Cross-organizational Collaborative Web Service Composition Method Based on Local Quality Constraint Resolution

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Abstract
To achieve the reliability and real-time of service selection and composition with complex business constraints, a cross-organizational collaborative web service composition method based on local quality constraint resolution is proposed. The method calculates the quality levels of independent QoS (Quality of Service) attributes of candidate services, and chooses high-quality web services with balanced attribute values by matching the dynamic local ideal constraints step-by-step. A global dynamic service composition optimization model is established to solve the approximate optimal composite service based on global constraints of users. Experimental results based on simulated data sets have shown that the method proposed can improve the quality balance of the selected atomic services, provides users with the approximate optimal composite service, and has lower time cost.

Key words: Quality of Service, Service Composition, Constraint Resolution, Cross-organization Collaboration.

1. INTRODUCTION
Service-oriented computing provides organizations with the opportunity to find high-quality partners, and can compose various business applications into new value-added services. The organizations can publish web services representing their business on the service platform; and also find web services that can meet their requirements. The service platform realizes the matching and composition of web services through many forms of negotiation processes (Tao et al., 2013). For the cross-organizational collaboration, it is necessary to rapidly select high-quality web services satisfying user constraints from many candidate services with the same function and different quality of service, and achieve the optimal service composition. Recently, the study on effective service selection and composition method of cross-organizational collaboration has become an important issue.

QoS-aware web service composition problem can be converted to a single-objective or multi-objective optimization problem with QoS constraints (Alrifai, Risse, and Nejdl, 2012). Genetic algorithm, particle swarm optimization algorithm and their improved algorithms (Mardukhi et al., 2013; Liu et al., 2016; Wang et al., 2013) have been used to solve the problem. The goals of efficiency, quality and trustworthy are achieved by introducing some methods, such as Skyline query (Yu and Bouguettaya, 2013), trusted service quality measurement (Wu et al., 2013), weight assignment model (Li, Liu, and Cheng, 2015). For the domain-oriented service composition, a logistics QoS extension model is established with technology, logistics and user feedback as the first layer indicators (Huang, Wang, and Xue, 2012), and the hierarchical clustering algorithm and fuzzy comprehensive evaluation method are adopted to select the logistics web services. A comprehensive QoS evaluation model including general technology attributes and domain attributes is used for the service composition in supply chain (Moser, Rosenberg, and Dustdar, 2011). Most of the existing service selection methods do not consider a variety of government standards and industry standards of real business operation. Organizations use business knowledge and search ideal partners to establish collaborative network. The effective cross-organizational collaboration needs a more reliable and flexible service composition method.

The cross-organizational collaborative web service composition method based on local quality constraint resolution (LQCR method for short) is proposed in this paper. The local quality constraint of independent QoS attributes is divided into two levels: local ideal constraint and local standard constraint; the two levels are further divided into more levels using the quality levels calculated. The desired high-quality services are selected by the step-by-step resolution from local ideal constraint to local standard constraint. Based on reduced candidate service space, the mixed integer programming model is used to solve the approximately optimal composite service that has equilibrium QoS values and satisfy global constraints.

2. PROBLEM DESCRIPTIN
For the cross-organizational collaborative web service selection and composition, the concepts of three-layer QoS attributes and the corresponding constraints, weights are defined and described as follows:
(1) Task

\[ TK = \{tk_1, ..., tk_i, ..., tk_n\} (1 \leq i \leq n) \] represents a set of n tasks in the cross-organizational collaboration process, and these tasks belong to multiple organizations.

(2) Multi-layer QoS attribute of web services

\[ CRA = \{cr_{a1}, ..., cr_{a_k}, ..., cr_{at}\} (1 \leq a \leq k) \] represents a set of the first layer QoS attributes. The attributes represent the dimension of their subordinate attributes; nine dimensions can meet the demands of cross-organizational collaboration, the \( ws \cdot cr \) represents the attribute \( cr \) value of web service \( ws \).

\[ CRB = \{cr_{ab}, ..., cr_{abc}, ..., cr_{abt}\} (1 \leq b \leq y) \] represents a set of direct and subordinate attributes of the attribute \( cr_{ab} \). Each of the first layer attributes can have not more than nine direct and subordinate attributes. The \( ws \cdot cr \) represents the attribute \( cr \) value of web service \( ws \).

\[ CRC = \{cr_{ab}, ..., cr_{abc}, ..., cr_{abc}\} (1 \leq t \leq t) \] represents a set of direct and subordinate attributes of the attribute \( cr_{abc} \), \( t \) represents the number of direct and subordinate attributes of the attribute \( cr_{abc} \).

Each of the first layer QoS attributes have subordinate attributes. Whether or not each of the second layer QoS attributes has subordinate attributes depends on business requirements. The values of the third layer QoS attributes depends on business requirements. The values of the third layer QoS attributes without subordinate attributes are independent of the aggregation calculation of other attribute values, these attributes are called independent QoS attributes. The second layer attributes without subordinate attributes are represented with \( cr_{abc} \); the third layer attributes which represented with \( cr_{abc} \) are all independent QoS attributes. In this paper, both global constraints and local constraints are constraints that may be set only for independent QoS attributes.

