Comprehensive quality - aware Automated Semantic Web Service Composition

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Abstract. Semantic web service composition has been a prevailing research area in recent years. There are two major governance challenges faced by researchers. One is semantic matchmaking for discovering interoperable web services, which demands a rich machine understanding language such as OWL-S (Web Ontology language for Web Services), WSML (Web Service Modeling language, SAWSDL (Semantic Annotations for WSDL and XML Schema). This interaction of web services enables us to pair service functionalities through understanding and reasoning those semantic descriptions. Optimisation problems are another challenge. Many scholars have looked into nonfunctional optimisation problems in QoS-aware web service composition applying AI planning and Evolution Computing techniques. However, it is not sufficient without considering good balance between functional and nonfunctional quality in most scenarios. Therefore, the consideration in these two quality dimensions is a must, so that service composition needs to deal with optimisation problems in both quality of semantic matchmaking and QoS. This paper develops a more applicable way for measuring a proposed comprehensive quality model in both semantic matchmaking and QoS for automated semantic web service composition.

1 Introduction

Service-oriented computing (SOC) is a novel computing paradigm that employs services as fundamental elements to achieve agile development of cost-efficient and integratable enterprise applications in heterogeneous environments [22]. Service Oriented Architecture (SOA) could abstractly realise service-oriented paradigm of computing. This accomplishment has been contributing to the reuse of software components, from functions to units, and from units to services during the development in SOA [4]. One of the most typical realisations of SOA is *web service*, which is designated as "modular, self-describing, self-contained applications that are available on the Internet" [6]. Several standards play a significant role in registering, enquiring and grounding web services including particularly UDDI, WSDL and SOAP [9].

Web service composition pertains to a combination of multiple web services to provide a value-added composite service that accommodates customers' arbitrarily complex requirements. This application is developed by integrating interoperable and collaborative functionalities over heterogeneous systems. Due to the increase in the number of large-scale enterprise applications, the number of Web services has increased dramatically and unprecedentedly, which cause an immense redundancy in functionality in a huge searching space. Therefore, manual and semi-automated web service composition are considered to be less efficient while automated web service composition is deemed to be less human intervention, less time consumption, and high productivity.

Two most notable challenges for web service composition are (1) ensuring interoperability of services and (2) achieving QoS optimisation [9]. *Interoperability* of web services presents challenge (1) in the dimensions of syntactic and semantics [9]. The syntactic dimension is covered the XML-based technologies (such as $WSDL$, $SOAP$). The semantics aspect, on the other hand, demands further research. Through semantics given by ontologies [20], web services understand and better collaborate with each other. Historically, there are many ontologies languages and formats for semantic service descriptions, such as OWL-S [17], WSML [10], and SAWSDL [13]. The logical characteristics in reasoning makes "machine understanding" possible through identifying and matching semantic similarity in input/output parameters of web services in heterogeneous environments. The second challenge (2) is related to finding *optimised solutions* to Quality of Service (*QoS*) over composite web services. This problems give birth to *QoS-aware service composition* that considers the composition of service-level agreements [23] manifesting a collection of SLA rules and policies for supporting QoS-based composition.

Existing works on service composition focus mainly addressing two challenges above. One group optimises the quality of compositions under a pre-defined abstract workflow, which is considered to be a *semi-automated Web service composition* approach. Another group attempts to generate a composite plan automatically in discovering and selecting suitable web services, which are deemed to NP-hard [19]. *Semantic web services composition* is distinguished from the syntactic service composition. Its benefits are presented in eliminating conflicts by the semantic level of web services. In the past few years, substantial works have been done on semantic web service composition [9,14]. However, few works have enabled truely automatic semantic web service composition, where both QoS and quality of semantic match making will be optimised simultaneously. However, customers often prefer a service composition that matches their requirement most with highest QoS.

The overall goal of this paper is to *develop an comprehensive quality-aware automated semantic web service composition that satisfactorily optimises both functional and non-functional requirements*. Particularly, this paper considers the quality of semantic matchmaking quality and QoS and two structural constructs (sequence and parallel) for building optimised composition solution using Particle Swarm Optimisation (PSO). We aim to provide a more applicable and adaptive way to measure semantic matchmaking in automated semantic web service composition. We will achieve three objectives in this work as follows:

1. To propose a comprehensive quality model that address QoS and semantic matchmaking quality in considering different matching types associated with corresponding semantic similarity. This approach is consider to be a more applicable and adaptive way of finding an optimised solution in semantic web service composition.
2. To propose a PSO-based service composition model that utilise the proposed quality model. In PSO, weighted graphs with edges and vertices associated with quality of semantic matchmaking and QoS respectively represent the solutions of semantic web service composition as particles, which are decoded from an optimised service queue with the consideration of comprehensive quality.
3. To evaluate the performance of comprehensive quality awareness semantic web service composition by utilising benchmark datasets from Web Services Challenge 2009 (WSC09) [12].

