations of \( PIS, NIS \) and \( AVG_i \), each of them is an \( M \)-dimensional vector. The credibility \( Q \) of quality for service \( S_i \) can be calculated by (2)-(4), where \( DIST_{ij} \) is expressed as the scaled Euclidean distance between the points in \( M \)-dimensional space. Here, \( d(AVG_i, NIS(x)) \) and \( d(AVG_i, PIS(x)) \) are scaled Euclidean distances of \( AVG_i \) from \( NIS \) and \( PIS \) with respect to \( x\)-th dimension.

\[
Q = \frac{\text{DIST}(AVG_i, NIS)}{\text{DIST}(AVG_i, NIS) + \text{DIST}(AVG_i, PIS)} \quad (2)
\]

\[
\text{DIST}(AVG_i, NIS) = \left( \sum_{n=1}^{N} d(AVG_i, NIS(x)) \right)^{1/2} \quad (3)
\]

\[
\text{DIST}(AVG_i, PIS) = \left( \sum_{n=1}^{N} d(AVG_i, PIS(x)) \right)^{1/2} \quad (4)
\]

\( t \) is the index of \( x \)-th dimension.

iii) Calculate the credibility of negotiable QoS dimensions of candidate service \( S_i \), \( C_{q} \) and \( Q \) have already been calculated above, where \( C_i \) denotes the quantity of executions that satisfy the user’s constraints, and \( Q \) expresses the satisfaction degree of the quality. Then the credibility of negotiable QoS dimensions \( C_{neg}(S_i) \) can be calculated with SAW (Simple Additive Weight) \([10]\), i.e.,

\[
C_{neg}(S_i) = \alpha C_i + \beta Q_i \quad (5)
\]

where \( C_i \) denotes the quantity of executions that satisfy the user’s constraints, and \( Q_i \) expresses the satisfaction degree of the quality.

\[ i \] is the index of \( C \) and \( Q \) is the index of \( Q \).

\[
\text{Credibility}(S_i) = \sum_{w=1}^{M} C_{q}(S_i) + \sum_{w=1}^{M} C_{neg}(S_i) \quad (6)
\]

Since the computation of credibility is based on execution history, the service selected by our method holds the largest probability of satisfying user constraints. If no candidate service satisfies the user’s constraints, the failure information will be returned to the user for relaxations of QoS constraints.

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**Step4:** Web service selection based on credibility evaluation

The final credibility of service \( S_i \) can be computed, by synthesizing the negotiable QoS and nonnegotiable QoS dimensions with SAW method. It is supposed that the preferences on QoS dimensions could be transformed into corresponding weights \([5]\), i.e., \( W = (w_1, w_2, \ldots, w_M) \) with \( w_1 + w_2 + \ldots + w_M = 1 \). So, according to (1) and (5), the final Credibility(\( S_i \)) of service \( S_i \) can be computed by the formula (6). The algorithm of computing the credibility of candidate services is proposed in Fig.2. Among all the candidate services, the service with the highest value of credibility is selected, denoted as \( S_i \), i.e., \( \text{Credibility}(S_i) \geq \text{Credibility}(S_j) \), where \( 1 \leq i \leq L \).

**Fig.2 Algorithm of computing the credibility of services**

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**IV. A CASE STUDY**

In this section, a case study is discussed to demonstrate the process of our proposed method. It is supposed there are three candidate services for the task. Then the process of service selection using our method is demonstrated step by step as follows.

**Step1: Data preparation**

In our case, we just consider two nonnegotiable QoS dimensions, i.e., \( q_1 = \) successful execution rate and \( q_2 = \) reputation, and three negotiable QoS dimensions, i.e., \( q_3 = \) price, \( q_4 = \) availability and \( q_5 = \) execution time. Usually, the user will give not only the QoS constraints but also the preferences on each QoS dimension. Suppose the service request constraints on QoS and the weights are proposed in TABLE II.