(3) Global constraint

\[ \text{MINCONS}_{global}^{B} = \{\text{min cons}_{a1}, ..., \text{min cons}_{ab}, ..., \text{min cons}_{at}\} \] represents a global constraint set of direct and subordinate attributes of the composite service attribute \( cr_{a} \), \( \text{min cons}_{ab} \) represents the global constraint value of the second layer attribute \( cr_{ab} \) of composite services. If the attribute \( cr_{ab} \) is an independent QoS attribute without constraint or a non-independent QoS attribute, the value of \( \text{min cons}_{ab} \) is null.

\[ \text{MINCONS}_{global}^{C} = \{\text{min cons}_{a1}, ..., \text{min cons}_{abc}, ..., \text{min cons}_{abc}\} \] represents a global constraint set of direct and subordinate attributes of the composite service attribute \( cr_{abc} \). If the attribute \( cr_{abc} \) is an independent QoS attribute without constraint or a non-independent QoS attribute, the value of \( \text{min cons}_{abc} \) is null.

(4) Local ideal constraint and local standard (minimum) constraint

\[ \text{CONSB} = \{\text{cons}_{a1}, ..., \text{cons}_{ab}, ..., \text{cons}_{at}\} \] represents an ideal constraint set of the direct and subordinate attributes of the task \( tk \) candidate service attribute \( cr_{a} \).

\[ \text{CONSC} = \{\text{cons}_{ab}, ..., \text{cons}_{abc}, ..., \text{cons}_{abc}\} \] represents an ideal constraint set of the direct and subordinate attributes of the task \( tk \) candidate service attribute \( cr_{ab} \).

\[ \text{MINCONS}_{B} = \{\text{min cons}_{a1}, ..., \text{min cons}_{ab}, ..., \text{min cons}_{at}\} \] represents a standard constraint set of the direct and subordinate attributes of the task \( tk \) candidate service attribute \( cr_{a} \). The \( \text{min cons}_{ab} < \text{cons}_{ab} \) represents that the standard constraint of \( cr_{ab} \) is within its ideal constraint.

\[ \text{MINCONS}_{C} = \{\text{min cons}_{a1}, ..., \text{min cons}_{abc}, ..., \text{min cons}_{abc}\} \] represents a standard constraint set of the direct and subordinate attributes of the task \( tk \) candidate service attribute \( cr_{abc} \). The \( \text{min cons}_{abc} < \text{cons}_{abc} \) represents that the standard constraint of \( cr_{abc} \) is within its ideal constraint.

(5) Global weight

\[ \text{WGTA}_{global} = \{w_{1}, ..., w_{i}, ..., w_{j}\} \left( \sum_{a=1}^{n} w_{a} = 1 \right) \text{\( w_{a} \geq 0 \)} \] represents a set of weight values of the first layer QoS attributes of composite services. The \( w_{a} \) represents the weight value of the composite service attribute \( cr_{a} \).
satisfying global constraints fast and reliably. The composite service selection problem. The purpose is to get the approximate services selected is new candidate service space, and the mixed integer programming model is used to solve the problem to obtain the new reliable candidate service space. The purpose is to select the composite service, which has the maximum or near maximum QoS utility and independent QoS attributes with the dynamic quality constraints step-by-step.

Gradually levels by the average discretization of major range of each independent QoS attribute value. The purpose is to

requirements and has low time complexity, which is divided into three stages.

The first stage is the quality level calculation of candidate services. Statistically determine the major range of each task has the same number of candidate services

WEB SERVICE COMPOSITION METHOD BASED ON LOCAL CONSTRAINT RESOLUTION

The key of the cross-organizational collaboration web service composition problem based on local quality constraints is to select the composite service, which has the maximum or near maximum QoS utility and satisfies local and global constraints. This paper proposes the LQCR method which takes into account domain requirements and has low time complexity, which is divided into three stages.

The first stage is the quality level calculation of candidate services. Statistically determine the major range of each independent QoS attribute value of the task \( tk_i \) candidate services, and obtain multiple discrete quality levels by the average discretization of major range of each independent QoS attribute value. The purpose is to gradually resolute quality constraints when candidate services do not satisfy local ideal constraints.

The second stage is the selection of a limited number of ideal web services. Match the attribute values of independent QoS attributes with the dynamic quality constraints step-by-step, and the limited number of web services with the larger aggregate utility value will be selected from the candidate service space. The purpose is to obtain the new reliable candidate service space.

The third stage is the selection of the approximate optimal composite service. The set of high-quality web services selected is new candidate service space, and the mixed integer programming model is used to solve the composite service selection problem. The purpose is to get the approximate optimal composition service satisfying global constraints fast and reliably.

\[
WGTB_{global} = \left\{ w_{a,1}, \ldots, w_{a,k}, \ldots, w_{a,r} \right\} \left( \sum_{i=1}^{r} w_{a,i} = 1 \right) \left( w_{a,i} \geq 0 \right), \text{ represents a set of weight values of the direct and subordinate attributes of the composite service attribute } cr_a. \text{ The } w_{a,i} \text{ represents the weight value of the composite service attribute } cr_{ab}.
\]

\[
WGTB_{global} = \left\{ w_{ab,1}, \ldots, w_{ab,k}, \ldots, w_{ab,l} \right\} \left( \sum_{i=1}^{l} w_{ab,i} = 1 \right) \left( w_{ab,i} \geq 0 \right), \text{ represents a set of weight values of the direct and subordinate attributes of the composite service attribute } cr_{ab}. \text{ The } w_{ab,i} \text{ represents the weight value of the composite service attribute } cr_{abc}.
\]

