A QoS-based service retrieval methodology for digital ecosystems

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Abstract: The emergence of the World Wide Web and its influence on the fields of industry, commerce, healthcare and so on, has led to an innovative, dynamic, open, collaborative and interactive environment – the digital ecosystem. Whereas service plays an important role in digital ecosystems, there is no technology available to retrieve heterogeneous and geographically dispersed services. Additionally, no methodology has been proposed in the literature that can distinguish or rank the services based on the Quality of Services (QoS). In order to address these issues, we propose a semantic service retrieval engine which incorporates a novel semantic QoS evaluation methodology. The salient feature of this methodology that sets it apart from any other QoS evaluation methodologies is that the evaluation of the service and the subsequent quantification of QoS is a combination of subjective and objective QoS measures. Another salient feature of our proposed methodology is that it enables the domain-specific ranking of services. Finally, an online prototype is implemented to evaluate our methodology, the results of which are discussed in this paper.

Keywords: CCCI metrics; digital ecosystems; quality of services; QoS; service computing; service retrieval.

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1 Introduction

The emergence of the World Wide Web and its influence on the field of industry, commerce and healthcare, *etc*., has led to a dynamic, open, collaborative and interactive web environment. This web-based environment has stimulated rapid business development for the past ten years, by generating a series of web-based business paradigms and providing increasing business opportunities. Meanwhile, this new business environment has led to the development of the Digital Ecosystems environment which transcends the old, static, closed and locally-based business environment (Chang and West, 2006; Boley and Chang, 2007).

Digital Ecosystems is an open, loosely coupled, and collaborative environment which provides species with underlying infrastructures and technologies in order to ensure their survival (Chang and West, 2006). Species in the Digital Ecosystems comprise biological species (*e.g.*, humans), economic species (*e.g.*, business organisations) or digital species (*e.g.*, agents). These species can act as dual roles in the Digital Ecosystems environment, which are service provider (or called server) and service requester (or called client). A service provider can simultaneously be a service requester. Services in the Digital Ecosystems can involve multiple forms including personal services for humans, business services for organisations, and web services for agents. Two issues emerge here as follows:

1. There are numerous services in the Digital Ecosystems which are heterogeneous and geographically dispersed. Currently, no technology exists that can semantically define the structure of these services and relationships between these services. In other words, the services in the Digital Ecosystems are not properly indexed, either semantically or syntactically. This raises the issue that a service requester cannot conveniently retrieve a service provider for a given service. Additionally, the search results are not precise and there is information overload (Berghel, 1997).

2. Since the services in the Digital Ecosystems are multitudinous and heterogeneous, and currently there is no technology specifically designed to evaluate the Quality of Services (QoS) in the context of Digital Ecosystems, this produces another issue – that it is difficult for a service requester to distinguish services based on their QoS. Additionally, it is not possible for service requesters to rank the service providers, based on their QoS values. By means of such a methodology, service requesters would be able to make informed and wise assessments about the service provider with whom they should be interacting.

To resolve the two issues, in this paper we propose a QoS-based service retrieval methodology for the Digital Ecosystems. The rest of the paper is organised as follows: in Section 2 we undertake a brief survey of the existing QoS evaluation methods and analyse the limitations of these methods; in Section 3, we employ a case study in order to illustrate the need for QoS-based service retrieval for the Digital Ecosystems; in Section 4, we propose some additional metrics which are based on the Correlation of Interaction, Correlation of Criterion, Clarity of Criterion, and Importance of Criterion (CCCI) metrics proposed by Chang *et al*. (2005b) and Hussain *et al*. (2004) in order to enable domain-specific ranking and evaluation of services; in Section, 5 we propose a conceptual framework of a QoS-based service retrieval engine; in Section 6, we present the prototype that we have developed for the evaluation of our proposed methodology. The results that we obtained are presented and discussed in this section. Finally, Section 7 concludes the paper and presents the conclusions.

2 Background

The term 'QoS' originated from the teletraffic engineering field, which is defined in the ITU standard X. 902 as 'a set of quality requirements on the collective behaviour of one or more objects' in the telephony field (ITU-T Study Group, 2006). In the network field, QoS is concerned with the level of QoS. The definition of QoS has been applied to many areas such as telephony, IP, remote systems, *etc*. QoS can be broadly classified into two types, namely subjective QoS and objective QoS. Objective QoS is something which can be measured directly; subjective QoS corresponds to users' perception of the service quality. Naturally, the subjective QoS is more difficult to track as it may be irrelevant to technical problems (Sutinen, 2004). Currently, there are a great number of QoS evaluation methods being designed, which vary depending on different application domains and user requirements.

While most of QoS research focuses on the field of mobile information systems (Bohnert *et al*., 2008; Ditze, 2006; Durresi *et al*., 2005; Nguyen-Vuong and Agoulmine, 2007; Papadimitriou and Tsaoussidis, 2005), networking (Cruz, 1995; Gelenbe *et al*., 2004; Georgiadis *et al*., 1996; Jo *et al*., 2005), real-time applications (Atdelzater *et al*., 2000; Clark *et al*., 1992; Lu *et al*., 2002; Tokuda and Kitayama, 2006), middleware (Afandi *et al*., 2006; Frolund and Koistinen, 1998; Hiltunen *et al*., 2000; Zinky *et al*., 2000), and workflow systems (Bettini *et al*., 2002; Eder *et al*., 1999; Klingemann *et al*., 1999; Klingemann, 2000), few researchers have concentrated their efforts on the QoS evaluation for web services, which mainly focuses on regarding the Non-Function Properties (NFPs) of web service as the metrics for QoS evaluation. NFP is a set of restrictions for the functional and behavioural properties of web services. The former relates to the functions of a web service and the latter is the mechanism of a web service (Chung, 1991). The typical QoS evaluation methods for web service are described in the rest of this section.

