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HOW TO ACCOUNT FOR THE UNCERTAINTY IN THE QoS SELECTION TASK*

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ABSTRACT. The paper presents an approach to QoS selection of web services. It introduces a theoretical frame and respective applicable selection procedures, in which the solution accounts for the uncertainty of the existing metrics data and client preference. Methods of two general cases are revealed in detail. The first method considers a selection based on one service quality. The second method assesses the integrated QoS of interesting properties. The theoretical analysis is validated through experimental investigation of real data of services' quality metrics.

1. Introduction. Nowadays, the Service-Oriented paradigm is the most commonly used one for developing distributed software systems. Since web services are among of the fundamental technologies used in the cloud, the problems related to their quality remain of primary importance. Much research

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effort is focused on the development of new approaches for quality of service (QoS) assessment as an efficient frame for further software system design [4].

The overall aim of the software system is to deliver services that can justifiably be trusted. Thus, the selection of a service that is most reliable and appropriate according to the client preferences is of major importance. This task is particularly relevant in the context of the contemporary tendency to choose a service from a number of possible choices. The web service selection is a challenging problem especially when different web services provide equal functionality [9]. The client aims to use the web service with the highest quality. However, the selection procedure meets several difficulties:

- The behavior of the web services with respect to QoS is difficult to predict. It depends on various factors such as availability of network connection or corresponding application server, the number of simultaneous invocations, and so on [3].
- The client's choice is a result of the subjectivity of their own understanding about the desired quality of the offered resources [4].
- The existing metrics data are uncertain due to the complexity of their accumulation and processing or, on the whole, lack of reliable metrics for their measurement [12].
- The web service quality is affected simultaneously by different QoS properties that are often inconsistent [1]. For example, increasing the availability of a given web service leads to an increase of its price, which is not reasonable for the client with a limited budget.

The QoS properties of web services can be divided into measurable and unmeasurable ones [11]. The QoS properties such as response time, availability and throughput are measurable, since they have numerical values of their measurement. Their metrics data are easily collected in the history log for further data processing but are subject of further analysis for clarity of hidden impression. The immeasurable QoS properties such as standard compliance, authentication method, data encryption and others cannot be directly measured in terms of numeric values. The values of these properties can be estimated expertly with a certain level of imprecision. Thus, part of the effort is directed to accounting for the existing uncertainties. The recently introduced approaches to software service quality estimation combine the two concepts of uncertainty – probability and fuzzy description – that ensure power and a well-grounded frame for assessment [1, 2, 6, 7].

The aim of the present paper is to summarize the achievements and to present a generalized approach to QoS selection that accounts for the imprecision of the existing service data and information. It presents a way to incorporate both numeric data, accumulated during the service monitoring, and expertly provided information. The approach is applicable to single and to multiple quality of service selection.

The paper is organized as follows. The next section reveals the different origin of the imprecision in the service data and information. The ways of the two different formalization frames of QoS are presented. A description of the uncertainties of the service quality and corresponding service selection procedures is given in the third section. An integrated quality selection method is presented in the fourth section. The fifth section discusses an experimental analysis that demonstrates the vitality of the proposed procedures. Finally, a conclusion is made and future work is outlined in the sixth section.

2. The uncertainty to take into account. Two different origins of uncertainty in the QoS selection problem exist. First, whenever there is a large amount of accumulated data of the properties of particular interest, the uncertain behavior of the web services with respect of their QoS properties could be considered in the sense of probability distribution. For this purpose a reliable metric of each characteristic should exist. The history log of the service acts as a data base for statistical data analysis and properties investigation.

However, in some cases the amount of accumulated metrics data is not enough for reliable statistical estimation. In other cases some software properties cannot be directly measured. Their values can only be assessed subjectively. Besides, the subjectivity of the customer preferences also creates a situation when subjective uncertainty has to be accounted for. A useful mathematical formalization frame in all these cases is the theory of fuzzy sets and fuzzy logic.

The appearance of the two types of uncertainty requires applying two different descriptions according to the context of the concrete situation and in an appropriate manner. Reliable analytical procedures for QoS selection tasks need to have a relevant interpretation. Below, the characteristics of the two mathematical concepts and respective procedures for description of the service quality properties are presented in detail.

