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COMPUTER SCIENCE | RESEARCH ARTICLE

Integrating fuzzy theory and visualization for QoS-aware selection of SaaS in cloud e-Marketplaces

Azubuike Ezenwoke^{1*} and Matthew Adigun²

Abstract: Most cloud service e-marketplaces incorporate basic features like search and billing but lack more sophisticated elements that optimise users' experience. The cognitive demands of searching for and evaluating multiple cloud SaaS along multiple QoS criteria can be overwhelming, giving rise to what Alvin Toffler called *choice overload*. There is a need to integrate mechanisms that handles the vagueness that characterises the human decision-making process when finding suitable services. The objective of this paper is to reduce cognitive overload during cloud service selection in e-marketplaces by employing low cognitive demanding tools that leverage the dynamics of human expressions. We proposed a QoS-aware SaaS ranking and selection framework that integrates fuzzy theory and information visualisation for optimal decision-making in cloud e-marketplaces. An illustrative case study of Customer-Relationship-Management-as-a-Service e-marketplace demonstrated the framework's plausibility. The demonstration shows that our framework is a viable approach to rank and select SaaS in cloud e-marketplaces in

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PUBLIC INTEREST STATEMENT

Existing cloud service e-marketplace such as SaaSMax, Oracle e-marketplace, AppExchange incorporates basic features of an e-marketplace like search and billing. However, these platforms lack the more sophisticated elements that optimise the user experience. The cognitive demands of searching for and evaluating cloud SaaS along multiple criteria in an e-marketplace setting can be overwhelming, giving rise to the phenomenon of choice overload. The cloud e-marketplace must incorporate how human reason and express themselves when finding suitable cloud services. The main objective of this study is to reduce cognitive overload during cloud service selection in e-marketplaces. We hoped to do this by using low cognitive demanding tools that leverage the dynamics of human expressions. We have proposed an approach that uses fuzzy theory and information visualisation to optimises decision-making. Our proposal is a viable approach for ranking and selecting cloud service in cloud e-marketplaces that serves the platform's customers satisfactorily and can also potentially drive the business objectives of the e-marketplace platform.

a way that satisfactorily serves both the users of the platform and can potentially drive the business objectives of the e-marketplace.

Subjects: User Interface; Computer Science (General); Information & Communication Technology (ICT)

Keywords: Cloud computing; Fuzzy-AHP; Information visualisation; Fuzzy theory; SaaS; cloud e-marketplace

1. Introduction

Nowadays, cloud services have become a popular means to provide and consume IT services. The cloud's advent has considerably impacted the computing landscape. Traditionally, there are three primary cloud services categories classified as Software-, Platform-, and Infrastructure-as-a-Service denoted as SaaS, PaaS and IaaS, respectively (Odun-Ayo et al., 2020; Qaisar, 2012). Various IT services can be provided through the cloud to fulfil business objectives and usage scenarios based on traditional models. The popularity of cloud services, driven by the pay-as-you-use billing model, underscores the commoditization of these IT services. Sometimes, cloud services are made available and traded (i.e. bought and sold) in a marketplace environment (Akolkar et al., 2012; Blasco et al., 2020; Menychtas et al., 2014). Hence, users can search, pay for and use cloud services in such e-marketplaces (Akolkar et al., 2012; Khadka et al., 2011; Vigne et al., 2013). The search is performed by evaluating both the cloud service's functional capabilities in line with the user's desires for the quality of service (QoS) attributes. QoS factors of cloud services are the performance dimensions, and they constitute the primary consideration when selecting cloud services (Chen et al., 2013; Choi & Jeong, 2014). Some existing cloud service e-marketplace includes AppExchange, SaaSMax, Oracle e-marketplace, etc.; while incorporating essential characteristics of an e-marketplace like search and billing, these platforms lack the more sophisticated elements that can enhance user experience (Akolkar et al., 2012).

The cognitive demands of searching for and evaluating multiple SaaS along multiple QoS criteria in an e-marketplace setting can be overwhelming (Blasco et al., 2020). The users' difficulties when selecting from multiple choices can be termed choice overload (Toffler, 1970). Put differently, the more the choices, the lower the motivation to choose or the less satisfying the final choice (Haynes, 2009; Scheibehenne et al., 2010). Employing intuitively low cognitive demanding decision-making tools and mechanisms can reduce choice overloads in an e-marketplace environment. Such tools must leverage the dynamics of human expressions while improving the user's experience. Therefore, cloud e-marketplace must include a means to manage the uncertainties and vagueness that characterise the human decision-making process while supporting the process of finding suitable services. These are major requirements that would foster a qualitative user experience for the users of such platforms. Given the preceding, uncertainty theories, such as fuzzy theory and visualisation techniques, are potential methodologies to address this requirement.

Most of the groups of objects in the real world lack precisely defined inclusion criteria; some sample expressions include "the class of expensive holiday resorts", "the class of cheap cars", etc. Such class expressions underlie human judgements, particularly in decision making. Fuzzy theory, proposed by Zadeh (1975), is one way to handle such vagueness. Fuzzy theory enables representing objects or concepts in a vague manner full of subjectivity and ambiguity like human concepts and thinking process (Bai & Wang, 2006; Oladipupo et al., 2019). Noting that the ranking of SaaS choices hinges on the user's QoS requirements, the accuracy of such rankings should not be undermined by using approximately vague descriptions. More so, the flexibility of expressing QoS requirements with the use of subjective and vague descriptions improves the user experience. This flexibility reduces the cognitive load of crafting crisp or precise values (Akolkar et al., 2012). This paper explored fuzzy theory's use to capture the vagueness, subjectivity, and ambiguity that characteristics of human expressions in eliciting the QoS requirements for suitable SaaS in a cloud e-marketplace environment.

On the other hand, information visualisation involves visualisation methods in enabling low-effort sense-making and utility as users analyse and explore large and complex dataset data (Almulla et al., 2012; Khan & Khan, 2011; Spence, 2014). Information is communicated using interactive graphical or spatial aids to enhance user understanding with information visualisation (Beets & Wesson, 2011; Draper et al., 2009). Therefore, we hypothesise that integrating information visualisation into our framework is more effective than listing similar information in a textual form. Thereby ensuring that the users can understand relationships among data elements as they can learn more from the visualisation in lesser time; users can, therefore, access a new understanding of, or knowledge about, the QoS ranking results generated by the service alternative evaluation module (Chittaro, 2006; Mamoon et al., 2013).