Zeng *et al*. (2003) propose a group of five NFP metrics for web service QoS measurement. The first metric is execution price; that is, the amount of money that a service requester has to pay for executing the service operation. The second is execution duration; that is, the expected delays in seconds between the moment that a request is sent and the moment the results are received. The third is reliability, which is the probability that a request is correctly responded to within a maximum expected time frame. The fourth is availability; that is, the probability that the service is accessible. The fifth is reputation, which is a measure of the web service's trustworthiness value. Of these, the first and second metric negatively affect QoS performance, whereas the third to the fifth metric positively affect QoS performance. The value of each metric is between 0 and 1. By computing a weighted aggregate (with the aggregate of the weights being equal to 1) of the five metrics, the integrated QoS score of a web service is obtained (between 0 and 1).

Roman and Lausen (2005) designed a Web Service Modelling Ontology (WSMO) approach that recommends a set of non-functional properties for each particular element of a web service description. Toma *et al*. (2007) propose a web service evaluation system based on two different evaluation strategies. One strategy is to use the WSMO to describe the values of NFPs of web service, such as QoS, Service Level Agreement (SLA), *etc*. Hence, web services can be ranked according to the values of user-preferred NFP. Another strategy is a multi-criteria evaluation, which considers evaluating multiple NFPs from three main perspectives – the user-preferred NFPs, the level of importance of the NFPs, and the ascending or descending order of services.

Gekas (2006) proposes a set of metrics for web service evaluation. Four main categories of evaluation strategies are provided by these metrics: degree-based evaluations that calculate the percentage of fed services in each web service, hubs-authorities-based evaluations that calculate the ratio between the number of incoming services and the number of outgoing services, non-functional evaluations that focus on the NFPs of web service, and non-connectivity rankings that focus on the connectivity of web service networks.

Zhou *et al*. (2005) propose a DARPA Agent Mark-up Language (DAML)-based QoS management framework. The framework contains a QoS Metrics layer that provides the DAML-annotated definitions of QoS metrics for QoS measurement. The layer is a server-client structure in which a ComplexMetric stands in the centre to calculate the evaluation results collected from distributed AtomicMetrics that collects the first hand measurement data from the measurement handler (NFP metrics).

The limitations of the above web service QoS evaluation methods can be concluded as follows:

- The existing QoS methods are designed for the web service environment. However, in the Digital Ecosystems, the content of services is more than just web service, which concerns both concrete services (*e.g.*, personal and business services) and virtual services (*e.g.*, web services). Therefore, these metrics cannot cover all services and are difficult to apply to the Digital Ecosystems.
- The existing QoS approaches do not provide any mechanism to enable domain-specific criteria assessments. The reason that we need domain-specific criteria is that the criteria for service assessments could different in different domains. In other words, the criteria for service assessments are not necessarily the same across all the domains in Digital Ecosystems. For example, the criterion 'confidentiality' for evaluating a web service in social communities cannot be regarded as semantically similar to a criterion with the same name for a web service in e-business, and the two services cannot be ranked under the same criterion.

- Most of these methods are objective QoS evaluations, which do not consider the service requesters' perceptions about quality. It is well-known that service requesters are the recipients of services and who provide the QoS assessment and hence who should have the most important impact on deciding QoS.

3 Case study

In this section, by means of the case study below, we will discuss the issues associated with QoS-based service retrieval in the Digital Ecosystems:

> Hai lives in City A and one day he needs an air cargo service. There are many companies that provide air cargo services within City A. As a result, Hai intends to find out the overall QoS ranking for the air cargo companies in order to make an objective decision. In addition, Hai may intend to make a service selection by assigning greater preference to certain criteria. Moreover, after selecting an air cargo company and conducting a service transaction with the company, Hai may intend to contribute to the ranking of air cargo companies by evaluating this company's performance in this transaction.

Here we formalise Hai's requirements in the Digital Ecosystems as follows:

- A service retrieval engine is required to retrieve available service providers that can provide the desired service within a specific area, that is, retrieving service providers who can provide an air cargo service in City A.
- A QoS-based service ranking methodology is required to rank service providers under a service concept in multiple ways (or according to multiple criteria) according to their performance in the relevant service activities or against given criteria, *e.g.*, ranking the companies who can provide an air cargo service based on their past performance under the criterion of quality, quickness, price or a combination of these.
- A QoS-based service evaluation methodology is required to allow a given service requester to evaluate a service provider's performance in a service transaction comprising of multiple criteria, thereby allowing Hai to evaluate an air cargo company's performance under the criterion of quality, quickness, price, after he conducts an air cargo service transaction with the company.
- The service evaluation methodology can be utilised for the benefit of the service ranking methodology; that is, Hai's evaluation of the air cargo company can be employed as one of the foundations that the company relies on in its ranking within the air cargo service.

While there are a great number of available commercial search engines, such as Yahoo!, Google™, local search or online Yellowpages®, which would allow Hai to retrieve a desired service in a specific location, these search engines are not specially designed for service retrieval, which is not capable of semantically defining the service concepts. For example, the concept 'car sale' is often put in the same group as the concept 'car rental' in some commercial search engines. In fact, these concepts are in different domains of the Digital Ecosystems, with the former belonging to the product domain and the latter belonging to the service domain. Thus, there is a heterogeneous problem in defining service concepts in these search engines. Furthermore, another limitation of the search engines is that Hai cannot find out which service provider has better performance because these retrieval engines do not provide QoS evaluation and ranking mechanisms of the retrieved services. In addition, another crucial issue is that different service concepts should employ different evaluation criteria, which are specific to that service domain.

Ontology is defined as "an explicit specification of a conceptualization" (Gruber, 1995), which can be used to solve the heterogeneous problem in defining service concepts and to disambiguate their evaluation criteria. In other words, ontology can be adopted to define the boundary of service concepts and service evaluation criteria. By means of an ontology, each service concept has a clear definition and each set of evaluation criteria corresponds only to its relevant service concept. Even though two concepts have same evaluation criteria, according to ontology, the semantics of the evaluation criteria are different with regard to different concepts.