(6) Local weight

\[
WGTB_i = \left\{ w_{i,1}^{a}, \ldots, w_{i,k}^{a}, \ldots, w_{i,r}^{a} \right\} \left( \sum_{i=1}^{r} w_{i,i}^{a} = 1 \right) \left( w_{i,i}^{a} \geq 0 \right), \text{ represents a set of weight values of the direct and subordinate attributes of the task } tk_i \text{ candidate service attribute } cr_a \text{ of the task } tk_i \text{ candidate services.}
\]

\[
WGTB_i = \left\{ w_{i,1}^{ab}, \ldots, w_{i,k}^{ab}, \ldots, w_{i,r}^{ab} \right\} \left( \sum_{i=1}^{r} w_{i,i}^{ab} = 1 \right) \left( w_{i,i}^{ab} \geq 0 \right), \text{ represents a set of weight values of the direct and subordinate attributes of the task } tk_i \text{ candidate service attribute } cr_{ab} \text{ of the task } tk_i \text{ candidate services.}
\]

\[
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\]

(7) The candidate service pool

\[
WSpool_i = \left\{ ws_i, \ldots, ws_i^k, \ldots, ws_i^l \right\} \left( 1 \leq k \leq l \right), \text{ represents a set of function matching services of the task } tk_i \text{ candidate services, and obtain multiple discrete quality levels by the average discretization of major range of each independent QoS attribute value of the task } tk_i \text{ candidate services. } l \text{ represents the number of candidate services that meet the functional requirements of the task } tk_i. \text{ It is assumed that each task has the same number of candidate services.}
\]

(8) Composite service

\[
CS = \left\{ ws_i^k, \ldots, ws_i^{k-1}, \ldots, ws_i^1 \right\}, \text{ represents a composite service that meets the cross-organizational collaboration requirement, and } ws_i^k \text{ represents the } i \text{ candidate service in the service pool } WSpool_i.
\]

3. WEB SERVICE COMPOSITION METHOD BASED ON LOCAL CONSTRAINT RESOLUTION

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The first stage is the quality level calculation of candidate services. Statistically determine the major range of each independent QoS attribute value of the task \( tk_i \) candidate services, and obtain multiple discrete quality levels by the average discretization of major range of each independent QoS attribute value. The purpose is to gradually resolute quality constraints when candidate services do not satisfy local ideal constraints.

The second stage is the selection of a limited number of ideal web services. Match the attribute values of independent QoS attributes with the dynamic quality constraints step-by-step, and the limited number of web services with the larger aggregate utility value will be selected from the candidate service space. The purpose is to obtain the new reliable candidate service space.

The third stage is the selection of the approximate optimal composite service. The set of high-quality web services selected is new candidate service space, and the mixed integer programming model is used to solve the composite service selection problem. The purpose is to get the approximate optimal composition service satisfying global constraints fast and reliably.
3.1. Calculate the Quality Level of Candidate Services

The web service has many quality attributes, the unit or range of each attribute value is different. At the same time, the quality attributes can be divided into two types: positive attribute and negative attribute. The positive attribute considers the maximization of attribute value; the negative attribute considers the minimization of attribute value. To evaluate the attribute values of candidate services and composite services from the global optimum, we compare every QoS attribute value with corresponding maximum or minimum to normalize the attribute value, and each attribute value is converted into a real value (the range is [0, 1]). The literature (Xue, Liu, and Huang, 2013) gives the conversion formula that convert four data types of the numerical type, interval type, linguistic type and hierarchical type into the interval [0, 1]. The aggregate utility values of candidate services or composite services can be calculated by simple weighted method of standard data. In this paper, the negative attributes are converted into positive attributes through negative calculation (the attribute value multiplied by -1). To simplify the following discussion, suppose that the negative attributes of candidate services have been converted into positive attributes, and the local and global constraints of negative attributes have been negatively calculated.

For the candidate services of the task \( t_k \), use the statistical analysis method to determine the expectation \( \text{Exp}_{ab} \), variance \( \text{Var}_{ab} \), main range \([\min_{ab}, \max_{ab}]\) of the second layer independent QoS attribute \( c_{r_{ab}} \) value, as well as the expectation \( \text{Exp}_{abc} \), variance \( \text{Var}_{abc} \), main range \([\min_{abc}, \max_{abc}]\) of the third layer QoS attributes \( c_{r_{abc}} \) value. In normal distribution, the area of horizontal axis interval \([\mu-3\delta, \mu+3\delta]\) covered by the normal curve accounts for 99.9 percent of the whole area covered by the curve. When the values of the attributes \( c_{r_{ab}} \) and \( c_{r_{abc}} \) of the task \( t_k \), candidate services obey normal distribution, the value of \([\min_{ab}, \max_{abc}]\) is equal to \( \left[ \text{Exp}_{ab}-3\times\text{Var}_{ab}, \text{Exp}_{ab}+3\times\text{Var}_{ab} \right] \), and the value of \([\min_{abc}, \max_{abc}]\) is equal to \( \left[ \text{Exp}_{abc}-3\times\text{Var}_{abc}, \text{Exp}_{abc}+3\times\text{Var}_{abc} \right] \).

Multiple discrete quality levels \( \{q_{i_{ab}}, q_{i_{abc}}, \ldots, q_{i_{abc}^{\text{Max}}}\} \) \((1 \leq i \leq j_{ab})\) are obtained by the average discretization of the range \([\min_{ab}, \max_{ab}]\), \( q_{i_{ab}}^{\text{Max}} = \max_{ab} - (e-1) \times \frac{\max_{ab} - \min_{ab}}{j_{ab} - 1} \), and the quality levels form a large to small order. The difference between any two adjacent quality levels is called the quality level step of the independent QoS attribute \( c_{r_{ab}} \) of the task \( t_k \), candidate services, which is denoted as \( \text{step}_{i_{ab}} = q_{i_{ab}^{f+1}} - q_{i_{ab}^{f}} \).