Several selection approaches for cloud services exist in the literature. Some of these approaches either do not consider the subjectivity and vagueness during QoS elicitation or present the ranking results to increase users' cognitive demands in making a final decision. To this end, there exist some gaps with these approaches concerning their suitability in the cloud service e-marketplace environment. This paper proposed a QoS-based approach to rank and select cloud services by integrating fuzzy theory and information visualisation for optimal decision-making. Without the appropriate expression of users' requirements, selecting a SaaS option could be overwhelming, leading to the choice overload phenomenon; more so, user requirements, broken into QoS aspiration and QoS preferences, are often shrouded in vagueness and subjectivity.

In contrast to existing approaches in which either only vague QoS preferences or aspirations are considered, our proposal collects user QoS requirements by taking into cognisance the vagueness characteristic of both the users' QoS preferences and aspirations. By so doing, our approach optimises these QoS inputs dimensions towards identifying suitable SaaS options. Furthermore, the search results from many cloud service e-marketplaces are shown as an unorganised list of symbols representing the SaaS options that best match the users' queries. With such approaches, users may still find it difficult to instantly differentiate among the cloud services for easy decision making. Our approach simplifies the decision-making process by allowing the users to quickly and easily find the most appropriate services that best fit their requirements using a bubble graph visualisation. The implementation of the proposed framework was accomplished using some software tools, technologies, and middleware frameworks. We also showed the framework's applicability through an illustrative case study based on Customer-Relationship-Management-as-a-Service.

2. Background

2.1. Cloud eco-systems and e-Marketplaces

Most cloud computing provisions still imposes vendor lock-in that discourages a dynamic combination of services from third-party sources that could provide more functionalities to the users (Papazoglou & Heuvel Van Den, 2011; Pericherla, 2020). Potentially, the concept of a cloud eco-system is an opportunity to overcome this limitation. In cloud computing, an eco-system consists of an interwoven mixture of infrastructure, platforms, and applications that contribute towards increasing their value collectively than the value provided by the individual components on their own. The famous "XaaS", an arrangement that connotes that anything/everything can be provisioned and consumed as services, is realisable and can be accelerated by successful service partnerships among various providers. This collaboration means that IT services can be aggregated in different ways to deliver more value-adding functionalities (Baek et al., 2014). The popularity of cloud computing services will culminate in the rise of e-marketplaces for buying and selling cloud services, enabling the search, discovery, selection of, and payment for cloud services under one e-market infrastructure (Akolkar et al., 2012; Blasco et al., 2020; Gatzoura et al., 2012).

A typical example of a cloud eco-system is Salesforce.com. Salesforce.com is a PaaS eco-system that allows thousands of independent software vendors (ISVs), developers, and consultants to contribute to the eco-system. Salesforce.com is reputed to pioneer the cloud business model based

on partnership. Salesforce.com boasts over 1.8 million users who shop for services (Apps) from its marketplace, AppExchange. As observed from the Salesforce.com case study, the natural point of convergence in cloud computing’s future advances is the emergence of cloud service e-marketplaces. AppExchange showcases thousands of enterprise and small business applications made possible by its partner programme of ISVs. AppExchange expands salesforce.com’s cloud-based CRM software into a more significant and more diverse business software portfolio and provides this portfolio as a combination of services.

2.2. Service selection in cloud service e-marketplace

We believe that the starting point for evaluating and selecting SaaS is the appropriate expression of the user’s QoS requirements, while likely service choices are suggested based on those requirements. In this paper, we conceptualise users’ QoS requirements into *QoS preferences* and *QoS aspirations*. QoS preferences are derived by processing the relative importance assigned to each of the QoS attributes. Cloud services are usually evaluated using multiple attributes, and the user judges the relevance of each QoS attribute differently. On the other hand, QoS aspirations are the users’ ideal QoS values for each QoS dimension. QoS dimensions have their specified values that define the QoS performance of the service. During requirement elicitation, the users can specify their desired threshold values; these QoS values serve as inputs to the evaluation process that suggests optimal service options. As an example, Figure 1 shows the QoS preference and QoS aspirations of two intending SaaS users.

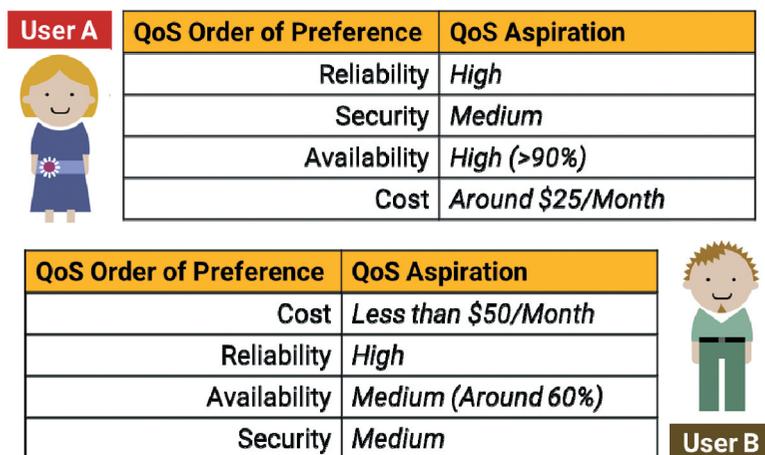
On a scale of preference, user A rates reliability as the QoS attribute with the highest priority, while User B is willing to concede the cloud service’s security. Also, Users A and B have provided their expected values for each of the QoS attributes, and the service evaluation process is expected to consider these inputs (i.e., the order of preference and aspiration value).

3. Related works

We present in this section a review of the related cloud service selection approaches proposed in the literature.

A personalised trust evaluation framework to aid the selection of IaaS is proposed by Qu and Buyya (2014). The approach computes trust as the degree to which the cloud service satisfies a user’s requirements based on past QoS performances. The user’s users’ subjective QoS requirements were elicited using membership functions and fuzzy hedges. After that, trust levels were generated for each cloud service using a hierarchical fuzzy inference system. In another work, Sun et al. (2014) presented a hybrid fuzzy MCDM-based framework that employs fuzzy-ontology for

Figure 1. Example of QoS preferences and aspirations for cloud service users.



function matching and service filtering. Their proposal addressed ambiguity in the input into the MCDM-based evaluation process and the evaluation itself, such as subjectivity in service requests, i.e., QoS aspirations and user preferences. A Fuzzy-AHP technique was implemented to generate informed weight for each criterion based on the subjective expression based on the reduced service choices. Besides, a fuzzy TOPSIS approach and the fuzzy weights were used to rank cloud services using the QoS performance's fuzzy descriptions.