Based on the above case study, it is observed that current search engines have inherent issues in carrying out QoS-ordered service search retrieval and ranking of service providers under a given service concept or which provide a given service. The research motivations in the field of QoS-based service retrieval have resulted from a need for:

- Designing an ontology-based service retrieval engine for the Digital Ecosystems which defines specific knowledge for service domains.
- Designing an ontology-based QoS evaluation methodology which allows a service requester to quantitatively evaluate a service provider from multiple respects of a service concept.
- Incorporating the QoS methodology into the service retrieval engine for service ranking and evaluation based on service requester-preferred criteria. These criteria for service ranking could be agreed upon for a given domain as the default criteria for ranking services, thereby leading to domain-specific criteria for service rankings.

4 Extension of CCCI metrics

In this section, based on the CCCI metrics proposed by Chang *et al.* (2005a–b) and Hussain *et al.* (2004; 2006), we propose two metrics which would assist in the process of:

1 ranking of the service providers based on their past behaviour

2 domain criteria specific ranking of service providers.

However, in order to understand the metrics that we are proposing in this paper, the users need to understand the definitions of trust, reputation and each of the metrics proposed in the CCCI metrics. In Section 4.1 and Section 4.2 we present a very brief overview of the CCCI metrics and the concepts of trust and reputation. In Section 4.3, we propose and define our proposed metrics.

4.1 Definition of trustworthiness and reputation

As proposed by Chang *et al.* (2005a–b) and Hussain *et al.* (2004; 2006), trustworthiness is defined as a numeric value that estimates the level of trust in a service interaction. Two roles are involved in such a service interaction, namely service provider and service requester. Service provider is an agent that provides a given service to another agent who is requesting for it. Service requester is an agent who is requesting a particular service (Chang *et al*., 2005a). The service requester has a given level of trust in the service provider, which is quantified and expressed as the trustworthiness value.

Based on the definitions proposed by Chang *et al*. (2005a–b) and Hussain *et al*. (2004; 2006), below we explain the terms 'a numeric value', 'estimate', 'level of trust', for elucidation purposes:

- 'A numeric value' refers to the quantification of the level of the trust in the service interaction.
- 'Estimate' refers to the measurement of the level of trust, which is a predictive and tentative measure.
- 'Level of trust' refers to the degree or the scale of trust that the service requester has in the service provider.

As proposed by Chang *et al*. (2005a–b) and Hussain *et al*. (2004; 2006), reputation is defined as the aggregation of the recommendations from the entire third party recommendation agents, in response to a service requester's reputation query with respect to the quality of a service provided by a given service provider, for a given service and within a given time slot.

Based on the definitions proposed by Chang *et al*. (2005a–b) and Hussain *et al*. (2004; 2006), we explain the terms 'reputation query', 'recommendation third party', 'recommendation' below for elucidation purposes:

- 'Reputation query' refers to the query made by the service requester with respect to the reputation of the service provider. It normally consists of the queried service provider, the context and the time lot of the query request.
- 'Third party recommendation agent' refers to an agent that has previously interacted with the service provider in the context and time lot specified in the reputation query. The third party recommendation agent can provide recommendations to the reputation query.
- 'Recommendation' refers to the opinion of the third party recommendation agent to the reputation query.

4.2 CCCI metrics

CCCI metrics is a group of metrics developed by Chang *et al*. (2005a–b) and Hussain *et al*. (2004), with the purpose of measuring the trustworthiness and reputation of services. These metrics are based on the premise that a service interaction between a given service provider and a service requestor takes place in a given context (or scenario) which in turn could be de-composed into a finite number of criteria. A criterion is defined as a decisive factor of the mutually agreed service performance between the service provider and service requester for quality assessment purposes. It is important to note that the service requester and the service provider engage in a negotiation phase before the interaction and agree on the mutually agreed service or the SLA.

By making use of the CCCI metrics, the service requester can evaluate the performance of the service provider according to the decisive factor(s) after the service interaction. The criteria are often a series of activities. Thus, the measurement of the QoS for the service provider in the interaction becomes the measurement of each criterion involved in the service interaction.

To enhance the application of CCCI metrics in the service evaluation and ranking, we extend the theory of CCCI metrics by proposing two additional metrics in addition to the existing ones. They are (a) the reputation of the service provider; and (b) the actual behaviour of the service provider against a given criterion. First of all, we provide the metrics for the third party recommendation agents (namely the service requesters who have previously completed the specified service interactions with the service providers in the Digital Ecosystems) to provide recommendations (quantitive evaluations) as their trustworthiness value about the service provider. Secondly, based on the trustworthiness values from all third party recommendation agents involved in the specified service interaction, the corresponding service provider's reputation value in the service can be computed and utilised for the service ranking. Finally, an additional function is provided from the extended CCCI metrics, by allowing service requesters to rank service providers based on given specified criteria.

In order to understand these metrics and their workings, it is very important to understand the workings of the proposed CCCI metrics. For elucidation purposes, we explain the proposed CCCI metrics by Chang *et al.* (2005a–b) and Hussain *et al.* (2004) in this section.

The CCCI metrics is a suite of four metrics as shown below:

1 Correlation of an interaction ($Corr_{Interaction}$)

2 Correlation of a criterion ($Corr_{Criterion}$)

3 Clarity of a criterion ($Clear_{Criterion}$)

4 Importance of a criterion ($Imp_{Criterion}$).

In the following sections, we will describe the four metrics and the other involved definitions in detail for elucidation purposes only.

Definition 1 *Correlation of an interaction (*$\mathrm{Corr}_{\mathrm{Interaction}}$*)*

As defined by Chang *et al.* (2005a) and Hussain *et al.* (2004), the $Corr_{Interaction}$ is a metric that expresses:

> "the degree of parallelism between the actual behaviour of a service provider in the service interaction ($ActualBehaviour_{Interaction}$) and the mutually agreed behaviour of the service provider in the service interaction ($MutuallyAgreedBehaviour_{Interaction}$)".

The $ActualBehaviour_{Interaction}$ can be determined by aggregating the actual behaviour of each criterion involved in the service interaction. Similarly, the $MutuallyAgreedBehaviour_{Interaction}$ can be determined by aggregating the mutually agreed behaviour of each criterion involved in the service interaction.