Similarly, \( \{q_{i_{abc}}, q_{i_{abc}^{f+1}}, \ldots, q_{i_{abc}^{\text{Max}}}^{f+1}\} \) \((1 \leq f \leq j_{abc})\) are obtained by the average discretization of the range \([\min_{abc}, \max_{abc}]\), and \( q_{i_{abc}^{f+1}}^{\text{Max}} = \max_{abc} - (f-1) \times \frac{\max_{abc} - \min_{abc}}{f_{abc} - 1} \). The quality level step of attribute \( c_{r_{abc}} \) of the task \( t_k \), candidate services is denoted as \( \text{step}_{i_{abc}} = q_{i_{abc}^{f+1}} - q_{i_{abc}^{f}} \).

3.2. Select the Limited Number of Ideal Web Services

In cross-organizational collaborative environment, the collaboration quality expected by organizations is often higher than the socially mandatory or non-mandatory minimum limits. Filter out some unbalanced services with low quality attribute values, select web services of which each attribute value approaches or exceeds the desired level, and the composite services obtained are more likely to satisfy global quality constraints. To find the high-quality services approaching the desired level in candidate service space, this paper proposes local ideal constraint and local standard constraint of independent QoS attributes to reflect the constraint level of users. And the two constraint levels are divided into more levels by some quality levels calculated in the first stage. When the number of expected web services satisfying local ideal constraints is not enough, more web services are obtained through reducing local ideal constraint to local standard constraint step by step, rather than directly reducing local ideal constraint to local standard constraint.

The local quality constraints \( \text{cons}_{ab} \) and \( \text{min}\text{cons}_{ab} \) of which the values are not null, respectively represent local ideal constraint and local standard constraint of independent QoS attribute \( c_{r_{ab}} \) of the task \( t_k \), candidate services, and they are denoted as \([\text{cons}_{ab}, \infty]\) and \([\text{min}\text{cons}_{ab}, \infty]\) respectively. The symbol \( \infty \) indicates the possible maximum value of the QoS attribute \( c_{r_{ab}} \). For example, the possible maximum value of
success rate is 100 percent, so $\infty$ is 100 percent; the possible maximum value of financial condition is excellent, so $\infty$ is excellent. Similarly, $\min_{zwpool}^{abc}$ and $\max_{zwpool}^{abc}$ of which the values are not null, respectively represent local ideal constraint and local standard constraint of the third QoS attribute $cr_{abc}$ of the task $tk_i$ candidate services, and they are denoted as $[\min_{zwpool}^{abc}, \infty]$ and $[\max_{zwpool}^{abc}, \infty]$ respectively.

For the local quality constraint set $\text{CONSB}_s$, $\text{MINCONSB}_s$, $\text{CONSC}_s$, $\text{MINCONSC}_s$ of independent QoS attributes $cr_{ab}$ and $cr_{abc}$ of the task $tk_i$ candidate services, initialize the quality constraints of which the values are not null to $[\min_{zwpool}^{abc}, \infty]$, $[\min_{zwpool}^{abc}, \infty]$, $[\max_{zwpool}^{abc}, \infty]$, $[\max_{zwpool}^{abc}, \infty]$ respectively. If the values of attributes $cr_{ab}$ and $cr_{abc}$ of the candidate service $ws_i^k$ in the service pool $WSpool_i$ satisfy all local ideal constraints, namely, $ws_i^k, cr_{abc} \in [\min_{zwpool}^{abc}, \infty]$, $ws_i^k, cr_{abc} \in [\max_{zwpool}^{abc}, \infty]$, put $ws_i^k$ into the service pool $Zwspool_i = \{ws_i^1, ..., ws_i^z, ..., ws_i^p\} (1 \leq z \leq l)(1 \leq z_i \leq z)$.

When selecting web services from the service pool $Zwspool_i$, it is necessary to calculate the aggregate utility values of the non-independent QoS attributes $cr_{ab}$ and $cr_{abc}$ of the candidate service $ws_i^k$, and the aggregation utility value of the candidate service $ws_i^k$. Formula (1) represents the aggregate function of the non-independent QoS attribute $cr_{ab}$ with subordinate attributes, $\min_{ws}^{abc}$ represents the minimum value of independent QoS attribute $cr_{abc}$ of the web service $ws_i^k$, the $\max_{ws}^{abc}$ is the maximum value.

$$U\left( ws_i^k, cr_{ab} \right) = \sum_{i=1}^{\infty} w_i^{abc} \times \frac{ws_i^k, cr_{abc} - \min_{ws}^{abc}}{\max_{ws}^{abc} - \min_{ws}^{abc}}$$

(1)

With the advancement in networking and multimedia technologies enables the distribution and sharing of multimedia content widely. Because the attribute $cr_{ab}$ may or may not have subordinate attributes, there are three kinds of aggregate functions of the attribute $cr_{ab}$ which are represented as formula (2), (3) and (4) respectively. The $\min_{ws}^{ab}$ and $\max_{ws}^{ab}$ represent the minimum value of the attributes $cr_{ab}$ and $cr_{abc}$ of $ws_i^k$, respectively, $\max_{ws}^{ab}$ and $\min_{ws}^{ab}$ are the maximum values, and the attribute $cr_{abc}$ is non-independent attribute. In formula (5) and (6), $w_i^{ab}$ and $w_i^{abc}$ represent the weight value of attributes $cr_{ab}$ and $cr_{abc}$ respectively. The aggregate function of the candidate service $ws_i^k$ is represented as formula (7).