2.1. Probability uncertainty. Probability theory relies on the fact that any experiment has a finite number of possible outcomes, whose statistical representation could be explored. This matter of fact could be considered for estimation of a certain service quality. The measured values of some quality property recorded in a history log for a given time interval can be considered as possible outcomes. Each outcome can be related to the number of its occurrences. The relative values of these numbers, known as probabilities, are values of a random variable. Theoretically the random variable can be discrete or continuous. However, as the service properties values are measured at distinct time instants, the discrete random variable is appropriate for the tasks of web service quality selection and prediction problem. Furthermore, the random variable can be described by a Probability Mass Function (PMF), which captures the probability values that the random variable can take. If x is any possible value of a discrete random variable X, the PMF of x, denoted by $p(x)$, is the probability of the event $\{X=x\}$ consisting of all outcomes that give rise to a value of X equal to x [5]:

$$p(x) = p(\{X = x\}). \tag{1}$$

Sometimes the information that the PMF of a random variable X gives has to be summarized in a single representative number. This is accomplished by an expected value of X denoted as $E(X)$ and calculated as follows:

$$E(X) = \sum_x xp\,(x). \tag{2}$$

The probability is an uncertainty related to the chance of occurrence of clearly defined events. It gives information on the relative frequencies of occurrence of the events.

2.2. Fuzzy uncertainty. Another type of uncertainty phenomenon is fuzziness. This is uncertainty due to ambiguity in the knowledge or lack of clarity on the deterministic events. The apparatus of the fuzzy sets is a powerful calculation frame for describing this type of uncertainty. This frame is able to formalize the subjectivity of human thinking, way of expressing, sensing and experiencing.

The concept of a fuzzy set (FS) allows partial set membership rather than crisp set membership or non-membership as for deterministic sets. Partial membership is formulated by a membership function, which represents numerically the degree to which the elements of the universe belong to a fuzzy set. Formally, a fuzzy set A is defined in universe U as a set of ordered pairs $A = \{(x, \mu_A(x)), x \in U, \mu_A(x) \in [0, 1]\}$, where $\mu_A(x)$ is the degree of membership of x in A. Thus, the membership function is seen as a mapping $\mu_A(x)$: $X \to [0, 1]$. As $\mu_A(x)$ approaches 1, the value x will increasingly belong to the fuzzy set A [8].

In practice, the fuzzy set is identified by its membership function. If we say that the fuzzy set A is given then we mean that its membership function $\mu_A(x)$ is known. The shape of the membership function could be defined differently as triangular, trapezoidal, Gaussian and others. Generally two approaches can be applied in order to determine the function shape—via expert knowledge or via data analysis. Also, the membership function can be given in a continuous or discrete form. Since the information for QoS properties is collected numerically by measurements made at distinct time moments, the discrete FSs are applicable to web service selection and prediction problems.

The membership function depicts the similarity between objects in terms of vaguely defined properties. It represents how much a particular feature or statement is satisfied. The fuzzy concept can be applied for description of customer requirements with respect to the properties of the web service. The concept is also useful to describe the level of satisfaction of the interesting feature of a considered service especially in the cases when there are not enough data for its statistical analysis.

3. Uncertainty description of service quality. The existence of two different uncertainties in the web service performance imposes different approaches to the QoS service selection. Below the two approaches are presented concisely.

3.1. Probability estimation of QoS properties. Probability models applied for QoS description provide information about the relative frequency of occurrence of the values of a service property. The approach introduced in [10] for QoS-aware web service selection identifies a discrete random variable X. The values x of X correspond to the respective numbers of occurrences of the property metrics in the recorded values accumulated in the service history log file.

As an example, Fig. 1 depicts 10 experimental measurements of a service quality property denoted as variable X. The occurrences of the variable are as follows: the event $\{x=2\}$ has happened one time, $\{x=3\}$ six times, $\{x=4\}$ two times, and $\{x=5\}$ one time. The discrete PMF of this experiment is presented. The PFM values are marked by squares; the line is drawn only for readability.