<table>
<thead>
<tr>
<th>QoS Dimension</th>
<th>Weight</th>
<th>Constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Successful Rate</td>
<td>0.90</td>
<td>≥ 0.90</td>
</tr>
<tr>
<td>Reputation</td>
<td>0.95</td>
<td>≥ 0.95</td>
</tr>
<tr>
<td>Price</td>
<td>0.80</td>
<td>≤ 0.80</td>
</tr>
<tr>
<td>Availability</td>
<td>0.75</td>
<td>≥ 0.75</td>
</tr>
</tbody>
</table>

Extract the QoS information from service execution log of these three candidate services, named \( S_1, S_2, \) and \( S_3 \). It is supposed there are eight execution records for each candidate service and the QoS values are proposed in TABLE III.

**Step2: The credibility of nonnegotiable QoS dimensions**

The credibility of nonnegotiable QoS dimensions is computed by (1) and the result is illustrated in TABLE IV. For example, \( C_{q_1}(S_i) = \frac{1}{8}(0.90 + 0.95 + 0.80 + 0.75 + 0.90 + 0.60 + 0.95 + 0.95)/8 = 0.85 \). As the constraint on successful rate in request \( R_Q \) is \([0.8, 1]\) and \( 0.75 \notin [0.8, 1] \), service \( S_1 \) is abandoned.
According to the description of TABLE II.

<table>
<thead>
<tr>
<th>Log index</th>
<th>$q_1$</th>
<th>$q_2$</th>
<th>$q_3$</th>
<th>$q_4$</th>
<th>$q_5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1-1</td>
<td>T</td>
<td>0.90</td>
<td>10</td>
<td>0.8</td>
<td>5</td>
</tr>
<tr>
<td>S1-2</td>
<td>T</td>
<td>0.95</td>
<td>15</td>
<td>0.95</td>
<td>4.1</td>
</tr>
<tr>
<td>S1-3</td>
<td>T</td>
<td>0.80</td>
<td>12</td>
<td>0.9</td>
<td>4.5</td>
</tr>
<tr>
<td>S1-4</td>
<td>T</td>
<td>0.75</td>
<td>10</td>
<td>0.8</td>
<td>5.2</td>
</tr>
<tr>
<td>S1-5</td>
<td>T</td>
<td>0.90</td>
<td>12</td>
<td>0.85</td>
<td>4.2</td>
</tr>
<tr>
<td>S1-6</td>
<td>F</td>
<td>0.60</td>
<td>12</td>
<td>0.9</td>
<td>9.0</td>
</tr>
<tr>
<td>S1-7</td>
<td>T</td>
<td>0.95</td>
<td>15</td>
<td>0.95</td>
<td>4.0</td>
</tr>
<tr>
<td>S1-8</td>
<td>T</td>
<td>0.95</td>
<td>10</td>
<td>0.8</td>
<td>4.6</td>
</tr>
<tr>
<td>S2-1</td>
<td>T</td>
<td>0.85</td>
<td>13</td>
<td>0.85</td>
<td>4.7</td>
</tr>
<tr>
<td>S2-2</td>
<td>T</td>
<td>0.90</td>
<td>15</td>
<td>0.90</td>
<td>4.4</td>
</tr>
<tr>
<td>S2-3</td>
<td>T</td>
<td>0.95</td>
<td>18</td>
<td>0.95</td>
<td>4.2</td>
</tr>
<tr>
<td>S2-4</td>
<td>T</td>
<td>0.75</td>
<td>13</td>
<td>0.85</td>
<td>5.2</td>
</tr>
<tr>
<td>S2-5</td>
<td>T</td>
<td>0.80</td>
<td>18</td>
<td>0.95</td>
<td>4.0</td>
</tr>
<tr>
<td>S2-6</td>
<td>T</td>
<td>0.95</td>
<td>15</td>
<td>0.85</td>
<td>4.4</td>
</tr>
<tr>
<td>S2-7</td>
<td>T</td>
<td>0.80</td>
<td>13</td>
<td>0.80</td>
<td>5.1</td>
</tr>
<tr>
<td>S2-8</td>
<td>F</td>
<td>0.60</td>
<td>15</td>
<td>0.9</td>
<td>10</td>
</tr>
<tr>
<td>S3-1</td>
<td>T</td>
<td>0.90</td>
<td>13</td>
<td>0.85</td>
<td>4.2</td>
</tr>
<tr>
<td>S3-2</td>
<td>T</td>
<td>0.90</td>
<td>11</td>
<td>0.8</td>
<td>5</td>
</tr>
<tr>
<td>S3-3</td>
<td>F</td>
<td>0.60</td>
<td>15</td>
<td>0.95</td>
<td>8.0</td>
</tr>
<tr>
<td>S3-4</td>
<td>T</td>
<td>0.80</td>
<td>13</td>
<td>0.85</td>
<td>4.3</td>
</tr>
<tr>
<td>S3-5</td>
<td>T</td>
<td>0.90</td>
<td>16</td>
<td>0.95</td>
<td>4.0</td>
</tr>
<tr>
<td>S3-6</td>
<td>T</td>
<td>0.80</td>
<td>15</td>
<td>0.9</td>
<td>5.0</td>
</tr>
<tr>
<td>S3-7</td>
<td>T</td>
<td>0.75</td>
<td>13</td>
<td>0.85</td>
<td>4.1</td>
</tr>
<tr>
<td>S3-8</td>
<td>F</td>
<td>0.60</td>
<td>11</td>
<td>0.8</td>
<td>10</td>
</tr>
</tbody>
</table>