$$U\left( ws_i^k, cr_{ab} \right) = \sum_{i=1}^{\infty} w_i^{ab} \times \frac{ws_i^k, cr_{abc} - \min_{ws}^{ab}}{\max_{ws}^{ab} - \min_{ws}^{ab}}$$

(2)

$$U\left( ws_i^k, cr_{ab} \right) = \sum_{i=1}^{\infty} w_i^{abc} \times U\left( ws_i^k, cr_{ab} \right)$$

(3)

$$U\left( ws_i^k, cr_{ab} \right) = \sum_{i=1}^{\infty} w_i^{ab} \times \frac{ws_i^k, cr_{abc} - \min_{ws}^{ab}}{\max_{ws}^{ab} - \min_{ws}^{ab}} + \sum_{i=1}^{\infty} w_i^{abc} \times U\left( ws_i^k, cr_{abc} \right)$$

(4)

$$\sum_{i=1}^{\infty} w_i^{ab} + \sum_{i=1}^{\infty} w_i^{abc} = 1$$

(5)

$$0 \leq w_i^{ab}, w_i^{abc} \leq 1$$

(6)

$$U\left( ws_i^k \right) = \sum_{i=1}^{\infty} w_i^{ab} \times U\left( ws_i^k, cr_{ab} \right)$$

(7)

If $1 \leq g \leq z$, $g$ web services with larger aggregate utility value can be selected from $Zwspool_i$, and put into the high-quality service pool $HQwspool_i = \{ws_i^1, ..., ws_i^x, ..., ws_i^p\} (1 \leq p \leq g)$.

Since the local ideal constraints are set in advance of the service selection process, the QoS attribute values that users expect may be larger than actual attribute values, the task $tk_i$ candidate services in the service pool

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Another exception is that the number of web services satisfying local ideal constraints is less than the number required, namely, \( z < g \). This paper proposes a step-by-step resolution method of local quality constraints to select the limited number of web services that have larger QoS attribute values and aggregate utility value.

(1) The conditions and actions of local ideal constraint resolution of independent QoS attributes

For each independent QoS attribute \( cr_{ab} \) of the task \( t_k \) candidate services, the conditions of local ideal constraint resolution are as follows:

\[
\begin{align*}
1) & \quad \left\{ \begin{array}{l}
\text{cons}^{ab}_i, \min \text{cons}^{ab}_i \neq \text{null}, \\
q^{ab}_i < \text{cons}^{ab}_i, \\
\min \text{cons}^{ab}_i \leq q^{ab}_i.
\end{array} \right. \\
2) & \quad \left\{ \begin{array}{l}
\text{cons}^{ab}_i, \min \text{cons}^{ab}_i \neq \text{null}, \\
q^{ab}_i < \text{cons}^{ab}_i \leq q^{ab}_{i-1} (2 \leq e \leq j_{ab}), \\
\min \text{cons}^{ab}_i \leq q^{ab}_i.
\end{array} \right.
\]

When the condition 1) is satisfied, resolve the local ideal constraint of the attribute \( cr_{ab} \), and the result is \( \text{cons}^{ab}_i = q^{ab}_i \). When the condition 2) is satisfied, resolve the local ideal constraint of the attribute \( cr_{ab} \), and the result is \( \text{cons}^{ab}_i = q^{ab}_i \). In either case, a new set \( \text{CONSB}^*_i \) of local quality constraints is obtained.

For each independent QoS attribute \( cr_{abc} \) of the task \( t_k \) candidate services, the conditions of local ideal constraint resolution are as follows:

\[
\begin{align*}
3) & \quad \left\{ \begin{array}{l}
\text{cons}^{abc}_i, \min \text{cons}^{abc}_i \neq \text{null}, \\
q^{abc}_i < \text{cons}^{abc}_i, \\
\min \text{cons}^{abc}_i \leq q^{abc}_i.
\end{array} \right. \\
4) & \quad \left\{ \begin{array}{l}
\text{cons}^{abc}_i, \min \text{cons}^{abc}_i \neq \text{null}, \\
q^{abc}_i < \text{cons}^{abc}_i \leq q^{abc}_{i-1} (2 \leq f \leq j_{abc}), \\
\min \text{cons}^{abc}_i \leq q^{abc}_i.
\end{array} \right.
\]

When the condition 3) is satisfied, resolve the local ideal constraint of the attribute \( cr_{abc} \), and the result is \( \text{cons}^{abc}_i = q^{abc}_i \). When the condition 4) is satisfied, resolve the local ideal constraint of the attribute \( cr_{abc} \), and the result is \( \text{cons}^{abc}_i = q^{abc}_i \). In either case, a new set \( \text{CONSC}^*_i \) of local quality constraints is obtained.

(2) Resolve local ideal constraints when \( z = 0 \)

When any one of the condition 1), condition 2), condition 3) and condition 4) is satisfied, perform the corresponding resolution and obtain the new local constraint sets ( \( \text{CONSB}^*_i \) and \( \text{CONSC}^*_i \)). Let \( \text{CONSB} = \text{CONSB}^*_1, \text{CONSC} = \text{CONSC}^*_1 \), select ideal web services based on the updated local ideal constraint sets.