In Kwon and Seo (2013), the authors proposed a Fuzzy-AHP model for selecting IaaS. With their approach, users can hand-pick the most desirable IaaS provider to deliver according to the company's objectives. Furthermore, Tajvidi et al. (2014) recommended a fuzzy-based multi-criteria decision-making approach that uses cloud service data from third-party QoS monitoring tools, together with user feedback about the past performance of services. This approach takes account of the ambiguity in the user's QoS preferences by using triangular fuzzy numbers to process the criteria' linguistic weight. These weights are then converted into precise numbers, which are used in the service ranking algorithm. Supplementing the hierarchical Service Measure Index for the cloud QoS model, this approach utilises a fuzzy AHP-based method to rank cloud services. The user's fuzzy expression of preference on the QoS dimensions expressed as weights derived using Buckley's method (Buckley, 1985) determines the ranking of cloud services.

Another approach for selecting cloud services was proposed by Mu et al. (2014). The approach combined the ambiguity in the user's preferences and the objective weights. In this approach, users' subjective weight preferences are expressed through linguistic terms, which are then processed using intuitionistic fuzzy set theory. The objective weight preference is proposed if the user has no knowledge of the preferences or based on the user's incomplete knowledge of the history of the preference information on that service, in which case, rough sets are used to derive objective weights.

Esposito et al. (2016) presented an approach that handles uncertainty inherent in the users' QoS preferences. The approach is particularly suited for situations where selfish service providers post false QoS levels and prices. The approach uses fuzzy theory to process the user's ambiguous QoS preferences towards the derivation of importance weights; after that, they employed a TOPSIS method to rank the services. The approach further uses the *Dempster-Shafer theory of evidence* to achieve a distributed selection of services and a *Mechanism Design* based on game theory to reveal actual QoS performance evaluation of the services to promote truth-telling among service providers.

There are scenarios where a cloud service is to be selected based on the preferences of members of a group in contrast to single-user scenarios. In the group scenario, the cloud service selected must meet the individual preferences of members of that group. To address this, a QoS-based services selection using Interval Numbers for group users, termed QSSSIN_GU, was proposed by Yu and Zhang (Yu & Zhang, 2014). The approach integrates vague QoS preferences of group members in the assessment process using Interval Numbers. The authors argue that the ambiguity in group users' QoS preferences can be expressed in a range of values, using Interval Numbers. Since the QoS preferences of the group members vary, Interval Numbers can appropriately describe those arrays of preferences and obtain a ranking that satisfies the group's aggregated preferences. QSSSIN_GU applies a linear scale transform normalisation function to normalise QoS properties' varying dimensions to ensure that the range of normalised interval numbers belongs to [0, 1]. QSSSIN_GU uses TOPSIS to rank and find the best service choice.

Wang et al. (2014) introduced an approach to assess cloud services' QoS for a service-oriented cloud computing context. The approach utilises a fuzzy synthetic decision to assess cloud services' performance based on users' preferences. Meanwhile, the proposed approach also computes cloud services' uncertainty based on monitored QoS data. After which final

evaluation of cloud service is obtained using fuzzy logic control. Garg et al. (2013) proposed an AHP-based approach called SMICloud, based on the Service Measurement Index QoS model, and utilises historical QoS measurement data and service provider's self-published QoS data to obtain actual QoS values. The SMICloud approach's principle is based on the interdependence between each QoS attribute and how they affect the services assessment process, and the ranking of service relies on the eventual priority weights of the QoS attribute during the selection process.

A systematic framework to assess and select cloud services was presented in Gui et al. (2014). The framework proposed comprised the following: a hierarchical information model that aggregates cloud data from a variety of service providers; a cloud service classification model; a schema for producing rules for instantiating specific cloud services; a dynamic preference-driven assessment model that suggests service solutions based on the user's preferences; and communicates the comparison of service options through a visualisation. The service evaluation is performed using Multi-attribute utility and TOPSIS-based techniques.

The review of related works revealed that some key issues had attracted the attention of authors on cloud service selection, which has influenced the trends of research in this domain so far. However, there are some gaps in the suitability of the existing techniques in a cloud e-marketplace environment. The gaps have been identified based on the following analysis dimensions—how and if both the user's QoS preferences and QoS aspiration were elicited; interactive GUI support to elicit QoS information from users; and the mechanisms for the presentation of ranking results. The gaps identified are summarised in [Table 1](#).

The analysis of the 10 techniques summarised in [Table 1](#) shows that six approaches possess the mechanism to elicit vague QoS preferences, while four approaches could elicit subjective QoS aspirations. Besides, the proposals by Qu and Buyya (2014) and Esposito et al. (2016) elicited both the QoS preferences and aspirations from the users. Three techniques integrated a user interface for expressing QoS requirements, while only three of the approaches reviewed employed any form of visualisation to present the ranked results of the cloud service alternatives.

Our analysis showed that none of the approaches reviewed completely addressed the vital dimensions required to lessen the service choice overload, thereby enhancing the user experience in cloud e-marketplaces. Therefore, the proposal in this paper fills these gaps.

4. The proposed framework

The cloud service ranking, and selection framework proposed in this paper combine fuzzy set theory techniques wrapped in an intuitive GUI for eliciting user's QoS requirements (including QoS preferences and aspiration). Simultaneously, a low-cognitive demanding information visualisation mechanism, specifically, a bubble graph visualisation, is employed to explore the ranking results. [Figure 2](#) shows the conceptual depiction of the proposed framework. The details of the components of the framework are subsequently elaborated.

4.1. Fuzzy-oriented elicitation of user QoS requirements

An accurate elicitation of user requirements involves interpreting fuzzy expressions and using this information in evaluating service alternatives. The difficulty imposed by expecting users to use exact or crisp values when expressing requirements necessitates the employment of uncertainty theories, such as fuzzy set theory, to effectively capture and interpret the vagueness that characterises user QoS requirements for services (Esposito et al., 2016; Qu & Buyya, 2014; Sun et al., 2014). To this end, subjective and ambiguous QoS aspirations and QoS preferences can be expressed through linguistic terminologies, a preferable mode of communicating such requirements (Esposito et al., 2016; Gatzoura et al., 2012; Qu & Buyya, 2014).