Mathematically, $Corr_{Interaction}$ is computed as shown below:

$$Corr_{Interaction} = \frac{ActualBehaviour_{Interaction}}{MutuallyAgreedBehaviour_{Interaction}}. \tag{1}$$

Definition 2 Correlation of a criterion ($\mathrm{Corr}_{\mathrm{Criterion}}$*)*

As defined by Chang *et al*. (2005a) and Hussain *et al*. (2004), the $Corr_{Criterion}$ is a metric that expresses "the degree of parallelism between the actual behaviour and the mutually agreed behaviour of the service provider in a given criterion".

Definition 3 Actual Behaviour Criterion Correlation ($\mathrm{ABCorr}_{\mathrm{Criterion}}$*)*

As defined by Chang *et al*. (2005a) and Hussain *et al*. (2004), the $AB_{CorrCriterion}$ is a metric that "qualifies and expresses the actual behaviour of the service provider in the given criterion" for the third party recommendation agent. The $AB_{CorrCriterion}$ could have seven levels as shown below:

0 – Ignorance

1 – Very dissatisfied

2 – Dissatisfied

3 – Neutral

4 – Partially satisfied

5 – Satisfied

6 – Very satisfied.

Definition 4 Mutually Agreed Behaviour Criterion Correlation ($\mathrm{MAB}_{\mathrm{CorrCriterion}}$*)*

As defined by Chang *et al*. (2005a) and Hussain *et al*. (2004), the $MAB_{CorrCriterion}$ is a metric that "qualifies and expresses the mutually agreed behaviour of the service provider in the given criterion". $MAB_{CorrCriterion}$ for each criterion that has been mutually agreed upon by both the interacting parties and documented in the SLA would be '1'.

Definition 5 Clarity of a criterion ($\mathrm{Clear}_{\mathrm{Criterion}}$*)*

As proposed by Chang *et al*. (2005a) and Hussain *et al*. (2004), the $Clear_{Criterion}$ is a metric that "qualifies the extent of weather a criterion is mutually agreed between the service provider and the service requestor".

For a given criterion, $Clear_{Criterion}$ can have two levels as shown below:

0 – This criterion or its output or both have not been mutually agreed upon by the involved parties.

1 – This criterion along with its output has been mutually agreed upon by the involved parties.

Definition 6 Importance of a criterion ($\mathrm{Imp}_{\mathrm{Criterion}}$*)*

As proposed by Chang *et al*. (2005a) and Hussain *et al*. (2004), the $Imp_{Criterion}$ is a metric that qualifies the extent of importance of a criterion for the service requestor in the interaction.

For a given criterion, $Imp_{Criterion}$ can have three levels as shown below:

1 – Not important

2 – Important

3 – Very important.

*Definition 7 Trustworthiness (*Trustworthiness*)*

As proposed by Chang *et al*. (2005a) and Hussain *et al*. (2004), the *trustworthiness* value of a service interaction is expressed as "the degree of consonance or parallelism between the actual behaviour of a service provider and the mutually agreed behaviour of the service provider in the service interaction, as perceived by a service requestor". As a result of this, the trustworthiness value of a service interaction would be same as the correlation of the interaction ($Corr_{Criterion}$).

Mathematically, the formula of computing *Trustworthiness* is shown below:

$$\begin{aligned} Trustworthiness &= Corr_{Interaction} \\ &= \frac{ActualBehaviour_{Interaction}}{MutuallyAgreedBehaviour_{Interaction}} \\ &= \frac{\sum_{i=1}^{n} ABCorr_{Criterion\,i} \times Clear_{Criterion\,i} \times \mathrm{Imp}_{Criterion\,i}}{\sum_{i=1}^{n} MABCorr_{Criterion} \times Clear_{Criterion\,i} \times \mathrm{Imp}_{Criterion\,i}} \end{aligned} \quad (2)$$

where n is the number of criteria involved in a given service interaction.

Trustworthiness can have seven levels as shown below:

0 – Ignorance or unknown

1 – Completely untrustworthy or extremely untrustworthy

2 – Untrustworthy

3 – Minimal trustworthy

4 – Partially trustworthy

5 – Trustworthy

6 – Extremely trustworthy.

By observing the formula of trustworthiness, it is found that the service requesters can evaluate the trustworthiness of the service providers in the service interaction by assigning values to the components of the formula, namely the components of CCCI metrics – $ABCorr_{Criterion}$, $Clear_{Criterion}$, and $Imp_{Criterion}$. Once these values have been assigned, the trustworthiness value can be computed. The service requester can make use of these assigned values for recommendation purposes in the future.

4.3 Extension of the CCCI metrics for QoS-based service ranking and domain specific criteria based QoS ranking

In this section, in order to apply CCCI metrics to QoS-based service ranking, we propose two new metrics in addition to the existing suite of CCCI metrics. The definitions of these metrics are given in this section. These metrics enable domain specific (or service requestor specific) service ranking.

*Definition 8 Reputation (*Reputation*)*

We define the *reputation* value of a service provider in a given context as the average of all involved third party recommendation agents' *trustworthiness* values for this service provider in the same service context:

$$\text{Reputation} = \frac{\sum_{i=1}^{m} Trustworthiness_i}{m} \tag{3}$$

where *m* is the number of third party recommendation agents for this service provider in the service interaction.

Reputation can have seven levels as shown below:

0 – Cannot determine reputation

1 – Extremely bad reputation

2 – Bad reputation

3 – Minimally good reputation

4 – Partially good reputation

5 – Good reputation

6 – Extremely good reputation.

This metric would enable the ranking of a set of service providers according to their reputation value. The reputation values computed by using the above formulae could be used foe context-based service ranking.

Definition 9 Actual behaviour of a service provider in a single criterion ($\text{ActualBehaviour}_{\text{Criterion}}$*)*

In addition, in order to allow service requesters' to rank services according to a given criterion, we propose the metric of Actual behaviour of a service provider against a single criterion ($ActualBehaviour_{Criterion}$).

We define the $ActualBehaviour_{Criterion}$ as a metric that qualifies and expresses the actual behaviour of a service provider against a given criterion, as perceived by all involved third party recommendation agents.