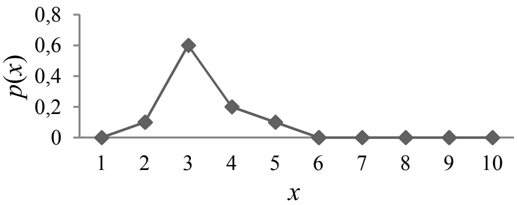


Fig. 1. PMF of service property X

In general, the calculations of PMF of an interesting property can be performed for each candidate web service that satisfies the desired functional requirements. Then the client is able to select a web service comparing the obtained probability of all candidate services. The comparison of the web services is accomplished by the expected values of the QoS property that have been estimated by equation (2). The preference is given to the service that maximizes the expectation value.

These considerations can be given in more formal way. Let us define a set S of n candidate web services S_i that satisfy the functional requirements:

$$S = \{S_1, S_2, ..., S_n\}, \iota = 1, ..., n. \tag{3}$$

Let us also consider that the variable X_i representing the QoS property of the ith service has a set of data values x_j, $j = 1, ..., m_i$. Note that m_i is the number of the occurrence values obtained for the events from a history log of the ith service. Then the selected service S_{selected} is the one whose expectation value is maximized:

$$S_{\text{selected}} = \underset{i}{\arg} \max E(x_i). \tag{4}$$

Typically web service characteristics that have a representative QoS property metrics are Response time (RT), Throughput (TR), Completed requests (CR). If we have a large amount of samples of such quality metric data, then representative statistical analysis of the approach to QoS selection given above is applicable.

3.2. Representation of a client requirement via the concept of fuzzy set. The information about QoS is objective itself as it is supposed to be data collected by a third party, which is independent of both the client and the web service provider. In contrast, the client's requirement has a subjective nature. The client's choice is a result of the subjectivity of his own understanding about the desired quality of the resources offered. This occurrence can be formalized mathematically via a fuzzy set.

The client's preference for the service property is defined linguistically. For instance, the statements 1) "*The quality value is less than 2*" and 2) "*The quality value is about 3*" are fuzzy propositions. Both express a certain level of uncertainty of the client's confidence about the desired value of the interesting service quality. A discrete fuzzy set defined on the universe set of values x describes each of these statements (Fig. 2). Thus, by giving different membership grades for the value of the desired QoS the client accepts a certain tolerance of the presented quality.

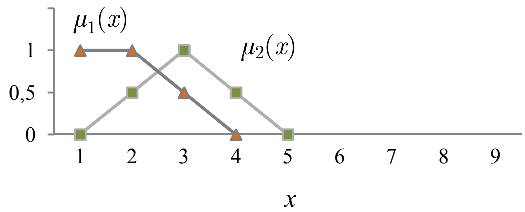


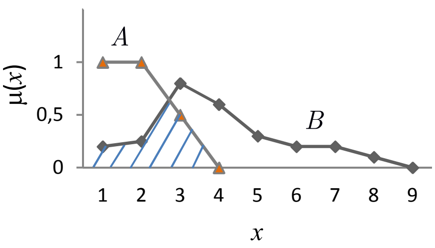
Fig. 2. Fuzzy sets of the client's preference: $\mu_1(x)$: the QoS value is less than 2 and $\mu_2(x)$: the QoS value is about 3

3.3. Joint assessment. Here we apply the intersection operation on fuzzy sets in order to assess how a given QoS property meets the customer requirement. The simultaneous performance of fuzzy statements is calculated by intersection operation of the respective fuzzy values. This operation could be estimated by any t-norm operator. Among numerous operators that realize it, the *min* operator is preferable due to its simplicity and common application [8]. Based on this operator the intersection of two fuzzy sets A and B, $A \cap B$, is defined as a new fuzzy set, whose membership function value takes the smallest value of the membership functions of A and B for each x:

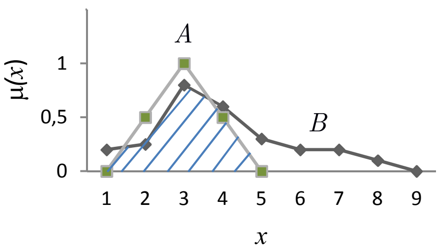
$$\mu_{A\cap B}(x) = \min\big(\mu_A(x), \mu_B(x)\big)\ \forall x \in X. \tag{5}$$