Table 1. Summary of review of related works

#	Source	Title	Fuzzy QoS Preference	Fuzzy QoS Aspiration	Employ GUI	
Incorporate Info Viz						
1	Qu and Buyya (2014)	A cloud trust evaluation system using hierarchical fuzzy inference system for service selection	•	•	•	○
2	Sun et al. (2014)	A hybrid fuzzy framework for cloud service selection	•	○	○	○
3	Kwon and Seo (2013)	A Decision-making Model to Choose a Cloud Service using Fuzzy AHP	•	○	•	•
4	Tajvidi et al. (2014)	Fuzzy cloud service selection framework	•	○	○	○
5	Mu et al. (2014)	QoS-aware cloud service selection based on uncertain user preference	•	○	○	○
6	Yu and Zhang (2014)	QoS-aware SaaS Services Selection with Interval Numbers for Group User	○	•	○	○
7	Esposito et al. (2016)	Smart Cloud Storage Service Selection Based on Fuzzy Logic, Theory of Evidence and Game Theory	•	•	○	○

(Continued)

Table 1. (Continued)

#	Source	Title	Fuzzy QoS Preference	Fuzzy QoS Aspiration	Employ GUI	
Incorporate Info Viz						
8	Wang et al. (2014)	Towards an accurate evaluation of quality of cloud service in service-oriented cloud computing	○	•	○	○
9	Garg et al. (2013)	A framework for ranking of cloud computing services	○	○	○	•
10	Gui et al. (2014)	A service brokering and recommendation mechanism for better selecting cloud services	○	○	•	•

○ = not supported; • = Supported

Figure 2. Conceptual depiction of proposed fuzzy- and visualization-driven framework.

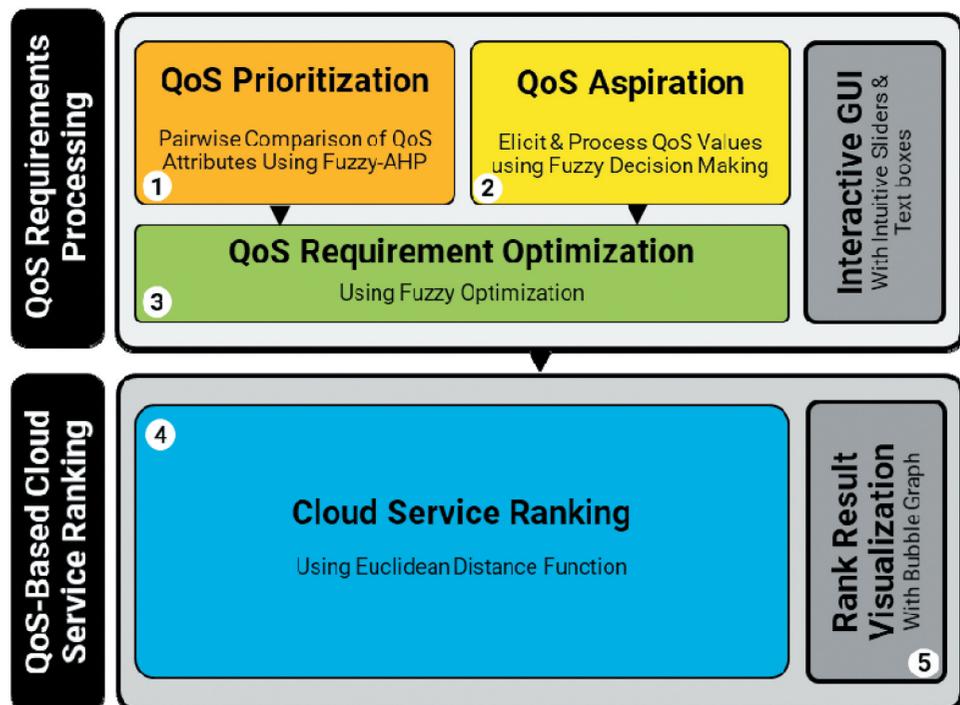


Figure 3. User requirements elicitation model.



Our framework employs the use of fuzzy set theory to elicit the user's QoS preferences and aspirations. The preference weights derivation is achieved using the fuzzy pairwise comparison of the fuzzy extension of the AHP technique, Fuzzy AHP (or FAHP), in Step 1. The fuzziness in the user's QoS aspirations is also analysed as a system of fuzzy goals and constraints with fuzzy linguistic variables and linguistic hedges in Step 2. In Step 3, the decision-making technique used to determine optimal service alternative is based on fuzzy multi-objective optimisation. The user's objectives are mainly to maximise their private utility (of the most optimal alternative available) while satisfying their aspiration and constraints. A depiction of a proposed fuzzy decision-making model is shown in [Figure 3](#).

In Step 4, our framework utilises Euclidean distance metrics to estimate the proximity of all functionally equivalent cloud services in the e-marketplace to the optimised QoS requirements derived from the user's QoS requirements in Step 4. The ranked services are presented to the user through a bubble graph visualisation in Step 5.

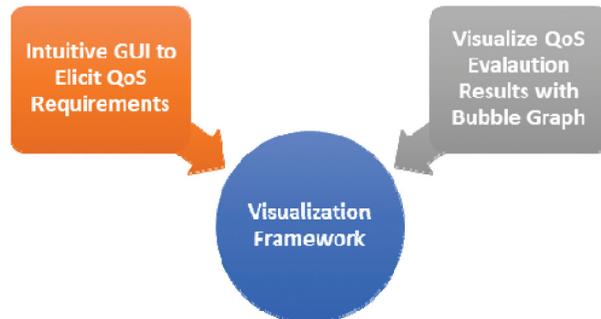
4.2. Graphical user interfaces

Graphical User Interface is a subset of Human-Computer Interaction (HCI); HCI studies the planning and design of how humans and computers work together to effectively meet a human's needs (Galitz, 2007). The GUI underscores input and output features; input is how a user expresses business and technical requests or requirements, whereas the output presents the result of those requests to the user (Galitz, 2007). The GUI obscures all the technical and computational processes underlying the e-marketplace operations while being a functional, enjoyable and satisfying means to explore the QoS ranking of cloud services towards making a cloud service selection. Indeed, an arbitrarily complex GUI design increases the cognitive difficulty in performing specific user-centric tasks (Galitz, 2007), a consequence for which could lead to a selection of a low or sub-optimal option or abandonment of the process altogether. Both outcomes have implications on the profitability and the perpetuity of the e-marketplace (Bonastre & Granollers, 2014; Galitz, 2007; Liu et al., 2012).

Since the primary medium of engagement in the e-marketplace environment is visual, we propose using a GUI that ensures the user can conveniently express QoS-based requests. Consequently, optimal services match can be found within the shortest time possible, and the information is intuitively presented in a manner that is easy to understand and facilitates quality decision-making (Galitz, 2007; Gui et al., 2014). Although the user experience covers all aspects of e-marketplace operations—such as billing, payment, deploying of a service instance, and SLA monitoring (Kuniavsky, 2003), its focus in this paper is how users use the GUI to request for services based on QoS requirements and to explore a set of likely alternatives. Our GUI framework is delineated into two, based on the support for the tasks that the users perform on the e-marketplace in their quest to select an optimal service alternative. These include interface design that: allow users to express QoS requirements and allow the visualisation and compelling exploration of ranking cloud services (see [Figure 4](#)).