In consonance with the levels of trustworthiness, $ActualBehaviour_{Criterion}$ can have seven levels as shown below:

0 – Ignorance

1 – Very dissatisfied

2 – Dissatisfied

3 – Neutral

4 – Partially satisfied

5 – Satisfied

6 – Very satisfied.

$ActualBehaviour_{Criterion}$ is determined by the average of all service requesters' evaluation values for this given criterion, namely the average value of Actual Behaviour Criterion Correlation ($ABCorr_{Criterion}$), which will be introduced in the next section. The formula of $ActualBehaviour_{Criterion}$ is given as:

$$ActualBehaviour_{Criterion} = \frac{\sum_{i=1}^{m} ABCorr_{Criterion\,i}}{m} \tag{4}$$

where m is the number of evaluators for this criterion.

With regards to the case study in Section 3, the functions of the extended CCCI metrics that can be utilised to satisfy Hai's requirements, by providing a series of quantitive methodologies for him, are as follows:

- Evaluating its performance in each air cargo industry standard (criterion) – $ABCorr_{Criterion}$.
- Evaluating Hai's trustworthiness toward a given air cargo service provider – *Trustworthiness.*
- Finding out the reputation of the companies that provide air cargo services in City A from the perspective of air cargo services – *Reputation.*
- Finding out the performance of the companies in each industry standard (criterion) of air cargo services – $ABCorr_{Criterion}$.

Therefore, the extended CCCI metrics can be applied to achieve the first objective of our research, which is to design an ontology-based QoS evaluation methodology that allows a service requester to quantitatively evaluate a service provider against multiple criteria.

5 System architecture

In this section, we will introduce the implementation details of our second and third research task – designing an ontology-based service retrieval engine and incorporating it into the extended CCCI metrics. Section 5.1 describes the workflow of the QoS-based service retrieval process; Section 5.2 presents the format of service ontology concepts and service metadata; Section 5.3 explains the system architecture of the service metadata evaluation.

5.1 QoS-based service retrieval workflow

Figure 1 displays the QoS-based service retrieval workflow. Three bases are involved in the service retrieval process: service ontology base, service metadata base, and service metadata evaluation database (database). The first and the second are an ontology mark-up language annotated Knowledge Base (KB), which is used to store the structured service concepts and service metadata. Meanwhile, the service metadata are linked to and classified by their semantically relevant service concepts. The third is a database used to store reputation evaluation criteria and their values. The service retrieval engine performs a five-step process for service retrieval, ranking and evaluation as shown below:

Step 1 *Service concept retrieval.* The service requester enters a set of key terms (*e.g.*, ‘air cargo’), combined with a set of Boolean operators (*e.g.*, and, or, not) and some parameters of the search. The query terms will be passed into the service ontology base to match with service concepts (introduced in Section 5.2).

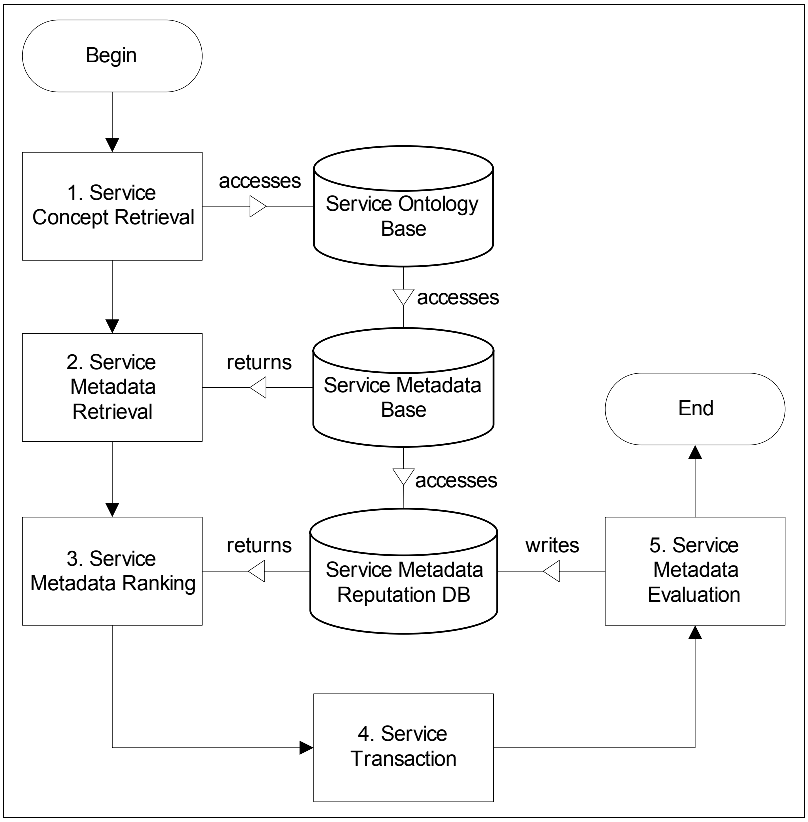
Step 2 *Service metadata retrieval.* If a service concept is matched with the query terms, its linked (semantically relevant) service metadata will be retrieved from the service metadata base, and displayed to the service requester.

Step 3 *Service metadata ranking.* The returned service metadata can be ranked according to multiple criteria by retrieving reputation criteria content and values from the service metadata reputation database.

Step 4 *Service transaction.* Upon receiving the multi-linearly ranked service metadata, the service requester is able to make a service selection based either a personal preference of evaluation criteria or based on their reputation values or based on domain-agreed service evaluation criteria. Once a selection has been made, the service requester can find the contact details and other information of the service provider from the selected service metadata (introduced in Section 5.2). The requester then can contact the service provider for the forthcoming service transaction. The service transaction process is out of the system boundary and needs to proceed without the supervision of the service retrieval engine.

Step 5 *Service metadata evaluation.* After the service requester completes a service transaction with the chosen service provider, he/she is authorised to evaluate the reputation of the provider in the service.