In seeking the joint performance of the service quality and client requirement the PMF that describes the web service in terms of the QoS property is interpreted as a fuzzy set, whose membership function is obtained through statistical data analysis. The second fuzzy set describes the client preference about this service quality as it was explained in section 3.2. The intersection shows the degree of satisfaction of the client's preference and the performed web service quality. The larger intersection shows a higher degree of satisfaction of the service quality.

Let us consider the example of the property having the PMF function given in Fig. 3. This PMF function is considered as a fuzzy set A with membership function $\mu_A(x) = p(x)$ that describes the level of the service quality according to the considered property. This assumption also allows us to consider a sample of data that may not guarantee statistical validity but still enable representative fuzzy values of the service quality assessment. The fuzzy set B with membership function $\mu_B(x)$ corresponds to the client's requirement. The intersection of these fuzzy sets is calculated according to equation (5). The intersection results for the examples of client preferences presented in Fig. 2 are depicted in Fig. 3.



a) for QoS less than 2



b) for QoS about 3

Fig. 3. Intersection of web service quality and customer requirement

Since the resulting intersection is a fuzzy set the result is difficult to interpret. We need a single representative (index) as a measure of the client satisfaction with the presented QoS. Similarly to the expectation value defined in the case of pure probability quality assessment, the respective fuzzy interpretation is defined as a sum of the products of QoS value x and its membership degree $\mu(x)$. The formula is applied to the intersection fuzzy set:

$$Ef = \sum_x x\mu_{A\cap B}(x) \tag{6}$$

The larger value of *Ef* corresponds to the larger overlapping of the web service quality and client's requirement. The web service that has a maximal value of *Ef* satisfies the client preference to the largest degree.

The cardinality C

$$C = \sum_x \mu_{A\cap B}(x) \tag{7}$$

could be used as an index in a similar manner. It returns the sum of all membership grades of the intersection fuzzy set. The maximal cardinality value of the resulting intersection corresponds to the most relevant web service with respect to the client requirement. This index gives only the level of confidence that the quality values are preferred, whereas the *Ef* index accounts for both quality value and its confidence. Using one or the other is a design choice.

3.4. QoS selection procedure. The considerations given above are used to summarize a procedure for QoS service selection. The procedure accounts for the uncertainty in the client preference. Let us have a set S of n candidate web services S_i, $i = 1, \ldots, n$, that satisfy the needed functional characteristics:

$$S = \{S_1, S_2, \ldots, S_n\}. \tag{8}$$

Let us also consider that the variable X_i represents a particular QoS property having a set of data values x_{ij}, $j = 1, \ldots, m_i$. Note that m_i is the number of values obtained for the events of X_i loaded in a history log of the ith service.

The steps of the web service selection procedure are as follows:

Step 1: Calculate the probability function P_i, $i = 1, \ldots, n$ for the QoS property of all candidate web services according to equation (1) as vectors:

$$P_i = \{p_i(x_{i1}), p_i(x_{i2}), \ldots, p_i(x_{im_i})\}, i = 1, \ldots, n, \tag{9}$$

where $p_i(x_{ij})$, $j = 1, ..., m_i$ is the probability of the QoS property of web service S_i taking a value x_{ij}.

Step 2: Represent the client requirement for the QoS property as a fuzzy set B with a membership degree $\mu_B(x_{ij})$.

Step 3: Find the intersection $P_i \cap B$ for each web service candidate:

$$\mu_{P_i \cap B}(x_{ij}) = \min\left(\mu_{P_i}(x_{ij}), \mu_B(x_{ij})\right), i = 1, \dots, n, j = 1, \dots, m_i. \tag{10}$$

Step 4: Calculate the numerical index Ef_i or C_i, $i = 1, ..., n$ for each intersection obtained in Step 3 according to equations (6) or (7), respectively.