We ensured that the GUI designs are intuitive and can naturally capture user QoS requirements, akin to human judgment or perception. The user's perception of the interface affects their attitude towards what is presented through it and, consequently, affects user satisfaction (Kuniavsky, 2003;

Figure 4. GUI and visualization model.



Sundar et al., 2014). Applying visualisation would, in a way, enable low cognitive demand in exploration by presenting a graphical overview of the rankings and help the user to understand the relationship of services to each other based on QoS attributes ranges. By interacting with the bubble graph visualisation, users can then perform a trade-off analysis by filtering services according to the desired QoS factors. Such graphical depiction is more convenient and reduces cognitive overload than a mere textual listing of the rank results (Beets & Wesson, 2011; Mamoon et al., 2013; Spence, 2014).

4.3. Implementation details

To realise the proposed framework and demonstrate its applicability, a set of technological tools has been identified. These tools were categorised into different functional areas: Integrated Development Environment (IDE), Front-end Components, and Back-end components. Java was the primary programming language used to implement components of the proposed framework. NetBeans 8.1 IDE served as the umbrella environment for the implementation of the components of the proposed framework. The graphical user interface components were realised using a combination of front-end technologies, languages, and framework, including JavaServer Pages (JSP), HyperText Markup Language, Cascading Style Sheets JavaScript. The proposed framework employed Bootstrap 3.3.6 (bootstrap.com), a free and open-source HTML, CSS and JS framework for creating and styling the web user interface. The bubble graph visualisation component was realised using Google Chart Visualization. The bubble charts are rendered in HTML5/SVG technology compatible with a variety of web browsers. The proposed framework used the Bubble Chart from the Google Chart types to visualise the QoS ranking of Cloud service alternatives concerning users' QoS requirements. The Back-end Components used Glassfish Web Server, Java Servlet Technology and Java Classes. All the optimisation processes were carried out through the MOEA Framework. The MOEA Framework (moeaframework.org) is a free and open-source Java library of Multi-Objective Evolutionary Algorithms.

The proposed framework uses MySQL Database and the relational database for the data. The summary of the technologies employed to implement the proposed framework is presented in Table 2.

5. Illustrative case study

We adopted a cloud-based Customer relation management software, called Customer Relationship-Management-as-a-Service (CRMaaS), which serves as an illustration of the cloud ecosystem and e-marketplace scenario to validate the framework proposed in this paper.

5.1. Customer relationship management

Customer Relationship Management (CRM) refers to how companies coordinate and analyse user interactions and data through a customer's lifecycle. These ways may include technology, people and organisational strategies deployed to collect user information about personal data, purchase history, preferences, and concerns across different channels through which the organisation engages with the user. These channels may include phone conversations, emails, social media etc. Customer information

Table 2. Summary of tool support to realise the FOCUSS framework

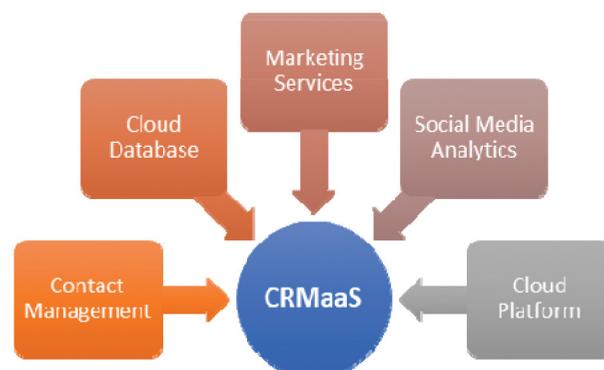
#	MODULE	LANGUAGE	TECHNOLOGY/LIBRARY/ FRAMEWORK
1	GUI: Front-end	Java	JSP
		HTML CSS JavaScript	Bootstrap 3.3.6
2	GUI: Visualisation	JavaScript	Google Chart API
3	QoS Aspiration Analyzer	Java	MOEA Framework 2.9
4	QoS Preference Prioritizer	Java	Servlet and Java Class
6	QoS Requirements Optimizer	Java	MOEA Framework 2.9, Servlet
7	QoS Ranking Engine	Java	Servlet and Java Class
8	Service Directory	SQL	MySQL 5.1.17, Java Servlet
Integrated Development Environment			NetBeans 8.1
Web Application Server			Glassfish Web Server

is consolidated into the CRM database, and the organisation utilises this data to improve business relationships to achieve user retention and increased sales. Traditional on-premises CRM software puts the burden of administration and maintenance on the organisation, however employing cloud-based solutions outsources these services to a third party, leaving the organisation to focus on its core business, mainly when technical expertise and budget is limited.

Based on the case study of CRMaaS presented in (Ezenwoke et al., 2017), we demonstrated the proposed framework’s plausibility through the CRMaaS e-marketplace. The CRMaaS is a cloud-based Customer Relationship Management software with the following components: Contact management service, Cloud Database, Marketing Service and Social media analytics platform and the cloud platform (see Figure 5).

An instantiation of the CRMaaS combines these component services and platform. The CRMaaS instances available on the e-marketplace are differentiated by QoS factors as may be relevant to any small business that is prospecting a CRM solution. On the e-marketplace, the cloud service selection in this context is concerned with evaluating the set of m CRMaaS instances based on the n QoS preferences and aspirations (Sahri et al., 2014). The user’s expressed requirements are transformed into a search query fed into the e-marketplace to

Figure 5. High-level structure of the components of a CRMaaS.



generate a ranking of the CRM instances according to the requirements expressed. We present a specific case for a newly opened *online drug store* and used it subsequently throughout this paper.

A high-level scenario description of the drug store's requirements is presented; thus, a new online drug store is being set up to extend an existing brick-and-mortar drug store. The online drugstore allows existing and prospective users to purchase and pay for over-the-counter medication online. The drug store owner prefers a low-priced, reliable CRM solution that can handle basic customer relationship management processes. Being a small start-up, there is less emphasis on reliability and the amount of funds that can be spent on the CRM solution is limited due to current cash flow realities,

6. Results

This section presents how the proposed framework is used in an e-marketplace setting, enabling the drugstore's designated information technology officer to search for and select appropriate CRM solutions based on their specific requirements.

6.1. CRMaas e-Marketplace services

The alternative services that contain the CRMaas components are given in [Table 3](#).