If all of the condition 1), condition 2), condition 3) and condition 4) are not satisfied, the web services satisfying local constraints cannot be selected, and the service composition failed.

(3) Resolve local ideal constraints when \( 0 < z < g \)

If there are \( z \) web services satisfying current local ideal constraints, they will be put into the service pool \( \text{Zwspool}_i \). At the same time, mark the corresponding web services in the service pool \( \text{WSpool}_i \) as selected, and update the value of variable \( g \), let \( g = g - z \).

When any one of the condition 1), condition 2), condition 3) and condition 4) is satisfied, perform the corresponding resolution, and let \( \text{CONSB} = \text{CONSB}^*_i, \text{CONSC} = \text{CONSC}^*_i \). Based on the updated local ideal constraint sets, select ideal web services from unselected web services in the service pool \( \text{WSpool}_i \). When all of condition 1), condition 2), condition 3) and condition 4) are not satisfied, put the current web services in the service pool \( \text{Zwspool}_i \) into the high-quality service pool \( \text{HQwspool}_i \).

3.3. Select The Approximate Optimal Composite Service

In the cross-organizational collaboration environment, the quality attributes can be divided into common attributes and domain attributes. According to the corresponding service composition type, such as order, probability, cycle, etc., the independent QoS attribute values of composite services can be obtained by aggregating the attribute values of single web service. Different service composition types can be converted to the sequence type (Wang, Zhu, and Yang, 2014), this paper only discusses the sequence service combination type. When calculating QoS attribute values of composite services, some attributes (such as response time, delivery period, drug residue, etc.) adopt the summation method, the aggregation function of the reaction time is \( \text{CS.price} = \sum_{i=1}^{m} \text{price}_i \); some attributes (such as reliability, availability, etc.) adopt the quadrature method, the
aggregation function of reliability is \( CS_{\text{reliability}} = \prod_{i=1}^{n} \text{reliability}_i \); some attributes (such as financial situation, supply quantity, natural environment pollution, etc.) adopt the minimum method, the aggregation function of financial situation is \( CS_{\text{finance}} = \min_{i=1}^{n} \text{finance}_i \).

The web services (at least 1, up to \( g \)) in HQwspool are new candidate service space of the task \( t_k \), each time one web service is selected from HQwspool to participate in service composition. The maximization of aggregate utility value of composite services is the objective function, the user global constraints (\([\min_{a_b}^{cons_{ab}}, \infty]\) and \([\min_{a_b}^{cons_{ab}}, \infty]\)) of the independent QoS attributes of composite services are the constraints, and the composite service selection problem is converted to a mixed integer programming problem represented with formula (8) - (19).

\[
\text{max} \sum_{a=1}^{r} w_a \times U(CS.cr_a) \tag{8}
\]

\[
\text{s.t.}
\]

\[
U(CS.cr_a) = \sum_{h=1}^{r} w_{a_h} \times \frac{CS.cr_{a_h} - \min_{a_h}}{\max_{a_h} - \min_{a_h}} \tag{9}
\]

\[
U(CS.cr_a) = \sum_{b=1}^{r} w_{a_b} \times U(CS.cr_{ab}) \tag{10}
\]

\[
U(CS.cr_{ab}) = \sum_{c=1}^{r} w_{a_bc} \times \frac{CS.cr_{abc} - \min_{abc}}{\max_{abc} - \min_{abc}} \tag{14}
\]

\[
CS.cr_{ab} = \text{Comp}^* \left( \sum_{p=1}^{g} w_{a_p} \times r_{a_p} \times r_{cr_{ab}} \right) \tag{15}
\]

\[
CS.cr_{abc} = \text{Comp}^* \left( \sum_{p=1}^{g} w_{a_p} \times r_{a_p} \times r_{cr_{abc}} \right) \tag{16}
\]

\[
\sum_{p=1}^{g} r_{a_p} = 1, \quad r_{a_p} \in \{0, 1\} \tag{17}
\]

\[
CS.cr_{abc} \in \text{Cons}_{abc} \tag{18}
\]

\[
CS.cr_{abc} \in \text{Cons}_{abc} \tag{19}
\]

Formula (8) represents the objective function; the attribute \( cr_{ab} \) may or may not have subordinate attributes, three kinds of aggregate function of the attribute \( cr_a \) are represented with formula (9), (10) and (11). The \( \min_{ab} \) and \( \min_{a_b} \) respectively represent the minimum value of independent QoS attributes \( cr_{ab} \) and \( cr_{a_b} \) of all composite services, the \( \max_{ab} \) and \( \max_{a_b} \) are the maximum values; and the QoS attribute \( cr_{a_b} \) is non-independent, \( w_{a_h} \) and \( w_{a_b} \) represent the weight values of the attributes \( cr_{a_b} \) and \( cr_{a_b} \) respectively. Formula (12) and (13) ensures that each weight value is between 0 and 1, and the sum of all weights is 1.

Formula (14) represents the aggregate utility function of the non-independent attribute \( cr_{ab} \), the \( \min_{abc} \), \( \max_{abc} \) respectively represent the minimum value and maximum value of independent QoS attribute \( cr_{abc} \) of all composite services. Formula (15) represents the aggregation function of independent QoS attribute \( cr_{abc} \) value of
the composite service $CS$, Formula (16) represents the aggregation function of independent QoS attribute $cr_{abc}$ value of the composite service $CS$, and calculate the attribute values according to the corresponding methods, such as sum, quadrature, minimum, etc. Formula (17) ensures that each time only one web service is selected from $HQwspool_i$ to participate in service composition. Formula (18) and (19) represent that independent QoS attribute $cr_{ab}$ and $cr_{abc}$ values of the composite service $CS$ satisfy global constraints. Solve the mixed integer programming model; obtain the composite service $CS_{optimal}$ with the largest aggregate utility value, which supports the business execution of cross-organizational collaboration.