Step 5: Recommend S_{selected}, which maximizes the index Ef_i or C_i, $i = 1, ...,$ n, to the client of the web service.

4. An integrated approach to multiple feature selection. Real practice shows that service selection usually requires accounting for more than one QoS property. The general problem is how to estimate the integrated quality of the service such as to reflect the joint performance of several quality properties. In solving this task different problems arise:

- Often distinct QoS properties have an effect contradictory to the service quality. Improving quality through one nonfunctional characteristic decreases the quality level of another. For instance, by improving the service reliability and safety the response time could be worsened. Therefore, QoS selection is a matter of a certain compromise.
- Another difficulty results from the fact that some service properties do not have a reliable metric as there is no numeric representative one. A way to overcome the problem is to represent the property in a fuzzy manner by describing the quality levels through a fuzzy membership function.
- The dynamic environment in which a software service operates needs to be accounted for when we estimate its quality. This objective underlines the fact that an accurate estimation of the integrated quality presented by the service could be done only for the estimation moment.

In the present solution we treat the service quality selection as a dynamic assessment task that estimates and compares the integrated quality of all interesting services at an instant time. For this we process the quality data accumulated within a certain time period till the estimation time. Thus, it could happen that the client chooses different services in different moments, although the preferences have not been changed (Fig. 4).

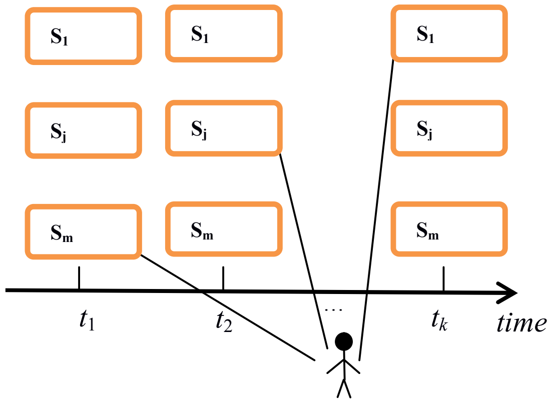


Fig. 4. A concept of dynamic selection of software services having equal functionality

4.1. Grid data space analysis for integrated quality assessment. Integrated service quality assessment is based on the monitoring quality metrics data of a particular web service accumulated in a certain time window. The data form a space whose dimensions are the distinct quality properties. The method presented here calculates the level of integrated service quality through assessment of the data strength in the sense of a fuzzy relationship. Further the obtained strength values of each service are compared in order to select the preferable one for the current moment.

Let us consider again that we have n different web services S_i, $i = 1, \ldots, n$ presenting equal functionality. Let us also assume that we have q quality properties to determine the integrated quality according to which the web service has to be compared with the other services. To this end each quality property value is presented as a fuzzy set $Q^S{}_i$, $i = 1, \ldots, n$, $s = 1, \ldots, q$, with membership function $\mu_{Q^s{}_i}(x^s{}_{ij})$, $j = 1, \ldots, m_i$. We also accept the probabilistic approach for representing the membership function, where the membership degree is defined by equation (1) as $\mu_{Q^s_i}(x^s_{ij}) = p_i(x^s_{ij})$. The joint relation of all interesting properties of a service could be estimated via Cartesian product [8]. The Cartesian product of the ith service is a new fuzzy set Q^j defined as the cross product of the fuzzy sets Q^s_i:

$$Q_i = Q^1{}_i \times Q^2{}_i \times \ldots \times Q^q{}_i \tag{11}$$

In fact the obtained fuzzy set Q_i is the set of all possible pairs that consist of: 1) a tuple of QoS properties' vector $x_i = (x^1{}_i, \ldots, x^q{}_i)$ and 2) membership degree $\mu_{Q_i}(x_i)$ of this tuple to the fuzzy set Q_i:

$$Q_i = \{(x_i, \mu_{Q_i}(x_i))\}. \tag{12}$$

Note that the element $x^s{}_i$ of the vector $x^1{}_i$ is a value of the sth quality of the ith service.