Notation Ms = milliseconds; \$/Mon = Dollars per Month

6.2. Fuzzification of QoS information of services in the directory

We fuzzified the QoS information of the e-marketplace CRMaas instances by representing at least three ranges of QoS values with linguistic variable and underlying membership functions. The range of QoS values for Availability QoS is broken into four: Very High, High, Medium, and Low. The range for Reliability is Very high, high, Average and Low, while that of Response time is Low, Acceptable and below Average. The linguistic values for Cost QoS are Premium, Standard, Moderate and Cheap. [Table 4](#) shows the QoS attributes, the linguistic variables and the membership function used to represent each QoS attribute.

Based on the available QoS information of all CRMaas instances (see [Table 3](#)), [Figure 6](#) shows the range of values under each linguistic variable for each QoS attribute and the membership function diagram used in this case study.

Apart from the linguistic range for the QoS attributes, users can also qualify the linguistic term selected. [Table 5](#) shows the various linguistic hedges and their associated membership functions. These constraints include: In the Vicinity of x , and very close to x ; and x is a QoS value specified by the user.

a and b are actual QoS values specified by the user. μ is the membership function

6.3. Eliciting user requirements

Based on the scenario of an online drug store presented earlier, the user is expected to complete a pairwise comparison of all QoS attributes to enable the e-marketplace mechanism to determine the relative importance of each QoS attributes to the user. The user specifies QoS aspirations using the linguistics terms and hedges for QoS values described in the previous section. [Tables 6 and 7](#) show the QoS priorities and aspirations for Online drug store. An example of how Availability QoS requirements are expressed using the GUI for the online drug store is shown in [Figure 7](#).

The GUI employs dual colour coded slider bars that correspond to the colour code for the two QoS attributes being compared. When the slider bar is in the middle (i.e., the length of either colour in the slider bar are equal), then the underlying fuzzy comparison scale is "about

Table 3. List of service alternatives in the CRMaaS cloud ecosystem and e-marketplace

SaaS_ID	QoS Values			Cost (\$/Mon)
	Availability (%)	Response Time (Ms)	Reliability (%)	
S1	98.68	668.89	75.73	340.64
S2	97.16	668.89	72.78	331.15
S3	98.67	546.24	75.43	390.64
S4	97.16	546.24	72.48	381.15
S5	98.29	648.77	74.48	304.14
S6	96.79	648.77	71.53	294.65
S7	98.29	526.12	74.19	354.14
S8	96.79	526.12	71.23	344.65
S9	98.49	668.89	75.02	335.64
S10	98.49	546.24	74.72	385.64
S11	98.11	648.77	73.77	299.14
S12	98.11	526.12	73.47	349.14
S13	99.03	668.89	75.73	336.15
S14	97.53	668.89	72.78	326.66
S15	99.51	682	76.3	340.48
S16	98.01	682	73.34	330.99
S17	99.03	546.24	75.43	386.15
S18	97.53	546.24	72.48	376.66
S19	99.51	559.35	76	390.48
S20	98.01	559.35	73.04	380.99
S21	98.66	648.77	74.48	299.65
S22	97.15	648.77	71.53	290.16
S23	99.14	661.88	75.05	303.98
S24	97.63	661.88	72.1	294.49
S25	98.66	526.12	74.19	349.65
S26	97.15	526.12	71.23	340.16
S27	99.14	539.23	74.75	353.98
S28	97.63	539.23	71.8	344.49
S29	97.88	526.12	74.75	349.65
S30	98.24	526.12	74.75	345.16
S31	98.73	539.23	75.32	349.49
S32	98.02	551.35	75.62	360.46
S33	96.52	551.35	72.67	350.97
S34	97.84	551.35	74.91	355.46
S35	98.62	489.46	75.72	360.98
S36	97.12	489.46	72.76	351.49
S37	98.39	551.35	75.62	355.97
S38	96.88	551.35	72.67	346.48

Table 4. QoS factors, fuzzy sets and underlying membership function

QoS ATTRIBUTE	FUZZY SETS	FUZZY MEMBERSHIP FUNCTION
Availability	Very High; High; Medium; Low	Trapezoidal Membership Function
Response Time	Below Average; Acceptable; Low	
Reliability	Low; Average; High; Very High	
Cost	Cheap; Moderate; Standard; Premium	

Figure 6. Linguistic variables for the QoS attributes.

Linguistic Variable: Availability

Linguistic Term	QoS Value Range
Very High	90% -- 100%
High	70% -- 95%
Average	60% -- 85%
Low	50% -- 75%

Linguistic Variable: Response Time

Linguistic Term	QoS Value Range
Low	200ms -- 560ms
Acceptable	500ms -- 790ms
Below Average	700ms -- 1000ms

Linguistic Variable: Reliability

Linguistic Term	QoS Value Range
Very High	90% -- 100%
High	70% -- 95%
Average	60% -- 85%
Low	50% -- 75%

Linguistic Variable: Cost

Linguistic Term	QoS Value Range
Premium	370\$ -- 500\$
Standard	280\$ -- 400\$
Moderate	190\$ -- 300\$
Cheap	100\$ -- 200\$

Table 5. Linguistic hedges and membership functions for each QoS attributes

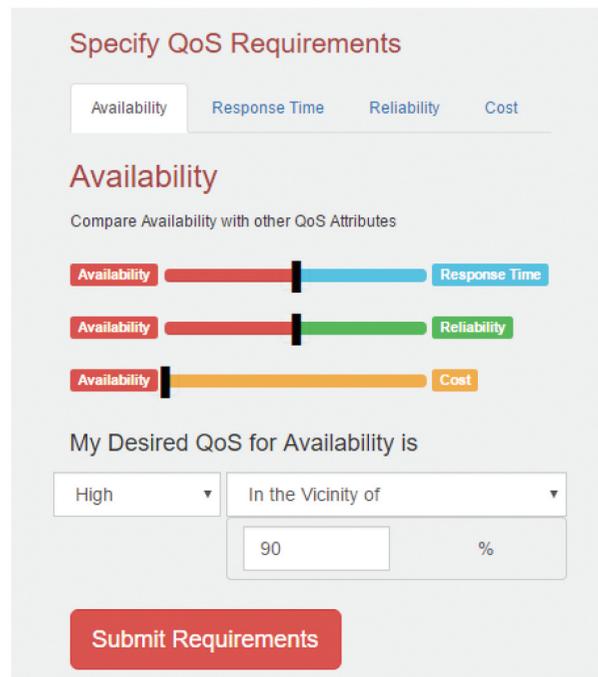
LINGUISTIC HEDGES FOR QoS VALUE	MEMBERSHIP FUNCTION
x is In the Vicinity of a	$\mu_c(x) = 1/(1 + (x - a)^4)$
x Very close to a	$\mu_c(x) = 1/(1 + (x - a)^2)$
x Substantially Higher than a	$\mu_c(x) = (1 + (x - a)^{-2})^{-1}$
x Substantially Lower than a	$\mu_c(x) = (1 + (a - x)^{-2})^{-1}$
x Approximately between a and b	$\mu_c(x) = (1 + a(x - b)^{-5})^{-1}$