Step3: The credibility of negotiable QoS dimensions

Then compute the credibility of negotiable QoS dimensions by formula (2)-(4), suppose $\alpha = 0.3$ and $\beta = 0.7$. According to the description of $PIS$, $NIS$, and $PIS = (10,1,3)$ and $NIS = (15,0.85,5)$. The intermediate result and the credibility of negotiable dimensions are proposed in TABLE V. Take service $S_1$ for example, the calculation processes is deduced as follows: execution log S1-2, S1-3, S1-5 and S1-7 cover the user’s QoS constraints, so $Count_i = 4$ $C_i = 4/\max \{4,3\} = 1$ $AVG_{q_1}(q_1) = (15 + 12 + 15 + 12)/4 = 13.5$ $AVG_{q_2}(q_2) = (0.95 + 0.9 + 0.85 + 0.95)/4 = 0.9125$ $AVG_{q_3}(q_3) = (4.1 + 4.5 + 4.2 + 4.0)/4 = 4.2$ $DIST(AVG_{q_1}, NIS) = 0.651$ $DIST(AVG_{q_2}, PIS) = 1.091$ $Q_i = DIST(AVG_{q_1}, NIS) [DIST(AVG_{q_1}, NIS) + DIST(AVG_{q_2}, PIS)]$ $= 0.651/(0.651 + 1.091) = 0.374$ $C_{neg}(S_1) = 0.3 \times 1.0 + 0.7 \times 0.374 = 0.5618$ $Step4$: Web service selection based on credibility evaluation

The final credibility of each candidate service can be calculated according to formula (6) as follows. After the credibility of service $S_1$ and $S_2$ are computed, service $S_1$ will be selected finally as $Credibility(S_1) > Credibility(S_2)$ (i.e., $0.6847 > 0.4938$) holds.

