A Proposal of Context-Aware Service Composition Method Based on Analytic Hierarchy Process

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Abstract. We propose a new service composition method with the analytic hierarchy process and discuss its availability. The concept of context-aware services has been attracting attention as an approach to improving the usability of computer-mediated services. In ubiquitous computing environments, there are several means to provide services for users, and thus, to select an appropriate mean among them is a challenge. Our method for context-aware service composition determines service behaviors by context data. Through the implementation and examination of the method, we have found that the method can output reasonable results.

1 Introduction

The concept of *context-aware* services has been attracting attention as an approach to improving the usability of computer-mediated services [1]. Especially in ubiquitous computing environments [2], the context-aware services are expected to become more effective and beneficial. The term, context-aware or context awareness is used for meaning that specific services are provided for users' desired results according to the users' contexts. For taking the usability of services into account, we have to consider not only what services are provided, but also how they are provided.

In ubiquitous computing environments, there are several ways to provide services for users, and thus, to select an appropriate mean among them is a challenge. When a call is coming in a user's mobile phone, for example, the phone can notify the user of the call with several means, such as its vibrator, speaker, or display device in general. For getting the notification with an appropriate mean, the user needs to configure which device is to be used in advance. However, in ubiquitous computing

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environment, it is difficult to configure all such means (devices) beforehand, because there might be too many services and means there. Thus, we have to consider how to combine previously created service components (service contents and means) automatically depending on user contexts. To achieve this automation, it is necessary to select most suitable combination of service components in accordance with service contents and user contexts.

As one of previous studies for the *service composition* for use in ubiquitous computing environments, Yamato et al. proposed a system named service composition engine [3, 4, 5]. The system discovers suitable service components from network based on a user context and binds them dynamically in accordance with a semantic-level service scenario. In this study, different evaluation functions are assigned to each evaluation items such as proximity, price , and set evaluation value, and the total of the functions is addressed as the overall score of the current context. As an evaluation standard for service composition, the system calculates the overall score according to service elements or components and user contexts. However, it is difficult both to evaluate qualitative factor such as taste, feeling, and sensibility; and to investigate the weight of each evaluation function for the overall score.

In this paper, we propose a new service composition method with the analytic hierarchy process (AHP) [6] and discuss its availability. With introducing the AHP, we can deal with qualitative factor and treat wide variety of context entities. Moreover, we can facilitate finding and fixing flaw of evaluation function. In our method, service-device compositions are considered as hierarchical structures of the AHP, and their overall score are derived with these hierarchies. We claim that our method might enable to develop efficient context-aware services.

2 Context-Aware Service

Context-aware services dynamically recombine their components depending on the surrounding contexts of the services and users. The context used here is some information that characterizes the situation of an entity, such as a person, an object, or a place that relevant to the interaction between a user and a service. For offering context-aware services, a system needs to

1. acquire some sort of data from circumstances with its sensors,
2. abstract the data and interpret its meanings for comprehending the contexts, and
3. determine service compositions and behaviors based on the contexts.

Our method is used at the second and third step, for comprehension of contexts and composite service components.

The term, service composition means that composing some combinable services, contents, and devices developed in advance, according to dynamically-changed contexts. This enables to utilize dynamically-composed and suitable service provided in ubiquitous computing environments.

3 Service Composition Method

Our method for context-aware service composition determines service behaviors based on context data. The method derives the most suitable mean to provide service from context data of services, devices, surroundings, etc. After that, it outputs derived service composition policy as XML descriptions.

3.1 Analytic Hierarchy Process

The analytic hierarchy process (AHP) is a structured technique for helping people to deal with complex decisions relative to a wide variety of situation and various criteria. When evaluating alternative solutions, it is not necessarily the case that they satisfy all criteria. The AHP decompose their decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently. An AHP hierarchy consists of an overall *goal*, *alternatives* for reaching the goal, and *criteria* that relate the alternatives to the goal. Each alternatives and criteria is compared by means of pairwise comparison method, and the obtained pairwise comparison matrix is converted to the importance degree of the alternatives and criteria. Next, the importance degree of each element of the hierarchy is calculated from the pairwise comparison matrix using the eigenvalue calculation. When A is the obtained pairwise matrix and W is the importance degree of each element, the eigenvalue expression is given by