The remains of this paper are organised as the following: Sect. 2 provides the background on the semantic web service composition, and related works; Sect. 3 presents an overview of comprehensive quality-aware semantic automated web service composition consisting of comprehensive quality evaluation model and PSO-based service composition algorithm; Sect. 4 describes the experiments conducted to test the effectiveness of proposed model; Sect. 5 presents and analyses the experiment; Sect. 6 concludes our work.

2 Background

2.1 Problem Description

The purpose of web service composition is to accomplish an arbitrarily complex task fulfilling customer's requirement, which could be denoted as a composite goal: $Comp.G(F(T_{Input}, T_{Output}), NF(T_{QoS}))$. This overall composite goal is demonstrated in two parts. The first functional part is a given task input or input set to get the desired Task output or output set. It typically refers to users' functional requirement. Another nonfunctional part specifies the acceptable level of composite quality of service. To accomplish the composite goal, two stages are involved: services discovery and service selection. Firstly, service discovery is to find matched web service: $S_n(F(S_{Input}, S_{Output}), NF(S_{QoS}))$ from a Service Repository: $S = \{S_1, S_2, ..., S_n\}$ with the given T_{Input}. If no atomic web service could satisfy the composite goal, a combination of web services will be found concretely to meet $Comp.G$. Firstly, a output set is initialised and updated with found services output, which could be denoted as $OutputSet(T_{input}, S_{output} \in S_1, ..., S_{output} \in S_{n-k})$. The Output set is used to discover all related services until the desired T_{Output} found in the updated Output Set. The discovery process normally results in more than one service compositions. Therefore, Service selection is to select one of those composite solutions considering the best QoS according to T_{QoS}. To ensure the composite solution returns the desired $Comp.G$, we consider a comprehensive quality model defined in 3.3 for service discovery and selection, where challenges (1) and (2) mentioned in Sect. 1 are also addressed in Sect. 3.

2.2 Semantic Web Service matchmaking Type

The semantic service matchmaking aims to discover appropriate services from service repository relevant to a customer's functional requests. A semantic web service is defined by $S(F(S_{Input} \in C_1, S_{Output} \in C_2), NF(S_{QoS}))$ with both Input and Output are linked to concept C_1 and C_2 in an ontology (O) respectively, satisfying $O = \{C, Taxonomy\}$. A web service matching process is to match the output and input concepts of two services according to the Taxonomy within an Ontology (O). To measure the quality of semantic matchmaking, different matching levels are typically considered in the literature [21]. To understand these levels, let us define two web services associated with parameters in a particular domain. S_1 $(F(S_{Input} \in C_1, S_{Outputs} \in C_2), NF(S_{QoS}))$ and S_2 $(F(S_{Input} \in C_3, S_{Output} \in C_4), NF(S_{QoS}))$ and an Ontology(O) with C_1, C_2, C_3, and C_4. The matching levels to be considered are:

- *Exact* ($\equiv$): Output of Web service S_1 and Input of Web service S_2 are Exact match ($S_{output} \in S_1 \equiv S_{input}S_2$), if Concept C_2 and Concept C_3 are equivalent.
- *Plugin* ($\sqsubseteq_n$): Output of Web service S_1 and Input of Web service S_2 are Plugin match ($S_{output} \in S_1 \sqsubseteq_n S_{input} \in S_2$), if Concept C_2 is a sub-concept of Concept C_3, and $n = \{1, 2, ..., n\}$ presents the levels of children concepts ($n = 1$ stands for direct children).
- *Subsume* ($\sqsupseteq_n$): Output of Web service S_1 and Input of Web service S_2 are Subsume matched($S_{output} \in S_1 \sqsupseteq_n S_{input} \in S_2$), if Concept C_2 is a sub-concept of Concept C_3, and $n = \{1, 2, ..., n\}$ presents the levels of parent concepts ($n = 1$ stands for direct parent).
- *Fail* ($\perp$). Output of Web service S_1 and Input of Web service S_2 are not matched (Fail) ($S_{output} \in S_1 \perp S_{input} \in S_2$), if none of the previous matches discovered.

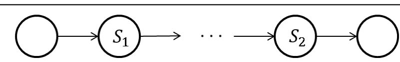
Note that, to find relevant services for service compositions according to a given goal, we consider Exact, Plugin, Subsume and Fail match types in our paper. Therefore, these matches will be used to discover web service candidates for service composition with consideration of the threshold α to enhance the accuracy and efficiency in our proposed the comprehensive quality-aware model in Sect.3.1

2.3 Quality of Service and Composition Constructs

Currently, most of the optimisation problems [8,11,16,26] in web service composition are focusing on QoS, which covers aspects in non-functional requirements. This problem has been explored in both single objective and multi-objectives optimisation problems. Customers prefer lowest execution cost with highest response time and reliability so that it could be involved as a single objective optimisation problem while cost and reliability of web service are two conflicting objectives that could be optimised simultaneously in multi-objective problem. According to [31], four most often considered QoS parameters are as follows:

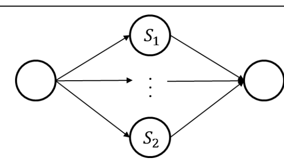
– *Response time* (T) measures the expected delay in seconds between the moment when a request is sent and the moment when the results are received.
– *Cost* (C) is the amount of money that a service requester has to pay for executing the web service
– *Reliability* (R) is the probability that a request is correctly responded within the maximum expected time frame.
– *Availability* (A) is the probability that a web service is accessible.