$Credibility(S_1) = 0.3 \times 0.875 + 0.1 \times 0.825 + 0.6 \times 0.39 = 0.4938$

$Credibility(S_2) = 0.3 \times 0.875 + 0.1 \times 0.85 + 0.6 \times 0.6 = 0.6847$

V. Evaluation

A. Complexity Analyses

It is assumed that $N$ nonnegotiable QoS dimensions and $M$ negotiable QoS dimensions are considered, and there are $K$ pieces of execution log for each candidate service. For a service, the credibility of nonnegotiable dimensions is computed separately and each piece of execution log is used once, so the time cost is $O(N \times K)$. In computing the credibility of negotiable dimensions, the number of executions that satisfies the user’s requirement is accounted and the average quality is computed. As the data is accessed in finite times, the time cost is $O(M \times K)$. Let $L$ be the number of candidate services. The complexity of the algorithm for computing credibility of all candidate services proposed in this paper is $O(L \times I \times K)$, with $I = N+M$. The service with the highest credibility is selected based on credibility evaluation, its time cost is $O(L)$. According to these analyses, the time cost for our method is $O(L \times I \times K)$.

B. Related Work and Comparison Analyses

The issue of web service evaluation has been widely investigated and researched in the fields of web service selection and service composition. Generally, service selection is driven by user’s functional requirements. Recently, as many services may share identical or overlapping functionality, increasing interest has been devoted toward user’s nonfunctional requirements, i.e., QoS [3-6]. For instance, Marco Comuzzi, et al. [3] provided a QoS model, which aimed at the service contract specification and establishment in automation. L. Zeng, et al. [7], proposed a quality model and a mechanism for service selection based...
on multi-attribute utility theory, which were addressed for selecting web service by maximizing users’ satisfaction degree expressed as utility functions over QoS dimensions. An automated service selection model is presented in literature [11], based on expectancy-disconfirmation theory derived from market science. The trustworthiness of service providers is commonly measured by their reputations, and the reputation tends to rely on users’ ratings of past service experiences [3, 6]. However, this might create some issues, in terms of subjectivity and rating unfairness. N. Limam and R. Boutaba proposed a framework in literature [11] for reputation-aware software service selection and rating, which is essential to compute reputation on the basis of fair and objective feedbacks.

To our best knowledge, most service selection methods are based on the QoS information published by the service providers and reputation of the providers. The QoS information of a service may be variable and random, meaning it can only be determined after execution, e.g., execution time. And the credibility of the QoS information offered by service providers is usually not taken into consideration in some previous work. Besides, many approaches neglect the fact that some QoS dimensions have some underlying correlations.

Given the problems discussed above, a criterion named credibility is proposed to evaluate the quality of a service and the degree of satisfaction of a service requestor. Besides, an algorithm is proposed to calculate the credibility of a candidate service on the negotiable and nonnegotiable dimensions respectively. As different users usually have different QoS requirements, it is inappropriate and unreasonable to compute the credibility of services based on the potentially unfair and subjective users’ feedbacks. In our method, the calculation of services’ credibility is mainly based on the requestors’ special QoS requirements and the execution log, which is more credible to describe the trustworthiness of these services. More specifically, the correlations of some QoS dimensions are taken into account, and the SAW technique and TOPSIS method are adopted for service selection, i.e., a multi-criteria decision making problem. The web service selection method based on credibility evaluation is proved to be feasible and efficient by the case study stated in last section and complexity analyses.

C. Further Discussions

In order to select a credible and qualified web service for a user, a concept of credibility is defined in this paper. Based on credibility, a QoS-aware service selection method is put forward to evaluate and rank all the functional qualified candidates. Since the credibility score of a service is abstracted from its historical execution log, the evaluation results based on credibility could reflect the actual quality level of a candidate service, as much as possible.

However, there are still some limitations. Firstly, the execution log is hard to be captured, as users may have not much incentive to give their feedback after service execution. Secondly, a newly published service may have no historical execution records, which makes it difficult to calculate the credibility of the service. We will investigate these more complicated situations as our future research topics.

VI. Conclusions

In this paper, we put forward a QoS-aware web service selection method based on credibility evaluation. Firstly, the credibility of different QoS dimensions are computed in different methods, according to the correlation of some dimensions and the user’s special service request. Then the aggregated credibility of each candidate service is calculated with the SAW technique, and the service with the highest credibility is chosen. At last, the feasibility of our selection method is validated by a case study. The more real-life experiments and applications are under way in our future research.

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