Table 6. QoS pairwise comparison for online drug store

QoS Attribute	Judgement	QoS Attribute
Availability	About Equal	Response Time
Availability	About Equal	Reliability
Availability	Extremely Less important than	Cost
Response Time	About Equal	Reliability
Response Time	Extremely less Important than	Cost
Reliability	Extremely less Important than	Cost

Table 7. QoS aspiration for online drug store		
QoS Attribute	Goal	Constraints
Availability	High	In the Vicinity of 90%
Response Time	Acceptable	In the Vicinity of 600 ms
Reliability	High	Very close to 70%
Cost	Cheap	In the Vicinity of 250\$

Figure 7. Availability QoS requirements for online drug store with GUI.



equal”. Furthermore, there are eight steps on either side of the slider bar’s midpoint corresponding to the other scales in the fuzzy Saaty pairwise comparison scale.

6.4. QoS requirements processing

6.4.1. Step1: QoS prioritisation

Based on the Geometric Mean Method (Buckley, 1985), the fuzzy prioritisation method was applied to derive crisp weights representing the degree of the relative importance of each QoS attributes from the fuzzified pairwise comparison matrix. The crisp weights from the fuzzy pairwise comparison for the ODS requirements is shown in Table 8. Table 8 shows that the cost is the most important QoS factor, while other QoS attributes have equal weights.

6.4.2. Step 2: QoS analyser

Applying the fuzzy decision-making concept, we process the QoS attributes’ value from the user’s fuzzy estimations. We obtained the fuzzy estimations by finding the item with the highest membership function by fuzzy sets intersection that denoted the user’s desired QoS aspirations. Table 9 shows how QoS aspirations were synthesised from representing the fuzzy sets.

Table 8. Priority weights and order of relative importance for QoS attributes

QOS ATTRIBUTES	IMPORTANCE WEIGHTS	IMPORTANCE RANK
Cost	0.7152	1
Availability	0.0950	2
Response Time	0.0950	2
Reliability	0.0950	2

Table 9. Synthesised QoS aspiration for online drug store

QOS ATTRIBUTE	LINGUISTIC TERM	LINGUISTIC HEDGES	SYNTHESISED QOS VALUES
Availability	High	In the Vicinity of 90%	97.12%
Response Time	Acceptable	In the Vicinity of 600 ms	559.35 ms
Reliability	High	Very close to 70%	72.1%
Cost	Cheap	In the Vicinity of 250\$	290.16\$/Month

6.4.3. Step 3: QoS requirements optimizer

Table 10 shows a summary of priority weights and QoS values obtained from the users. These inputs are fine-tuned according to the values of the QoS attributes of available services in the service directory. Optimized QoS requirement is obtained by finding those QoS values that are the most ideal and closest to the user’s requirements. Our Framework optimises the fuzzy goals very close to both the most ideal QoS values and the user’s requirements.

For this case study, each service alternative is evaluated with respect to the user’s weight of importance using the Simple Additive Weighting (SAW) function, and the similarity of each service QoS attributes to a combination of user’s preference weights, and aspiration values are performed with the exponential Euclidean distance function. Using the MOEA framework, the optimal QoS values that satisfy both the fuzzy goal and constraints are obtained as being very close to the service alternatives with the best performance and closest to user requirements. Table 11 shows

Table 10. Completely elicited QoS requirements

QOS ATTRIBUTES	QoS Weight	QoS Values
Availability	0.0950	97.12
Response Time	0.0950	559.35
Reliability	0.0950	72.1
Cost	0.7152	290.16

Table 11. Comparison of initial QoS requirements and optimised QoS values

QOS ATTRIBUTES	Initial Requirements		Optimised Requirements
	Weight	Values	
Availability	0.0950	97.12	97
Response Time	0.0950	559.35	559
Reliability	0.0950	72.1	72
Cost	0.7152	290.16	290.2

a comparison of the initial QoS requirements and the final QoS requirements with respect to the user’s priority weights and QoS aspiration.

6.5. QoS-based ranking of services

6.5.1. Step 4: cloud service ranking

Having obtained the optimised QoS requirements, our framework’s final stage is to rank the CRMaaS instances based on the requirements. We employed the exponential Euclidean distance functions to find the nearest CRMaaS instances to the optimised requirements. Table 12 shows the 10 most suitable CRMaaS instances with QoS values that match the online drug store’s optimised requirements.

6.5.2. Step 5: visualising the ranking

The result shown in Table 12 is then visualised using a bubble chart, from which the user can explore the relationships among the ranked alternatives. The user can then select the most satisfactory service that best satisfies their requirements. Figure 8 shows the bubble graph for data contained in Table 12. Meanwhile, Figure 9 shows the complete GUI for QoS requirements elicitation and the tabular and bubble graph visualisation.

7. Discussion

While incorporating basic characteristics of an e-marketplace like search and billing, existing cloud service e-marketplaces (e.g., SaaSMax, Oracle e-marketplace, AppExchange, etc.) lack the more sophisticated elements optimise user experience (Akolkar et al., 2012). Such platforms can readily benefit from the proposals made in this study by incorporating a human-akin mechanism for eliciting user requirements through an intuitive user interface and information visualisation to aid in browsing and comparing cloud service options.

An accurate elicitation of user requirements involves interpreting fuzzy expressions in evaluating services (Esposito et al., 2016; Qu & Buyya, 2014). This study’s illustrative case shows that the ability to express vague preferences or aspiration using linguistic terminologies naturally is a better way to explore cloud services for selection purposes and enable more comfortable and quicker expression of requirements (Esposito et al., 2016; Qu & Buyya, 2014). It is more convenient to use the following linguistic terminologies when expressing QoS aspiration “the threshold of reliability metric should be in the vicinity of x”, or “cost should be the in the range of x and y” or “High availability close to the value z”, etc., (where x, y and z are specific QoS values). Furthermore, the advantage of pairwise comparisons is that it allows the derivation of priority weights of the

Table 12. Top 10 CRMaaS service alternatives to the optimised requirements

SERVICE RANK	SERVICE_ID	AVAILABILITY (%)	RESPONSE TIME(MS)	RELIABILITY (%)	COST (\$/MONTH)
1	S22	97.15	648.77	71.53	290.16
2	S6	96.79	648.77	71.53	294.65
3	S11	98.11	648.77	73.77	299.14
4	S21	98.66	648.77	74.48	299.65
5	S24	97.63	661.88	72.1	294.49
6	S5	98.29	648.77	74.48	304.14
7	S23	99.14	661.88	75.05	303.98
8	S14	97.53	668.89	72.78	326.66
9	S2	97.16	668.89	72.78	331.15
10	S16	98.01	682	73.34	330.99

Figure 8. Bubble graph for ranked services for ODS requirements; one mouse hover, the details of the service_ID 23 is shown.