The aggregation value of QoS attributes for web services composition varies with respect to different constructs, which explains how services associated with each other in a service composition [31]. Here we consider two composite constructs: sequence and parallel constructs, in building the composite flow. The QoS calculation models are described as follows:



$$T = \sum_{n=1}^{m} t_n \quad C = \sum_{n=1}^{m} c_n \quad A = \prod_{n=1}^{m} a_n \quad R = \prod_{n=1}^{m} r_n$$

Fig. 1. Sequence construct and calculation of its QoS properties [30].



$$T = MAX\{t_n | n \in \{1, \ldots, m\}\}$$

$$C = \sum_{n=1}^{m} c_n \qquad A = \prod_{n=1}^{m} a_n \qquad R = \prod_{n=1}^{m} r_n$$

Fig. 2. Parallel construct and calculation of its QoS properties [30].

Sequence construct The composite web service executes each atomic service associated with a sequence construct in a definite sequence order. The aggregation value for total time (T) and total cost (C) is as the sum of time and cost of web services involved respectively. The overall availability and reliability in a sequence construct are calculated by multiplying their corresponding availability and reliability of each web service in probability theory. This construct is shown in Figure 1.

Parallel construct Web services in a parallel construct are executed in the meantime. The QoS aggregation value for total cost, availability and reliability are the same as these in sequence construct while the Total time (T) is delimited by the maximum time consumed path in the composite flow of the solution. This construct is presented in Figure 2.

2.4 Related Work

Semantic web service matchmaking. Substantial work [2,18,27,28,30] on web service composition focused mainly on non-functional requirements consistently neglecting functional requirements. However few researchers addressed both addressed both of them at the same time in web service composition. To the best of our knowledge, [7,14] are the papers could be found so far. Semantic matchmaking utilises Description Logic(DL) [1] reasoning between input and output parameter concepts of web services to ensure a semantic matchmaking. It is considered be a process consisting of seeking similarity of parameters (i.e., input and output) of web services and mapping between two knowledge representations encoded utilising the ontology [15].

In [24], three approaches are surveyed three approaches regarding the similarity measures using taxonomies: (1) The first one is based on nodes, in which similarity is determined by the information content of the nodes; (2) the second is entirely based on edge, where concept distance in a hierarchy structure is evaluated, and (3) the hybrid approach features a combination of (1) and (2). A new similarity measure based on edge counting in taxonomy is introduced in [24], which extends similarity measure defined by Wu and Palmer [29]. Neighbourhood concepts are considered in their model in Formula 1, when $\lambda = 1$ (default value as 0).

$$q(s_{similarity}) = \frac{2N \cdot e^{-\lambda L/D}}{N_1 + N_2} \tag{1}$$

In [14], the quality of matchmaking problem is transferred to measure the quality of semantic links $sl_{i,j} \doteq \langle s_i, Sim_T(Out\_s_i, In\_s_j), s_j \rangle$, one possible measure is applied for the degree of similarity using Common Description rate of a semantic link in Formula 2, where Extra Description $In_{s_x} \setminus Out_{s_y}$ and Least common subsume $lcs(Out_{s_i}, In_{s_j})$ are required to be pre-calculated. They also chained the web service with five well-known matching types: Exact, Plug-in, Subsume, Intersection, and Disjoint. Therefore, the quality of the semantic link is estimated as quality criteria q_m associated with their corresponding quality of vector q_{cd} defined as Formula 3.

$$q_{cd}(sl_{i,j}) = = \frac{|lcs(Out_{s_i}, In_{s_j})|}{|In_{s_x} \setminus Out_{s_y}| + |lcs(Out_{s_i}, In_{s_j})|} \tag{2}$$

$$q(sl_{i,j}) \doteq (q_{mt}(sl_{i,j}), q_{cd}(sl_{i,j})) \tag{3}$$

However, the weakness of semantic link quality is that calculating Extra description and Least common subsume requires well and completely defined ontology in class, class axioms and properties in OWL2. This makes it difficult to measure semantic matchmaking quality in most semantic web services applications, as it takes unpredictable cost and time for the domain experts to establish required ontology. Additionally, a semi-automated service composition approach is considered in their paper, rather than a fully automated method. In QoS, only cost and time are considered in the optimised problems. Therefore, we introduce a more applicable comprehensive quality model in a fully automated approach.

In [7], it covers the concerns in both functional and non-functional requirements in design time of semantic-based automatic service composition, where a GA-based approach with four unusual independent fitness functions are designed to solve the problems with these concerns. In details, a sequence of fitness functions are used in the binary selection of chromosome, rather than a single objective consisting of both functional and non-functional quality. Apart from that, match types are ignored in their quality evaluation of semantic matching.