The membership function of Q_i is calculated as the minimum of the membership degrees of the constituent membership degree values (see eq. (11)):

$$\mu_Q(x_i) = \min_{s=1,\ldots,q} (\mu_{Q^s i}(x^S_{ij})), j = 1, \ldots, m_i. \tag{13}$$

The meaning of the membership function (13) is the strength level of the relationship of the respective QoS values for the respective tuple x_i. Thus, the membership degree values obtained by (13) could serve for QoS assessment and web service comparison. The larger membership degree shows more strength of the involved quality values. By comparing the strength of all services we are able to select a preferred web service. This is the service that has the largest strength as this guarantees maximal QoS quality.

For the QoS properties whose best value is the minimal one for the quality assessment (as for instance response time), the fuzzy negation [8] of the membership function has to be calculated in advance. Thus, for the sth quality of the ith service:

$$\neg\mu_{\mathrm{Qs}_i}(x^S_{ij}) = 1 - \mu_{\mathrm{Qs}_i}(x^S_{ij}) \;\forall\, j = 1, \ldots, m_i. \tag{14}$$

Then the inverted value $\neg\mu_{\mathrm{Qs}_i}(x^S_{ij})$ should be implemented into the calculations (11–13). At the final stage the largest $\mu_{Q_i}(x_i)$ value determines the web service that has the best integrated quality showing the most preferable service performance:

$$S_{\text{selected}} = \arg\max_{i=1,\dots,n} \left(\mu_{Q_i}(x_i)\right). \tag{15}$$

4.2. Integrated QoS selection method. The theoretical results presented above can be summarized in a procedure that provides an integrated QoS web services assessment and selection. Let us have a set S, $S = \{S_1, \dots, S_n\}$, $i = 1, \dots, n$ of the candidate web services that satisfy the functional requirements of the client. Let us also know that for each service q properties are of a particular interest. We also have accumulated metrics data for all interesting QoS properties within a predefined time window.

The steps of the selection procedure of integrated QoS are:

Step 1: Calculate the PMF for each QoS property by (1) representing each property of each service as a fuzzy set $Q^s{}_i$, $i = 1, \dots, n$, $s = 1, \dots, q$ having a membership function $\mu_{Q^s{}_i}(x^s{}_i)$.

Step 2: If the best quality value of a certain QoS is the minimal one then negation of the membership degree is performed according to (14).

Step 3: Estimate the cross products Q_i, $i = 1, \dots, n$ for each web service according to (11–13).

Step 4: Select the highest strength by (15) and find the most preferred web service S_{selected} regarding the integrated quality for the monitored time window.

4.3. Integrated QoS selection method accounting for the client quality requirements. The preference can be accounted similarly to the way presented for a single property selection (section 3). If the client has a view of the preferred quality levels of each QoS expressed as fuzzy values then the intersections of these values with the respective fuzzy sets of the properties obtained by PMF can be defined by equation (5). Each intersection determines the level of satisfaction of the corresponding quality. The resulting intersections of each quality of each service could be processed by the procedure of Section 4.2 in order to define the integrated quality and then to select a service having maximal quality strength.

Alternatively the client could have a preference about the needed strength level. This is presented as a fuzzy quality given as a fuzzy set. For instance, if the strength level can have values of the strength term set {Low, Middle, High} (see Fig. 5), the client requirement can be expressed by a value equal to one of these.

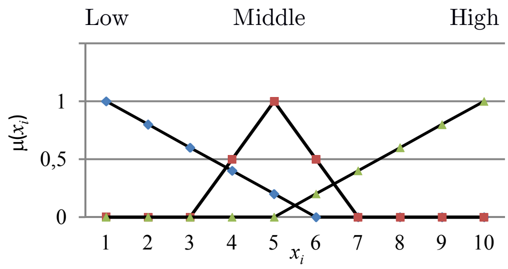


Fig. 5. Possible client's preference fuzzy values of the strength levels defined on the tuple values of the *i*th service

The chosen value is compared with the integrated quality value of each service. These are membership degrees $\mu_{Q_i}(x_i)$, $i = 1, ..., n$ that have already been calculated for each service according to the equations (11–13). Finally, in order to assess how the integrated quality of the *i*th service meets the client preference for the intersection of the two membership functions, we have to evaluate:

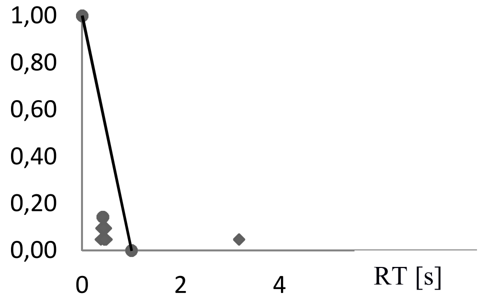
$$\mu_{B\cap Q_i}(x_i) = \min\left(\mu_{\text{strength}}(x_i), \mu_{Q_i}(x_i)\right)\ \forall\ i=1, ..., n, \tag{16}$$

where $\mu_{\text{strength}}(x_i)$ is the membership function of the strength preference given by a fuzzy set.

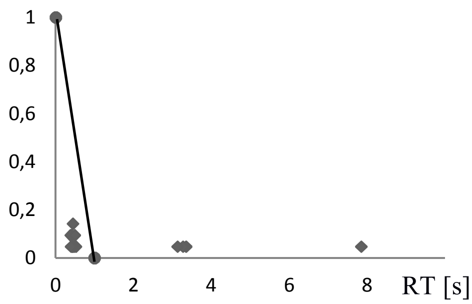
The obtained intersection fuzzy values (16) determine possible service choices. This operation gives certain information to reduce the complexity in the final service selection.

5. Experimental analysis. In order to evaluate the vitality of the given assessment methods we apply the proposed procedures as data given in open dataset [13]. It describes real-world QoS evaluation results from 142 users on web services. Data for response time (RT) and throughput (TP) have been collected over 64 different time slices at 15-minute intervals.

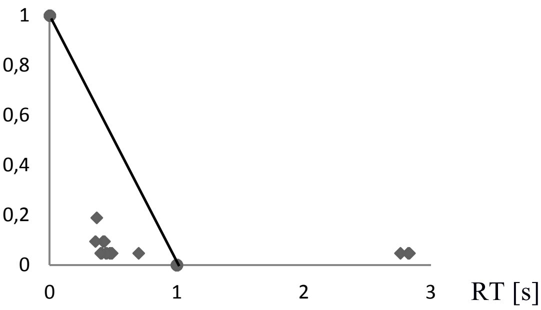
For the experimental purpose here we research only a part of the whole data set provided. We consider three services that have been used by a client for a time window of five hours consisting of 21 data for RT in seconds and TP of each service. The collected data were rounded for the purpose of practical evaluation. Further data were processed to obtain PMFs, which were considered as membership functions for the accumulated RT (Fig. 6) and TP values. The client requirement expressed as a fuzzy quality statement "RT less than 1 second" is a fuzzy set with a triangular membership function determined over the respective universe values of each service.



a) Service 1



b) Service 2



c) Service 3

Fig. 6. Membership degrees obtained as PMF of RT data (squares) and membership function (solid line) of the client preference

By applying the procedure of QoS selection described in Section 3.4 we are able to propose a service among those three that minimizes the response time for the considered time window. The calculated values of the index (7) are quite close, as $C_1 = 0.9$, $C_2 = 0.81$, $C_3 = 0.86$, but selection is still possible. Service 1 is chosen as it covers at most the client's requirement. According to the Ef index and as $Ef_1 = 0.97$, $Ef_2 = 1.189$, $Ef_3 = 0.769$, the preference is given to Service 2. This result is a consequence of the fact that the two indexes provide different information about the services. Which index to apply is a matter of design choice.

For the multiple case of service selection accomplished by both RT and TP properties the method of integrated QoS selection is implemented. For this purpose the mass function of each service and each property is estimated and treated as a membership function. As the best value of response time is the minimal one, Step 2 of the selection procedure (section 4.2) is applied in order to inverse the membership degrees of RT values according to equation (14). The cross product is estimated for the three services. It determines three tables of minimal membership degrees for all possible pairs (RT, TP). From each table we find a maximal value that determines the strength of the integrated quality of each service. The values are correspondingly 0.143 for Service 1 and Service 3 and 0.095 for Service 2. These calculations show that both Service 1 and Service 3 are preferable. Obviously additional information will be used in order to make a final choice. It could be additional service quality assessment or repeated calculations over increased monitoring volume of processed data.