Figure 1 QoS-based service retrieval workflow



5.2 Service ontology concept and service metadata format

The service ontology is a multi-layer service concept hierarchy, in which its upper level concepts are abstract service concepts that represent the abstraction of service taxonomies within specific domains. The bottom level concepts are concrete service concepts, which correspond to the actual services in the Digital Ecosystems. The main difference between the abstract concepts and concrete concepts is that only the latter can link service metadata.

The Service Ontology Concept is defined as the conceptualisation of the service, which is identified by a Service Concept Name and defined by a Service Concept Description.

We present the Service Ontology as the combination of the ontology name and a tuple where the elements of the tuple can be complex elements as follows:

Service [Service Concept Name, Service Concept Description].

Service Concept Name refers to the name that can be used to uniquely identify a service.

Service Concept Description refers to the definitional descriptions of a service. The purpose of this element in the tuple is to match the service concepts with service metadata when classifying metadata and to match the service concepts with query terms when a user makes a query. This process will be discussed in further detail in Section 6.

The service ontology concept is the definition of the service concept at the root of the service concept hierarchy. As children concepts, all other concepts in this hierarchy automatically inherit its properties. In addition, the concrete concepts have one extra property defined below:

Linked Metadata refers to the Uniform Resource Identifiers (URIs) of semantically relevant service metadata. By storing the URIs of metadata in the property, a concept can link itself to its semantically relevant service metadata and the service metadata can be classified into a category of service denoted by the service concept.

The major objective of service metadata is to provide meaningful information with regard to a given service provided by a service provider in the Digital Ecosystems. It is noted that a service metadata can be provided only by a service provider, which means that the services with the same name but which are provided by two different service providers must be conceptualised to two service metadata.

The service metadata can be represented as a tuple where the elements of the tuple can be complex elements as defined below:

> *[Service Name, Service Metadata Description, Service Provider Name, Provider Address, Provider Contact Details, Linked Concepts].*

Service Name refers to the name of a service metadata that can be used to identify itself by the service requester.

Service Metadata Description refers to the detailed text description with regard to the content of a service. This can be used for matching with a service concept, which will be described Section 6.

Service Provider Name refers to the name of the person or organisation that provides the service.

Provider Address refers to the physical address or street address where a service provider can be located.

Provider Contact Details refer to the information regarding how a service provider can be contacted, for instance, mail box, phone number, fax number, website and so on.

Linked Concepts refer to the URIs of semantically linked concepts. This is an inverse property of the 'linked metadata' property of the service concept, which allows a service metadata to link itself to its semantically relevant service metadata.

We would like to note that each service concept may link to more than one service metadata, and similarly, a service metadata may link to more than one service concept, which means that a service category denoted by a service concept may have more than one service and a service may belongs to more than one service categories in the Digital Ecosystems.

5.3 Service metadata evaluation

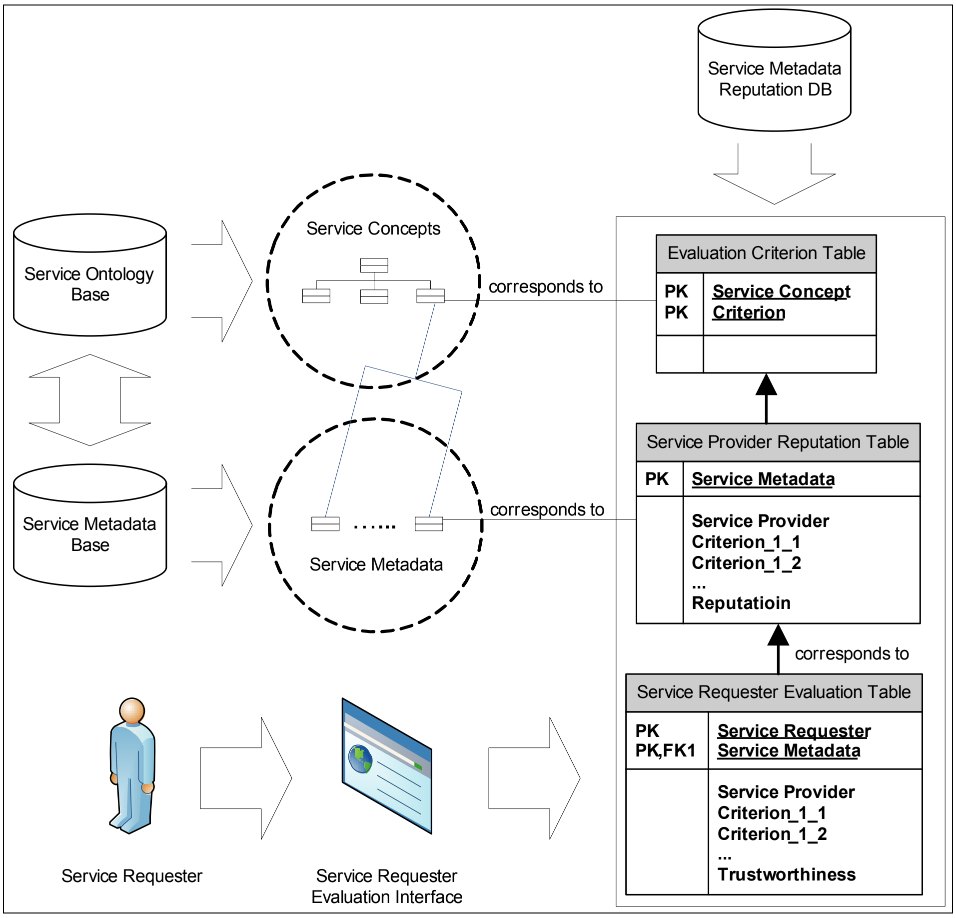
In this section, we will analyse the technical characteristics of the service metadata evaluation process. Figure 2 indicates the system architecture of the service metadata evaluation system, which consists mainly of a service requester evaluation interface and a service metadata reputation database. The interface is designed with the purpose of enabling a service requester to evaluate a given service provider's behaviour in the interaction, thereby contributing to the service provider's reputation. The tables in the service metadata reputation DB can be classified into three primary categories as follows:

1. *Evaluation criterion table* is designed to store the evaluation criteria for each service concept in the service ontology base. Therefore, each concept has its own particular criteria. There is only one evaluation criterion table in which each row corresponds to a criterion of a concept.
2. *Service provider reputation table* is designed to store the service provider's performance against each criterion of a service concept ($ActualBehaviour_{Criterion}$) and service provider's *Reputation* values for all service metadata linked a service concept. Apart from the service metadata evaluation, this table also functions as the data source for the service metadata ranking. Each service concept corresponds to a table in which each row corresponds to service metadata that are semantically relevant to the concept. In other words, if a service provider's services belong to a number of service concepts, there should be the same number of service provider reputation tables corresponding to the service provider. Furthermore, the contents of the criteria (column title, *e.g.*, 'Criterion_1_1' in Figure 2) are obtained from the evaluation criterion table.
3. *Service requester evaluation table* is designed to store a service requester's evaluation values to the service metadata linked by a service concept. Each service requester evaluation table corresponds to a service provider evaluation table. Each row of this table contains a service requester's evaluation value for each criterion of a service ($ABCorr_{Criterion}$) and the service requester's *Trustworthiness* value for this service.

In addition, there are some other available tables such as a service requester table that is used to store the basic information about service requesters and a service provider table that is used to store the basic information about service providers.

By means of the service requester evaluation interface (Figure 2), each service requester's evaluation values can be stored as a new row in the corresponding service requester evaluation table by obtaining the $ABCorr_{Criterion}$ values and calculating the *Trustworthiness* value. Subsequently the service providers' *Reputation* value and $ActualBehaviour_{Criterion}$ values in the corresponding service provider reputation table can be recomputed and updated immediately, to complete the whole service metadata evaluation process.

Figure 2 System architecture of the ontology-based service metadata evaluation system (see online version for colours)



6 System implementation

In this section, we will explain the implementation details regarding the QoS-based service retrieval engine for Digital Ecosystems. The implementation task can be divided into two phases – firstly constructing the service ontology base, service metadata base and service metadata reputation base; secondly building a web-based service retrieval engine incorporating the aforementioned bases.

For the first task, we utilise Protégé-OWL to build the two KB, and employ MySQL to build the database. In order to design the service ontology base, we choose the transport services as the domain for our ontology design, and we design a transport service ontology with 304 concepts on a 4-layer hierarchy. The in-depth information regarding the transport service ontology can be found in our earlier publications (Dong *et al.*, 2008b–c). To design the service metadata base, we choose the business webpages under the category of transport in the Australian Yellowpages® website as our service metadata source. In order to gather the service information from the business webpages and annotate them in Web Ontology Language (OWL), we designed a semantic crawler. The next task is to link the semantically relevant concrete (bottom-level) concepts and metadata. In order to carry this out, we designed an Extended Case-based Reasoning (ECBR) model, which originates from the set-theoretic Information Retrieval (IR) model. The ECBR model computes the similarity values between each concrete concept and metadata. If the similarity value is above a predefined threshold, the URI of each is stored in the corresponding property of the other. The in-depth information regarding the semantic crawler and the ECBR model can be found in our earlier publications (Dong *et al*., 2008a–b).

For the second task, we employ Java Server Pages (JSP), JavaScript, Java Servlet and Asynchronous JavaScript and XML (AJAX) in order to build the web-based prototype of our framework. Figure 3 and Figure 4 are the screenshots of the prototype, which are described as follows:

Figure 3 reveals the service metadata retrieval and ranking process of the prototype. Once a service requester enters the query terms (*e.g.*, air cargo) into the retrieval interface, the retrieval engine will match the query terms with all concepts stored in the service ontology base. If a concept is matched with the query terms, the concept will be displayed to the service requester. If this concept is an abstract concept in the ontology, all its subconcepts are displayed for the service requester's selection. This is a recursive process until the requester selects an abstract concept. Once an abstract concept has been selected, all its semantically relevant metadata from the service metadata base are displayed under the concept name (all the names under the label 'SDE'). These metadata are denoted by their service providers' names (usually a company's name, *e.g.*, 'lynair international'), in order to enable the service requester to easily distinguish between these service metadata. These metadata can be ranked in a multi-linear manner, including their $ActualBehaviour_{Criterion}$ values on each criterion (all the values under the label 'quality', 'quickness', and 'price' in Figure 3), their *Reputation* values (all the values under the label 'reputation'), number of evaluations (all the values under the label 'NumOfEva'), and states where the service providers are located (*e.g.*, 'SA').

Figure 4 depicts the service metadata evaluation function of the system. After a service requester completes a service transaction with a service provider, the service requester needs to obtain the evaluation permission from the system administrator by sending the administrator an inquiry e-mail. The administrator will forward the e-mail to the service provider to ask for confirmation. If the provider confirms the transaction, the service requester will obtain the permission immediately. Once the requester logs into the system and find the metadata under the corresponding service concept, he/she will find an available reputation evaluation form under the metadata information. The service requester needs to assign values to the metric of $ABCorr_{Criterion}$ (labelled as 'Your evaluation' in Figure 4), $Clear_{Criterion}$ (labelled as 'Clarity'), and $Imp_{Criterion}$ (labelled as 'Importance') for each criterion (price, quality, quickness in this case) involved in the service interaction. Once the form has been submitted, the *Trustworthiness* value that the service requester has given to the service provided by the service provider will be shown in a dialogue box. Then the $ActualBehaviour_{Criterion}$ value of each criterion and the *Reputation* value of the service provider will be updated in the service metadata reputation DB. It is noted that a service requester will have only one opportunity to evaluate the service provided by a service provider after the service transaction.