QoS-aware EC approaches. Evolution Computing techniques are widely used to solve optimisation problem. Genetic Programming (GP) [27,28] is a typical EC technique to solve automated web service composition. This GP-based approach utilises tree representations, on which service and constructs as represented as terminal nodes and functional nodes respectively. The crossover and mutation operations reproduce various individuals while ensuring the correctness of structure. In [30], the author optimises the overall quality of service composition by using a fitness function, which is also liable for the correctness in functionality through penalising infeasible solutions.

To simplify the checking of constraints for solutions, an indirect PSO-based approach was introduced in [27], firstly, the best location is searched using PSO considering optimising QoS for building up service queue, then web services in this service queue are selected to build up a graph representation of the solution. However, this solution does not distinguish different matching types and parameter similarity, which could lead to the outputs returned by the selected service that we think may be too general. In fact, customers' perspectives, application domains and ontology granularity all could have significant impacted on the outputs requested by users. In some scenarios, the output returns too broad consequences that have no meaning for the customers, even though those web services selected leads to a very good overall QoS. Therefore, we fill the gap by considering different matching types and the similarity when evaluate an overall quality of web service composition and utilising weighed graphs as different particle representations from [27].

3 QoS-aware Semantic Automated Web Service Composition

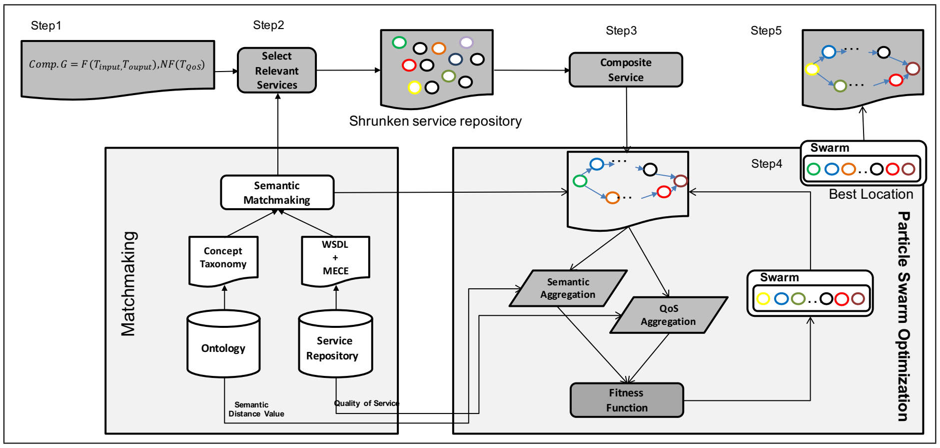


Fig. 3. Overview of the proposed approach.

In this paper, we model comprehensive quality awareness automated semantic service composition with graphs. PSO has shown its efficiency in solving combinatorial optimisation problems. Therefore, we will propose a PSO-based approach, which is considered to be simple and efficient without penalising or repairing comparing to GP [26]. Fig. 3 shows the overview of our approach with the five steps included. Step 1: The composite process is triggered by a composite goal defined in Subsection 2.1, which describes customers requirements in functional and non-functional parts. The first functional one is defined as $F(T_{Input}, T_{Output})$, and the second nonfunctional one is users' accepted level of QoS. Step 2: Those requirements are initially used to discover all relevant web services, which leads to a shrunken service repository that further used by PSO as a searching space. Step 3: a graph representation is randomly built up interleaving with semantic matchmaking process, where web services are discovered and connected while calculating matchmaking quality that will be explained in Subsect. 3.3. Step 4,5: The selection of web services is performed over the PSO algorithm in subSect. 3.5, which is used to find best particle location mapped back to a service queue for building graph solutions considering comprehensive quality. This approach [27] is an indirect representation of web service composition using PSO.

3.1 Semantic matchmaking

To perform semantic matchmaking transfer a function match between $S_1 : S_{output} \in C_1$ and $S_2 : S_{output} \in S_b$ to a pair of concept match in 2.2. The matching process attempts to determine semantic matching between the source concepts of C_1 and the target concepts of C_2 calculated in the quality model in subSection 3.3. The advantage of semantic matchmaking quality is to find a more closely requested service output with acceptable level of QoS.

The semantic matchmaking is achieved by utilising semantic annotation with OWL and OWL-S. In this paper, we use MECE ontologies [3], which could be considered to be an alternative form of ontology for services. In ontology, semantics specifies the both concepts and individuals in the terms of classes and instances wherer semantic concepts are expressed with the their statements and relationship in RDFs (such as subClassOf), and the semantic individuals are related to the input and output parameters of web services. The MECE is an extensive annotation to WSDL files, which defines the each parameter of services associated with their semantic individuals. The overall matching making process is demonstrated in Figure 4.

3.2 Ontology-based Index Cache

In PSO, particles represent weighted graphs with edges and vertices associated with quality of semantic matchmaking and QoS respectively, the bottlenecks of generating weighted graph lie in building edges and nodes, which are related to the cost of semantic quality calculation and the size of service repository respectively. To effectively construct weighted graphs, we pre-calculate semantic matchmaking quality and mark the input-parameter concepts with a set of services. The key idea of the index is to create a mapping from the output-related concepts to matched input-related services while considering different levels of match types. Furthermore, the repository size could also be reduced by considering users' predefined acceptable semantic matching quality, which eliminates the influence of low composition accuracy. The service repository size is further reduced to the available output parameter concepts are input-relevant and more than the threshold.