3.4. Algorithmic Process

Input: cross-organizational collaboration process, candidate service set, constraint set, weight set, the values of independent QoS attributes, the number of quality levels, the number of services that every task need to select

Output: the approximate optimal composite service $CS_{optimal}$

Steps:
1) Initialize $Zwspool_i \leftarrow \emptyset$, $HQwspool_i \leftarrow \emptyset$, $z \leftarrow 0$, $CS_{optimal} \leftarrow null$; the local constraints $cons_{ab}$, $min cons_{ab}$, $cons_{abc}$, $min cons_{abc}$ and global constraints $min cons_{ab}$, $min cons_{abc}$ are initialized in interval form;
2) Calculate the quality level $q_{ab}^{*}$ of independent QoS attribute $cr_{ab}$ of the task $tk_i$ candidate services, and the quality level $q_{abc}^{*}$ of independent QoS attribute $cr_{abc}$ of the task $tk_i$ candidate services;
3) Put the web services (in $WSpool_i$) satisfying local ideal constraints into $Zwspool_i$;
4) If $z = 0$ and the conditions of local ideal constraint resolution are satisfied, perform the corresponding resolutions, go to step 3, otherwise go to step 8;
5) If $0 < z < g$ and local ideal constraint resolution conditions are satisfied, perform the corresponding resolutions, go to step 3, otherwise, put current web services in $Zwspool_i$, into $HQwspool_i$, and go to step 7;
6) If $g \leq z$, calculate the aggregate utility values of web services in $Zwspool_i$, and select $g$ web services with larger aggregate utility value and put into $HQwspool_i$;
7) Solve $CS_{optimal}$ based on the candidate service space $HQwspool_i$ and user global constraints ($[min cons_{ab}, \infty]$ and $[min cons_{abc}, \infty]$);
8) Output $CS_{optimal}$.

4. EXPERIMENTS

4.1. Case Design

This paper chooses a food supply chain composed of five kinds of nodes as the experimental case, and the five kinds of nodes are: production of animal husbandry inputs, breeding, food processing, food circulation and catering operation. The business process of the food supply chain is as follows: (1) according to business strategies, catering enterprises find food distributors meeting their requirements to establish cooperative relation; (2) food distributors find suitable food producers according to the variety of goods; (3) food producers find qualified breeding enterprises to ensure a stable supply of primary products; (4) breeding enterprises need to find the reliable enterprises that produces animal husbandry inputs, such as feed, veterinary drugs, etc.; (5) enterprises that produces animal husbandry inputs need procure raw materials. According to the task sequence of the business process, the five kinds of nodes establish the supply chain collaboration relationship through selecting partners four times, and cater for customers finally. The candidate services that correspond to tasks of the above five kinds of nodes take part in service composition in this sequence. The data set in simulation experiments is as follows:

(1) Three-layer QoS attributes (shown in Figure 1) and the range of every attribute value

The range of response time, reliability, availability, and execution success rate is (0,1]; the range of supply is [700,1000]; the range of delivery cycle is [5,10]; the range of price is [60,100]; the range of reputation and credibility is {low, general, high, very high}; the range of financial situation is {qualified, moderate, good, excellent}; the range of drug residues, prohibited additives, unqualified raw materials, substandard nutrition, food spoilage is [0,0.001]; the range of natural environment pollution, unsanitary environment, substandard facility is {serious, general, minor, no}. The attribute values are randomly generated in the corresponding range.

(2) Local quality constraints and weight values of independent QoS attributes (for candidate services)
For positive attributes, such as reliability, supply, etc., the attribute value is required to be greater than or equal to the ideal or standard constraint value; for negative attributes, such as response time, unqualified raw materials, etc., the attribute value is required to be less than or equal to the ideal or standard constraint value. In the experiments, local quality constraints of negative attributes are converted through a negative calculation.

Figure 1. Three-layer QoS attribute system

Constraints and weight values of the direct and subordinate attributes of quality (cr21), product (cr2), service (cr1) and enterprise (cr3) are shown in Table 1, Table 2, and Table 3 respectively. The data in Table 3 is suitable for candidate services of each task in the above five kinds of nodes.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Constraints and weights</th>
<th>Tasks</th>
<th>Production of inputs</th>
<th>Breeding</th>
<th>Food processing</th>
<th>Food circulation</th>
<th>Catering operation</th>
</tr>
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<td>general</td>
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<td>food processing</td>
<td>food circulation</td>
<td>catering operation</td>
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<td></td>
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Table 2. Constraints and weight values of direct and subordinate attributes of product (cr2)

<table>
<thead>
<tr>
<th>constraints and weights of direct and subordinate attributes of service (cr1) and enterprise (cr3)</th>
<th>attribute</th>
<th>ideal constraint</th>
<th>standard constraint</th>
<th>weight</th>
<th>attribute</th>
<th>ideal constraint</th>
<th>standard constraint</th>
<th>weight</th>
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<td>cr11</td>
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<td>cr31</td>
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<td>general</td>
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<tr>
<td>cr12</td>
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<td>0.6</td>
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<td>cr32</td>
<td>high</td>
<td>general</td>
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<tr>
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<td>0.5</td>
<td>0.25</td>
<td>cr33</td>
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<td>moderate</td>
<td>0.333</td>
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<td>cr14</td>
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<td>0.25</td>
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</table>

Table 3. Constraints and weight values of direct and subordinate attributes of service (cr1) and enterprise (cr3)

(3) Global quality constraints and weight values of independent QoS attributes of composite services
The global quality constraints and weight values are shown in Table 4. The weight values of three QoS attributes (service, product, enterprise) of composite services are all 0.333.