$$AW = \lambda_{max} W, \tag{1}$$

where λ_{max} is maximum eigenvalue. Therefore, W is an eigenvector corresponding to the maximum eigenvalue of A. This enables to calculate the unknown value of W. The importance degree of the goal X is derived from applying this calculation for each element and multiplying mutually. The X, defined by

$$X = [W_1^T W_2^T \dots W_n^T]W, \tag{2}$$

is computed by multiplying by importance degrees of alternatives $[W_1^T W_2^T \dots W_n^T]$, importance degrees of criteria W. In this way, the alternative priorities are calculated by the method.

3.2 Method Procedure

We accounted for the method procedure with the example of a context-aware service scenario which is to notify a user of receiving a phone call. We determined this example's goal, alternatives and criteria (Table 1).

In accordance with the procedure of the AHP, the user creates a hierarchical structure of the criteria and the alternatives. Firstly, the user derives the importance

Table 1 The goal, criteria, and alternatives for the service composition example

Goal	To notify a user of receiving a phone call
Criteria	User-device distance (far or near) Awareness of incoming (high or low) User's taste
Alternatives	Speaker Display Vibrator

degrees of criteria by pairwise comparison method. In this case, the user determines which one of the criteria should be emphasized for notifying the call. Next, the user derives the importance degrees of alternatives by pairwise comparison method as well. For example, the user compares alternatives, which one of the alternatives (devices) should be emphasized from the viewpoint of fitting it to the user's taste. In this example, the user derives the importance degrees as shown in Fig. 1. In addition, with introducing dynamically-changed context data, context factors can be added to the AHP. The dynamically changed context data is converted to the importance degree of criteria, and introduce into the AHP expression. The expression is given by

$$X = [W_1^T W_2^T \dots W_n^T]CW, \tag{3}$$

where the importance degree of the goal X is computed by multiplying by importance degrees of alternatives $[W_1^T W_2^T \dots W_n^T]$, importance degrees of criteria W and dynamically-changed context data C.

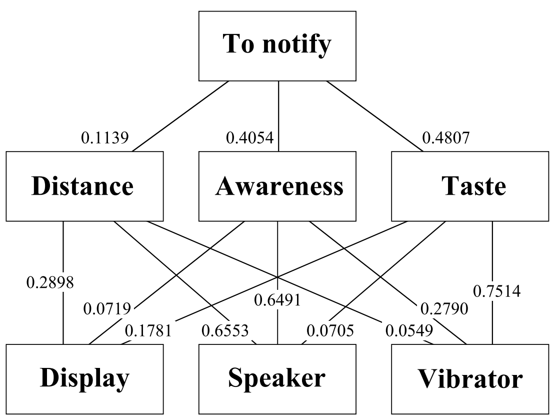

Fig. 1 AHP hierarchy for the sample scenario, with some associated priorities. The numbers show importance degrees of respective pairs of elements. $W_{Distance}^T$ = (0.2898, 0.6553, 0.0549) , $W_{Awareness}^T$ = (0.0719, 0.6491, 0.2790) , W_{Taste}^T = (0.1781, 0.0705, 0.7514) and W^T = (0.1139, 0.4054, 0.4807) , which are obtained by respective pairwise matrices $A_{Distance}$, $A_{Awareness}$, A_{Taste} and A

4 Experiments and Results

We implemented a prototype system of our service composition method, and had it calculate a representative service example of notifying a user of receiving a phone call we mentioned above. We created context data as an input, and examined that our method can evaluate each devices.

A user determines the importance degrees of alternatives by pairwise comparisons in accordance with the service. The system receives a context data as an input, which is created by various sensors in real time. The importance degrees of criteria and final evaluation value for an overall goal vary according to the real time data.