This implementation contributes to less time and constant time for weighted graph building.

3.3 Comprehensive quality model and aggregation matrix

In this paper, we propose a comprehensive quality model to evaluate the overall quality of semantic web service composition. This model overcome the disadvantages of current prevailing QoS-aware optimisation, in which quality of semantic matchmaking are not considered.

Semantic matchmaking model. Due to the discretisational characteristics of different match types driven by the cost of data type integration and manipulation [14]. Match type is considered to be one factor for the semantic matchmaking quality. Another factor in our proposed model is concept similarity, which could be evaluate based on edge counting method defined by [24] — a taxonomy-based measurement for ontology matching. In this paper, it could be used to estimate the parameter concepts similarity between the given output

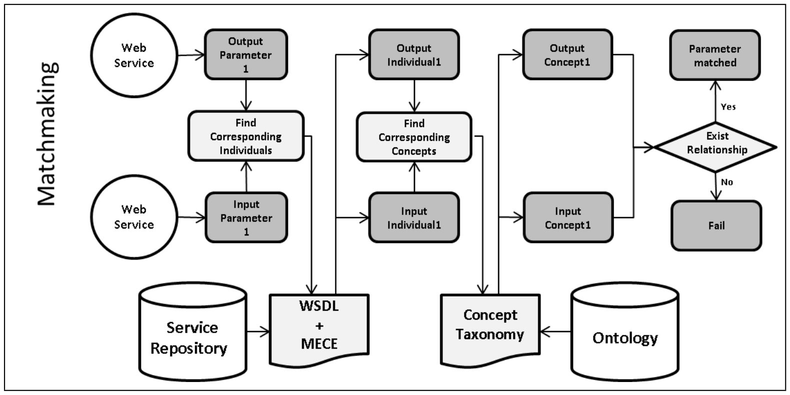


Fig. 4. Semantic matchmaking.

and available input for selecting web services. Therefore, given the quality match type and the similarity of two parameters, the semantic matchmaking quality is defined as Formula 4, where the value of $q(s_{matchType})$ is set up as the same as the quality of the semantic link in literature [14] as 1 (Exact), 0.75 (Plugin), 0.5 (Subsume) or 0.25 (Intersection) while $q(s_{similarity})$ is calculated utilising formula 1 in subsection 2.4.

$$q_{sm} \doteq (q(s_{matchType}),\ q(s_{similarity})) \tag{4}$$

Comprehensive quality model. Compared to QoS evaluation model, the comprehensive quality model is established to investigate both functional and non-functional requirements of composite goal. The non-functional properties typically refers to previously discussed QoS, which are given by service providers. Consequently, the comprehensive quality model integrated the semantic matchmaking quality $q(s_{sm})$ in Formula 5, which could be further broken down into Formula 6.

$$q_{cq} \doteq (q(s_{sm}),\ q(s_{QoS})) \tag{5}$$

$$q_{cq} \doteq (q(s_{mt}),\ q(s_s),\ q(s_a),\ q(s_r),\ q(s_c),\ q(s_t)) \tag{6}$$

Quality aggregate matrix.The quality aggregation is defined based on the constructs of composite web services on the criteria of functional and non-functional properties. Generally, web services could have more than one concept-related parameters. In semantic matchmaking process, two levels of quality aggregation are considered — edge level and construct level. At edge level, the edge-level quality aggregation is determined by the mean value of concept-related parameter quality in $q(s_{mt})$ and $q(s_s)$ respectively. Meanwhile, the construct-level quality is further calculated based on the constructs following the rules in Table 1 — a quality aggregate matrix for semantic web service composition. Both the $Q(s_{mt})$ and $Q(s_s)$ are considered by calculating the product function of involved edge-level $q(s_{mt})$, and mean function of edge-level $q(s_s)$ respectively. The QoS aggregation $Q(q_{QoS})$ calculation is same to [5].

Table 1. Quality aggregate matrix for semantic web service composition

Composition Construct			Sequence	Parallel
QualityFactors	Functional	$Q(s_{mt})$	$\prod_{n=1}^{m} q(s_{mt})$	$\prod_{n=1}^{m} q(s_{mt})$
		$Q(s_s)$	$(\sum_{n=1}^{m} q(s_s))/m$	$(\sum_{n=1}^{m} q(s_s))/m$
	NonFunctional	$Q(s_a)$	$\prod_{n=1}^{m} q(s_a)$	$\prod_{n=1}^{m} q(s_a)$
		$Q(s_r)$	$\prod_{n=1}^{m} q(s_r)$	$\prod_{n=1}^{m} q(s_r)$
		$Q(s_c)$	$\sum_{n=1}^{m} q(s_c)$	$\sum_{n=1}^{m} q(s_c)$
		$Q(s_t)$	$\sum_{n=1}^{m} q(s_t)$	$max(q(s_t))$