6. Conclusions. The proposed approach provides a theoretical frame for assessment of uncertainty in the QoS selection tasks of services with equal functionality. Both numerical and expertly given data could be encompassed. Two solutions are described in detail. One method considers the case of one quality accounted for the service selection. The second method assesses the integrated QoS of interesting properties. The introduced procedure is based on the strength of the QoS properties calculated as the level of satisfaction of the QoS properties.

Since the proposed approach is based on data obtained through monitoring, it could be realized in an automated manner. Further, it is a theoretical basis that enables considering not only measured but also unmeasured QoS properties. Future work includes a comparison of the proposed method with other approaches in case of equal web service scenarios and evaluating the method's effectiveness with larger QoS datasets.

REFERENCES

[1] ABBACI K. F., F. LEMOS, A. HADJALI, D. GRIGORI, L. LIÉTARD, D. ROCACHER, M. BOUZEGHOUB. Selecting and Ranking Business Processes with Preferences: An Approach Based on Fuzzy Sets. *Lecture Notes in Computer Science*, Springer-Verlag, Berlin, Heidelberg, **7044** (2011), 38–55.

[2] AMDOUNI S., M. BARHAMGI, D. BENSLIMANE, A. HADJALI, K. BENOUARET, R. FAIZ. Answering Fuzzy Preference Queries over Data Web Services. *Lecture Notes in Computer Science*, Springer-Verlag, Berlin, Heidelberg, **7387** (2012), 456–460.

[3] BENOUARET K., D. BENSLIMANE, A. HADJALI. Selecting Skyline Web Services from Uncertain QoS. In: Proceedings of Int. Conf. on Services Computing, Honolulu, Hawaii, USA, 2012, 523–530.

[4] CHEN X., Z. ZHENG. Web service Recommendation via Exploring Location and QoS Information. *IEEE Transaction on Parallel and Distributed Systems*, **25** (2014), No 7, 1913–1924.

[5] DEVORE J. Probability and Statistics for Engineering and the Sciences. Brooks/Cole Publisher, Belmont, USA, 2008.

[6] GEORGIEVA O. Joint Assessment of Software Service Quality Properties. In: Proceedings of 13th International Conference e-Society, Funchal, Portugal, 2015, 316–315.

[7] GEORGIEVA O., D. PETROVA-ANTONOVA. QoS-aware Web Service Selection Accounting for Uncertain Constraints. In: Proceedings of 40th IEEE Euromicro Conference on SEAA, Verona, Italy, 2014, 174–177.

[8] Klir G., B. Yuan. Fuzzy Sets and Fuzzy Logic: Theory and Applications. Prentice Hall, USA, 1995.

[9] Li M., J. P. Huai, H. P. Guo. An Adaptive Web Services Selection Method Based on the QoS Prediction Mechanism. In: Proceedings of Int. Joint Conf. on Web Intelligence and Intelligent Agent Technology, 2009, 395–402.

[10] Petrova-Antonova D. A QoS Aware Approach for Web Service Selection Based on Probability Evaluation. In: Proceeding of the IADIS International Conference on Informatics, Rome, Italy, 2011, 43–50.

[11] Tran V., H. Tsuji, R. Masuda. A new QoS ontology and its QoS-based ranking algorithm for Web services. *Simulation Modelling Practice and Theory*, **17** (2009), No 8, 1378–1398.

[12] Xiong P., D. Y. Fan. QoS-aware Web Service Selection by a Synthetic Weight. In: Proceedings of Int. Conf. on Fuzzy Systems and Knowledge Discovery, Haikou, Hainan, China, 2007, 632–637.

[13] Zheng Z., Y. Zhang, M. R. Lyu. Investigating QoS of Real-World Web Services. *IEEE Transactions on Services Computing*, **7** (2014), No 1, 32–39. Dataset: `http://wsdream.github.io/dataset/wsdream_dataset2.html`, 17 February 2018.

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