We evaluate the proposed method by examining the result for a sample scenario and some sample context data. Four sorts of sample data expressed by matrix are created according to whether user-device distance is far or not, and user awareness level is high or low (Fig. 2). Each diagonal value represents the weight corresponding to the criteria in the context. In reality, these values are dynamically-changed in real time. In this instance, four representative values are prepared and calculated. The device which has the maximum score is the most suitable mean for providing the service in the context (Fig. 3). Since distance and awareness vary according to surrounding contexts, the importance degrees also change. The result shows that when the user-device distance is near and the user can awake easily, the method put much weight in the taste, while when the user-device distance is far and the user can hardly awake, the method put much weight in distance and awareness to do reliably. This relation fits in the way of thinking that a user selects the favorite device when either notifying device is located near or surroundings are not loud, because which device can notify user of receiving a phone call.

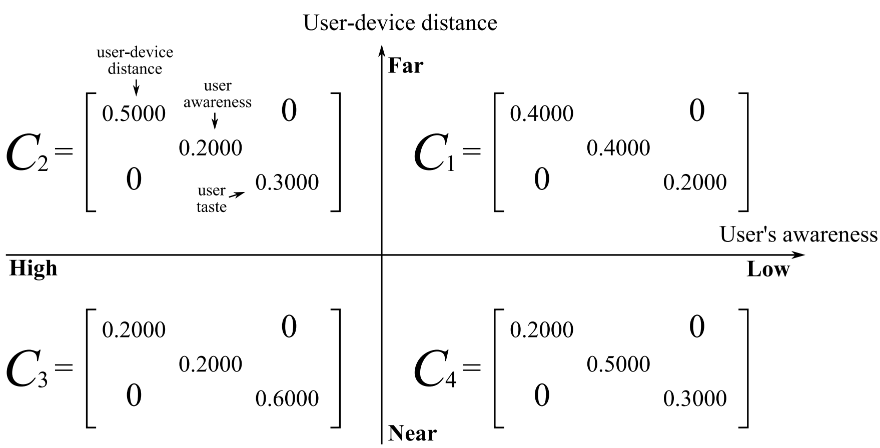

Fig. 2 Each criterion's weight calculated by the sample data under each context, and expressed by matrix $C_1,\ldots,C_4$. Diagonal values represent the weights corresponding to the criteria, such as distance, awareness, taste in the context

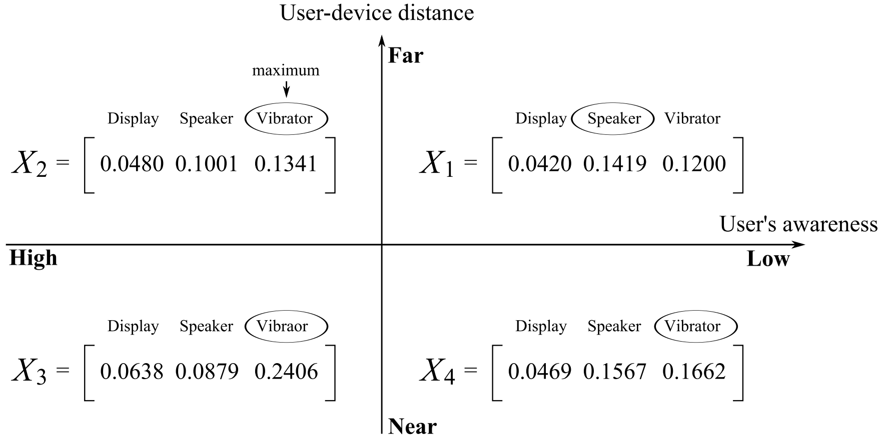

Fig. 3 The Results of the method. $X_1,\ldots,X_4$ are calculated from $C_1,\ldots,C_4$. Elements of vector $X_1,\ldots,X_4$ represent the importance of degrees of alternatives. The device which has the maximum score is the most suitable mean

5 Conclusion and Future Work

In this paper, we have presented the method for context-aware service composition based on AHP for use in ubiquitous computing environments. We have performed the preliminary experiment and examined the availability of the method using sample data, and have confirmed that the method can output reasonable results for each sample context. The advantage of our method is that it can deal with qualitative factors in consideration of the weight through the pairwise comparison method, and can interpret each factor's weight and modify it by reconsidering the evaluation process. Further work is to apply this method to real-world situations, such as home network, wireless mesh network, and, intelligent building, to compare it to other methods, and to evaluate the effectiveness quantitatively.

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