3.4 Fitness Calculation

The fitness value is calculated from the aggregated value of quality components involved in a graph-based service composition. A weighted sum of those components is utilised in the fitness function 7, in which fitness value of 1 means the best comprehensive quality and 0 means the worst. As the sum of all the function weights (w1 to w6) is equal to 1, MT, S, A, R, T, and C must be normalised so that the fitness value falls within 0 to 1. Also, the lowest T and C value represent the best conponent quality so that the objective function is offset using $(1 - T)$ and $(1 - C)$.

$$Fitness = w_1MT + w_2S + w_3A + w_4R + w_5(1 - T) + w_6(1 - C) \tag{7}$$

where $\sum_{i=1}^{6} w_i = 1$

3.5 QoS-aware Semantic Web Service Composition algorithm

The overall algorithm investigated here is a simple forward decoding PSO [27] with our comprehensive quality evaluation model. The idea is to translate the particle location into a service queue as an indirect representation of graph-based service composition, so finding the best fitness of the composite service solution is to discover the optimised location of the particle. In PSO, the dimension of the particle is set up as the same as the number of relevant web services in the shrunken service repository, and all the services index is mapped to the location in a particle, and we put services in a queue in ascending order, from which we decode a corresponding graph using a forward graph-building technique. The particle's fitness value can be calculated based on that built graph. During the evolutionary process, pBest and gBest value are assigned and updated in each generation with new-updated particles' position while graph-based solutions are generated at the same time. eventually, we return the graph built from the last

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Algorithm 1. Steps of graph-based PSO optimisation technique.

Input: I, O
Output: G
1. Randomly initialise each particle in the swarm.
while *max. iterations not met* **do**
    forall *particles in the swarm* **do**
        2. Sort particle's position vector as a service queue in ascending order
        3. Initialise OutputSet with Task Input $\leftarrow I$
        4. Initialise a graph G with a startNode
        while *max. OutputSet not contains Task Output* $\leftarrow O$ **do**
            5. Get web service from service queue
            if *All inputs of current web service satisfied with output from outputSet* **then**
                6. Create and connect service edge associated with matchmaking quality to graph.
                7. Create and connect node(current web service) to graph.
                8. Remove current web service from the queue.
                9. Update OutputSet with outputs current web service.
            10. Get next web service from service queue
        11. Connect endNode the graph G
        12. Remove dangle services from the graph G
        13. Remove dangle edges from graph G
        14. Aggregation of semantic matchmaking and QoS
        15. Calculate the particle's fitness.
        if *fitness value better than pBest* **then**
            16. Assign current fitness as new pBest.
        else
            17. Keep previous pBest.
    18. Assign best particle's pBest value to gBest, if better than gBest.
    19. Calculate the velocity of each particle according to the equation:
    19. Update the position of each particle according to the equation:
20. return Graph in the last iteration $\rightarrow G$.

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generation as an optimised solution. In the forward graph building algorithm. We select and connect web services to the startNode from the service queue if the web service can satisfy the given T_{input}. Meanwhile, an Output Set is initialised and kept being updated using outputs from the new-added web services in the graph, later on, more services are connected if services' inputs could be satisfied by any output in the Output Set. At last, The end node is connected if the updated Output Set contains the T_{output}. In addition, dangle service nodes and edges should be removed.

4 Experiment Design

In this section, a quantitative evaluation approach is adopted in our experiment design. The objectives of the evaluation are to measure the effectiveness of the comprehensive quality model in automated semantic web service composition approach, and to explore the impacts of the semantic matchmaking that contributes to overall composition quality, and to compare solutions generated by QoS-ware approach with our method.

We utilise benchmark dataset web service challenge 2009 (WSC09) [12] to perform a standard evaluation. WSC09 provides problems, WSDL+MECE, taxonomy files in formats of xml, xml, and owl respectively, where five tasks consisted in with variable size in both services, and ontologies. Therefore, it is a proper dataset for the scalability measures in our defined quality evaluation model. Table 2 presents the features of the WSC09 dataset. The number of concepts, individuals in the ontology and services in each data set is shown in the second, third, fourth column respectively. Also, we extend all the datasets with QoS attributes from service providers to perform a comprehensive quality evaluation.

Table 2. Features of the WSC09 datasets

Dataset	No.Concept	No.Individual	No.Service
WSC09 01	1578	3102	572
WSC09 02	12388	24815	4129
WSC09 03	18573	37316	8138
WSC09 04	18673	37324	8301
WSC09 05	31044	62132	15211

We run the experiment under computing grid comprising of almost 170 NetBSD (Unix operating system) workstations operated by the Sun Grid Engine. Experimentation was done using the approach explained in Section 3, and evaluated in the comprehensive quality model introduced in Subsection 3.3. The parameters were chosen based on general settings from [25] for our PSO-based approach, 30 particles evolved in 100 generations in the searching space, in which problem dimension's size equals to the relevant service size shown in graph. we run 30 times independently for each dataset. In addition, weights setting are flexibly defined by users' preferences. As part of their requirement, we configure weights of fitness function to properly balance functional side and nonfunctional side. Therefore, w_1 and w_2 are equals to 0.1 and 0.4, and w_3, w_4, w_5, w_6 are all set to 0.125 accordingly.