Ranking Visualisation

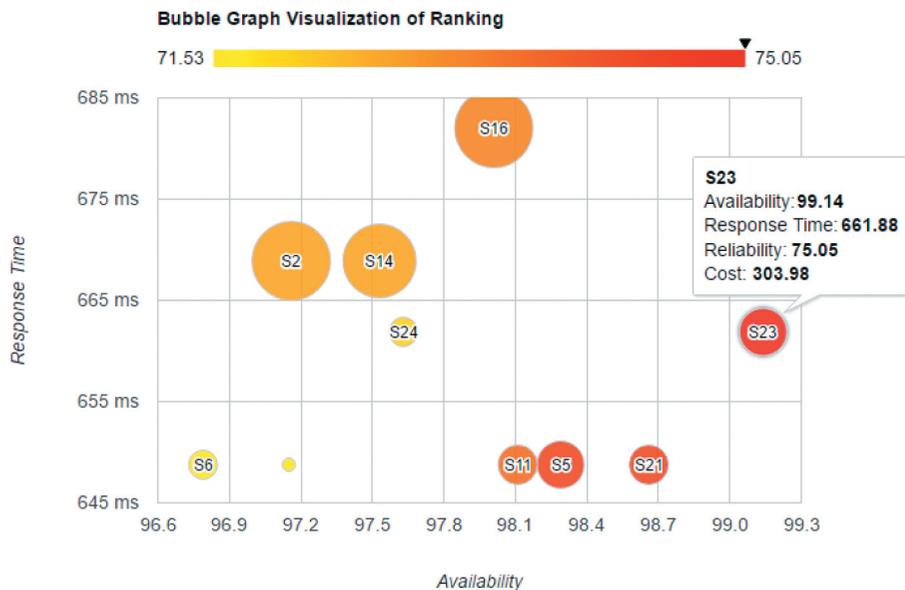


Figure 9. Complete GUI showing QoS requirements, table and bubble graph.

CRMaas Marketplace

Customer Relationship Management as a Service Platform

Specify QoS Requirements

Availability Response Time Reliability Cost

Cost

Cost has been Compared with other QoS

My Desired QoS for Cost is

Cheap Very Close to

250 S/Mon

Submit Requirements

Ranking Results

ID	Availability	Response Time	Reliability	Cost
1 S22	97.15	648.77	71.53	290.16
2 S6	96.79	648.77	71.53	294.05
3 S11	98.11	648.77	73.77	299.14
4 S21	98.06	648.77	74.48	299.05
5 S24	97.03	661.88	72.1	294.49
6 S5	98.29	648.77	74.48	304.14
7 S23	99.14	661.88	75.05	303.98
8 S14	97.53	668.89	72.78	326.06
9 S2	97.16	668.89	72.78	331.15
10 S16	98.01	682	73.34	330.99

Ranking Visualisation

criterion from comparison matrices rather than arbitrarily assigning weights directly (Javanbarg et al., 2012).

The user interface underscores input and output features of the cloud service e-marketplace; input is how a user expresses QoS requirements, whereas the output presents the result of those requests to the user (Galitz, 2007). In eliciting users' requirements, user interface designs that intuitively capture these subjective requests are desirable because the user's perception of the interface affects attitude to what comes out through it and ultimately affects user satisfaction (Kuniavsky, 2003; Sundar et al., 2014). As shown in the illustrative case, integrating fuzzy-enabled web-based widgets for eliciting vague preferences and aspirations under one integrated visual interface can enhance user experience.

One of the laws of e-commerce states that if users cannot find it, they cannot buy it either. However, there are increases in shopping cart abandonment, dissatisfaction and frustrations experienced due to the difficulties experienced during the search for the item; this raises the need for optimal user experience in online shopping endeavours (Bonastre & Granollers, 2014; Liang & Lai, 2002; Liu et al., 2012). For cloud e-marketplaces, many alternate cloud services sorted according to QoS ranks with respect to user requirements emphasise the need for an effective decision-making aid to support cloud services exploration. Since the primary medium of user's engagement in the cloud service e-marketplace is visual, information visualisation mechanism aids in effective user interaction and simplifies decision-making. Most cloud service selection approaches act like black boxes that generate a ranked list of cloud services without providing insight into the basis of the rankings (Chen et al., 2013). We propose incorporating Bubble graph visualisation to improve the users' understanding of cloud services rankings' rationale. It has been proven that humans can quickly and effortlessly recognise elements in a picture with spatial arrangements and interpret the relationships among those elements (Shneiderman, 1994). Because of this, humans tend to comprehend the content of a picture or graphics faster than from mere text. Consequently, this well-developed human visual processing ability aids better decision making (Shneiderman, 1994).

Similarly, the main drawbacks with textual representation in web service discovery were highlighted: ineffective search facility and poor presentation of the web services, as textual lists do not effectively support the user in finding suitable web services (Beets & Wesson, 2011). These findings can be extended to the domain of cloud services. Earlier studies on the effect of textual/tabular representations of data as against graphical representation in decision-making contexts revealed that graphical representations performed significantly better (Coll et al., 1994; Jarvenpaa, 1989): thus, supporting our proposal that the use of graphical representation to improve the user experience in cloud service selection.

8. Conclusion

One major challenge of operationalising a cloud service e-marketplace is *service choice overload*, describing the complexity of decision making because of the availability of too many service alternatives, which often lead to unsatisfactory choice. Low cognitively demanding decision support apparatus can be used to minimise service choice overload. Such apparatus used during requirement elicitation and presentation of rank result should combine both fuzzy QoS preference and aspiration information in the evaluation process; Employs intuitive user interface to elicit fuzzy user QoS requirements and includes means to visualise ranking results in a way that reduces service choice overload. This paper describes a framework that encompasses the points raised above and shows demonstrate the utility of the proposed framework by identifying the tool support base to realise the framework and an illustrative case study to show its practicability. We also demonstrated how a user's requirements would be elicited and how the framework would rank available alternatives and presented them to the users through a bubble graph visualisation. The illustration shows that our framework is a viable approach for QoS-based ranking and selection

of cloud service in cloud service e-marketplaces which will serve the platform's customers satisfactorily while driving the profit or business objectives of the e-marketplace platform itself.

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