Figure 3 Screenshot of the QoS-based service metadata ranking (see online version for colours)

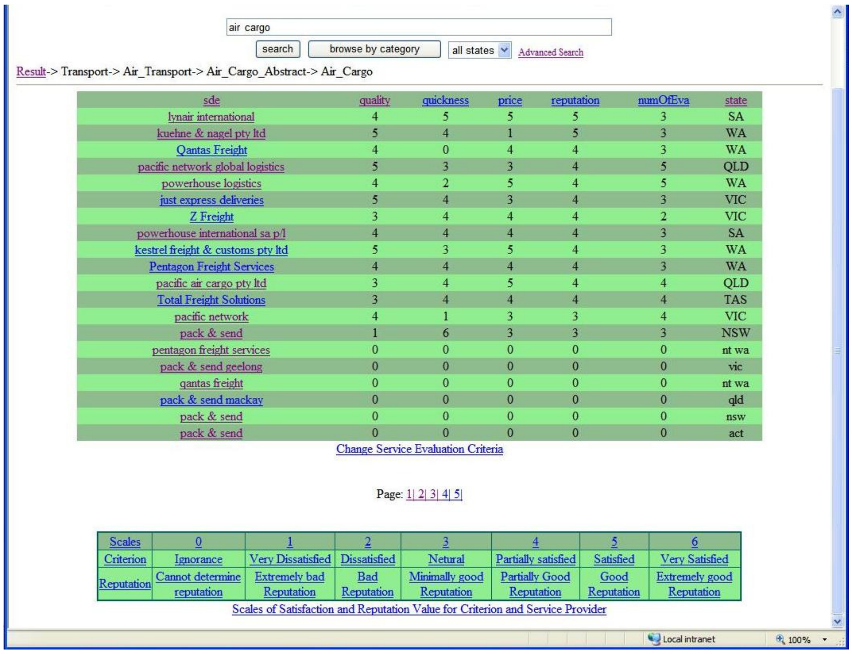
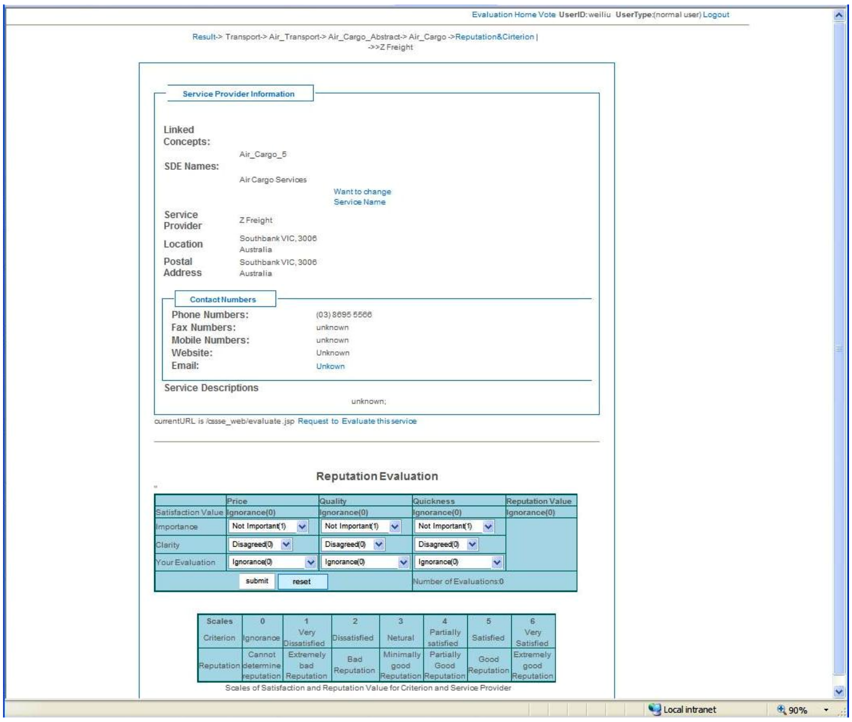


Figure 4 Screenshot of the service metadata evaluation window (see online version for colours)



7 Conclusion and future works

In this paper, by analysing the literature pertinent to the Digital Ecosystems, we discover two research issues that need research attention as follows: a service requester cannot conveniently retrieve a service provider for a given service or rank service providers providing the same (or similar) service based on their QoS values. Next, we briefly review the existing researches concerning QoS evaluation methods for web services, and observe that none of these existing research achievements can be applied to the context of Digital Ecosystems, since services in Digital Ecosystems have broader boundaries than services in the web service. In addition, none of the methods considers the domain-specific evaluation criteria. Moreover, most of these methods ignore the power of subjective QoS evaluation, as subjective evaluation has a higher impact on the evaluation of QoS. A case study is then presented to reveal the motivations of this research – designing an ontology-based service retrieval engine incorporated an ontology-based QoS evaluation methodology enabling service requesters to retrieve and evaluate services and to rank services on user-preferred manner. In order to address this objective, we propose two additional metrics in addition to the already proposed CCCI metrics. These new proposed metrics allow users (or service requestors) to rank services based on user-defined criteria or user-preferred criteria or domain-agreed criteria or based on their reputation values. To implement these metrics, we design the conceptual framework of a QoS-based service retrieval engine. The framework follows a five-step process for service retrieval, ranking and evaluation, namely: service concept retrieval, service metadata retrieval, service metadata ranking, service transaction and service metadata evaluation. A service ontology base, a service metadata base and a service metadata reputation base are involved in the working process. The service ontology base stores a service ontology that represents the knowledge of a specific service domain. The service metadata base stores service metadata that represent the knowledge of services provided by service providers. Service metadata are classified by the service ontology. Therefore, if a requester requires a service, s/he can search a service concept and then obtain all available services relevant to the service concept(s). The service metadata reputation database has the function of allowing requesters to evaluate a service after service transaction, and rank services based on user-preferred criteria or domain agreed criteria. Three primary types of tables are introduced in the database: an evaluation criterion table that stores the evaluation criteria based on service concepts, a service provider reputation table that stores service providers' reputation values and performance values on each evaluation criterion classified by service metadata and service concepts; and a service requester evaluation table that stores service requesters' trustworthiness values and evaluation values for each criterion classified by service metadata and service concepts. Finally, in order to evaluate our conceptual framework, we implemented a web-based prototype of the transport service domain. In addition, we designed a transport service ontology and a semantic crawler for collecting metadata for the service metadata base.

For our future work, we plan to invite service providers and requesters from the Australia-wide transport domain to participate in this service retrieval engine platform, in order to valuate the feasibility of this methodology by means of practical application.

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