5 Results and Analysis

5.1 Convergence Test

To analysis the effectiveness of our approach, we explore the convergency rate of the proposed method in this section to investigate the convergency of five tasks in WSC09. To further study an overall effectiveness of evaluation model and impacts of all involved components in the fitness function. We analysis all the

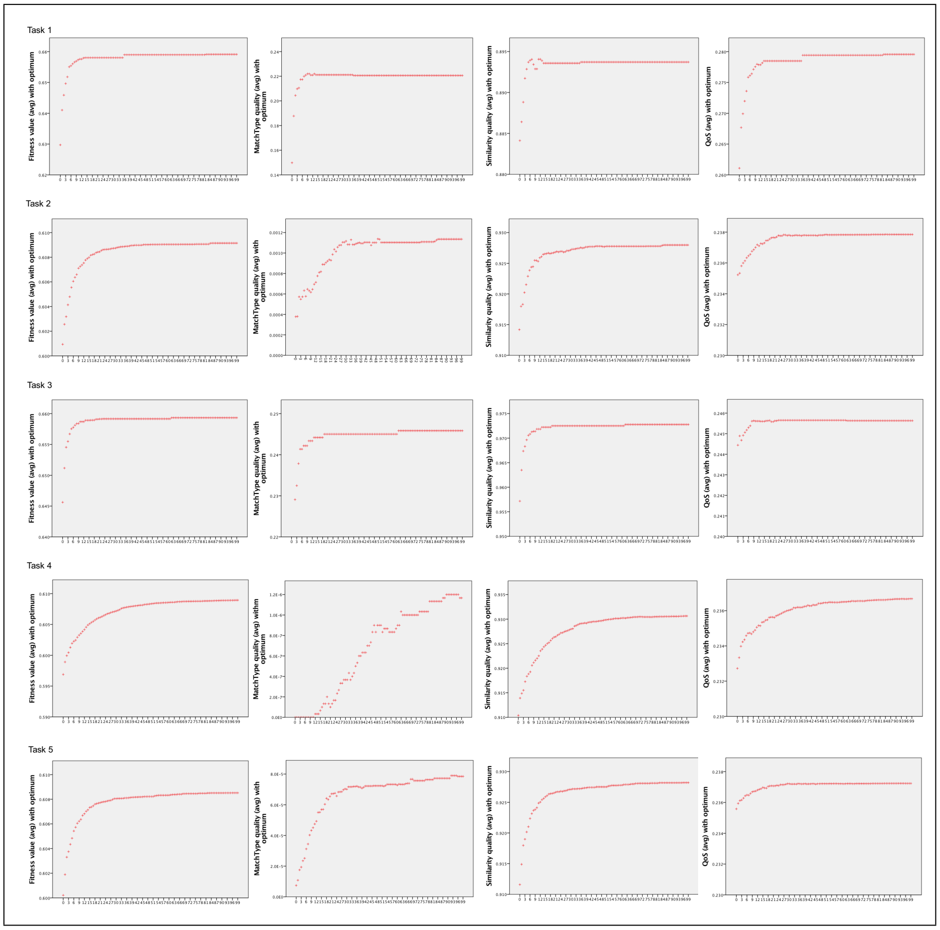

Fig. 5. Average Fitness, Average MatchType Quality, Average Similarity quality and Average QoS per generation with comprehensive quality optimum

performances of these components in the whole evolutionary process in Figure 5, in which the five tasks' experiment results are arranged in four groups consisting of average fitness, average matchType quality, average similarity quality and average QoS for generation 0-99 with optimum.

Firstly, the average fitness value with optimum is calculated by the average value of best fitness found in each generation over 30 independent runs. The value plotted in the first column group ranges from 0 to 1 in figure 5, and it is considered to be more optimised if its value is closer to value 1. We can see that there is a significant increase in the fitness value (avg) with optimum between generation 0 and generation 15-25, the remained generation continues to produce a steady but moderate improvement in the fitness value and eventually reach a plateau with no further changes. The same behaviour is observed over the rest tasks. Also, there is a fast convergence of the fitness value that be observed. That is simply because of many repetitive solutions in the indirect web service composition representations in the search space.

We also investigate the variation of two factors consisted in the functional quality part — average matchType quality with optimum and average similarity quality with optimum from generation 0 to 99 in second and third column groups of Figure 5. In these groups, both the average matchType quality with optimum and average similarity quality with optimum are the mean value corresponding to the best fitness value found in each generation over 30 independent runs. The dominant tendency of the marked value representing a similar characteristic compared to the average fitness value group trend in five tasks. However, there are some slight fluctuations over the generations, it due to the single objective fitness function that prevents selecting the worst component quality without granting for the best.

Lastly, It is interesting to look at the average QoS per generation for the 30 independent runs when the behaviour of functional quality moves upward. Here average QoS with optimum is also the value corresponding to the fitness value with optimum in each generation, and we display the results in the fourth column group in Figure 5. It is obvious that the overall trend of QoS moves upward to a high constant level in five independent tasks. Additionally, we don't see too much trade-off from the QoS.