Table 4. Global constraints and weight values of composite service attributes

<table>
<thead>
<tr>
<th>attribute</th>
<th>global constraint</th>
<th>weight</th>
<th>attribute</th>
<th>global constraint</th>
<th>weight</th>
</tr>
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<td>cr11</td>
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</tr>
<tr>
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<td>cr12/ cr13/cr14</td>
<td>0.035</td>
<td>0.25</td>
</tr>
<tr>
<td>cr217</td>
<td>general</td>
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<td>cr31/cr32</td>
<td>general</td>
<td>0.333</td>
</tr>
<tr>
<td>cr218</td>
<td>0.0013</td>
<td>0.1</td>
<td>cr33</td>
<td>moderate</td>
<td>0.333</td>
</tr>
</tbody>
</table>

(4) Experiment environment
CPU is Intel(R) Core(TM) i5-3230M, RAM is 4.00GB, OS is Windows8, the programming language is C++, and the linear programming tool is LP-Solve5.5.

4.2. Experiment Analysis
(1) Quality balance verification of high-quality services selected
We choose the LO-IP method (Qi and Dou, 2011) with constraint resolution ability and the LQCR method in this paper to solve the experiment problem at the same time. The number \( d \) of discrete quality levels in LO-IP method and the number \( j_{ab} \cdot j_{ab} \) of discrete quality levels in LQCR method are all fifteen; the number of tasks is five. For the two methods, the number of web services selected from candidate services of each task is five and nine. The number of the selected high-quality services satisfying local quality constraints is shown in Figure 2. The horizontal axis represents the number of candidate services of every task; the vertical axis represents the average number of web services of each task, which are selected from candidate services and
satisfy local quality constraints when two methods have the same number of candidate services and same number of high-quality services needed to select.

In Figure 2, when the number of candidate services of each task is small (e.g. thirty), only some of the five tasks have web services satisfying corresponding local quality constraints, the LQCR method cannot achieve the service composition. Among the atomic services of the optimal composition service solved by the LO-IP method, only some satisfy corresponding local quality constraints. With the increase of candidate services of each task, the average number of high-quality services which are selected by two methods and satisfy local quality constraints also increases. Since the LO-IP method does not consider local quality constraints, the average number of high-quality services that are selected by the LQCR method and satisfy local quality constraints in each task is larger than that of the LO-IP method under the same condition. When the number of candidate services of each task reaches 150 and 240, the LQCR method can respectively select five and nine high-quality services satisfying local quality constraints for each task. The quality of web services selected by the LQCR method is more balanced.

Figure 2. Comparison of quality balance of web services selected by two methods

(2) Quality verification of the optimal composite service

The Global method (Zeng et al., 2004) and LO-IP method have good performance in solving the optimal service composition problem; the Global method, LO-IP method and LQCR method are used in the simulation experiment. For the LO-IP method and LQCR method, the number of discrete quality levels of each attribute value range is fifteen. the number of high-quality services selected from candidate services of each task is nine. In Figure 3, when the number of candidate services of each task is small (e.g. 30), the LQCR method cannot achieve the service composition; the Global method and LO-IP method can obtain the corresponding optimal composite service and utility value in the condition of global quality constraints. When the number of candidate services of each task reaches 150, the aggregate utility value of optimal composite service solved by the LQCR method is close to that of optimal composite service solved by the LO-IP method and Global method. When the number of candidate services in each task is large (e.g. 200), the LQCR method can still obtain the approximately optimal composite service under the premise of the local quality constraints of each task.

Figure 3. Comparison of aggregate utility values of optimal composite services solved by three methods
(3) Time cost test of service composition

For the LO-IP method and LQCR method, the number of discrete quality levels of each independent QoS attribute value range is fifteen, and the number of high-quality services selected from candidate services of each task is nine. When the number of candidate services of each task is same, the service composition time cost of three methods is shown in Figure 4. Because the LO-IP method and LQCR method can reduce the candidate service space by quantitative restriction, the time cost is much lower than the Global method. The quality of atomic services selected by the LQCR method is more balanced through setting the ideal constraints and standard constraints, the quality of composite services can better satisfy global quality constraints, and the time cost of the LQCR method is less than that of the LO-IP method.

Figure 4. Time cost comparison of three service composition methods

5. CONCLUSIONS

To solve the approximate optimal composite service, the LQCR method proposed mainly includes the formalization model of a three-layer QoS attribute system and corresponding constraint system, and the global dynamic optimization model of service composition. The step-by-step resolution of local quality constraints is used to filter out web services with unbalanced quality attribute values, select the high-quality services close to the expectation level, and narrow candidate service space. The mixed integer programming model is used to solve the approximate optimal composite service with balanced aggregate attribute values.

Based on the experiment results of the quality balance of atomic services, quality of optimal composite service, time cost of service composition, the LQCR method can realize reliable and effective service composition when the number of tasks is small and the number of candidate services is larger. The LQCR method effectively solves the problem of service composition in cross-organization collaboration environment, and gets the balance between quality and efficiency.

REFERENCES