5.2 Comparision Test

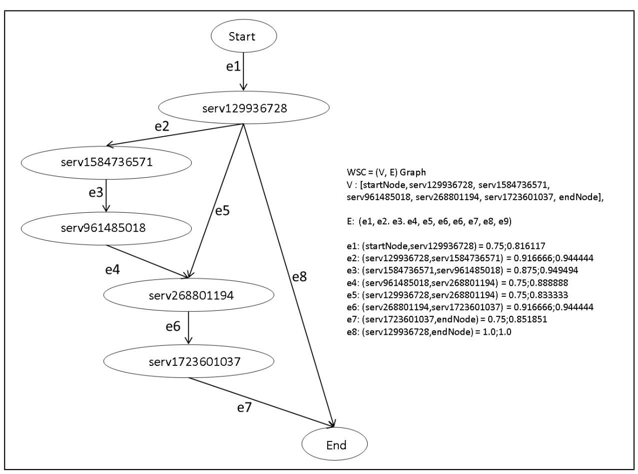

Fig. 6. Example composition solutions for problem1 WSC'09.

We defined our optimised web service composition as $WSC = (V, E)Graph$, where V is a set of services as vertex: $V = [S1, S2...Sn]$ and E is a set of service connections as edges associated with two values of matchType quality and semantic similarity quality: $E = e_1, e_2, ...e_n$ where $e1$ is define as $(S_1, S_2) = q_{mt}, q_s$. Here we provide an example of the web service composition solution to task 1, which can be described in the Figure 6. The data of composite web service flows from the start to the end, where five web services involved and linked with each other using edge connections. Besides that, $q(s_{mt})$ and $q(s_s)$ are calculated for all edges $e_1, e_2, ...e_n$, and further aggregated in Q_{mt} and Q_s respectively. In addition, Q_{QoS} is calculated by all the non-functional attributes of V using aggregation rules defined before. The demonstration of the solution is to make better comparison of results using the same solution model from different approaches .

Now we look at Q_{mt}, Q_s and Q_{QoS} defined in the solution model using black-box testing for the comparison, where the comprehensive quality awareness approach and QoS awareness approach [8,11,16,26] are compared to reveal how good our evaluation mode is in a decision table shown in Table 3. Solutions to five tasks are compared using two evaluation models in WSC09. In each task, we compare Q_{mt}, Q_s and Q_{QoS}, and Q_{QoS} is normalised to make it comparable to another method in our comprehensive awareness approach

Table 3. Quality of two evaluation model in a decision table

		Approach 1 QoS-aware Evaluation	Approach 2 Comprehensive Quality Evaluation
Condition	dataset1	√	√
	dataset2	√	√
	dataset3	√	√
Task1 Optimised solution	Q_{mt}	.232635	.232635
	Q_s	.903572	.903572
	Q_{QoS}	.578577	.578577
Task2 Optimised solution	Q_{mt}	.001828	.000851↓
	Q_s	.917172	.938840↑
	Q_{QoS}	.480251	.473002↓
Task3 Optimised solution	Q_{mt}	.191188	.247836↑
	Q_s	.951509	.973723↑
	Q_{QoS}	.493927	.491538↓
Task4 Optimised solution	Q_{mt}	.919678	.943406↑
	Q_s	.000000	.000009↑
	Q_{QoS}	.480818	.472485↓
Task5 Optimised solution	Q_{mt}	.000094	.000109↑
	Q_s	.927476	.930975↑
	Q_{QoS}	.476236	.475128↓

In Table 3, Task 1 represents the same solution using different methods where the values of Q_{mt},Q_s and Q_{QoS} are all the same. It is due to the size of dataset 01 is very small in both available services and ontologies. However, As the size of dataset increase, we can recognise a trade-offs in task 2 using our evaluation approach, where a 0.021668 increase in similarity quality and a 0.00098 decrease in matchType quality with weights 0.4 and 0.1 respectively so that solution to task 2 is still considered to be an improvement in the functional quality part while a decrease value of 0.007249 in QoS. In task 3, the benefit of functional part quality is clearer with an increase value of 0.056648 and 0.078862 in similarity quality and matchType quality respectively while a slight decrease in QoS. later on, the rest tasks perform the same behaviour in Q_{mt},Q_s and Q_{QoS} as task 3. In conclusion, we can perceive that our evaluation could find out better functional quality with a reasonable trade off in QoS.

6 Conclusion

This work introduced a more applicable and simpler evaluation model for comprehensive quality awareness semantic automated web service composition that relies on semantic matchmaking quality extension to QoS-aware consideration. The key idea of these evaluation model is to consider the quality of semantic matchmaking corresponding to different matchmaking types. Also, the effectiveness of our model is also proved to obtain better functional quality with a reasonable trade-off in QoS. Future works in this area should investigate more reasonable matching types, explore the comprehensive quality in multi-objective approach, and improve efficiency in the functional quality calculation.

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