

Impromptu Service Discovery and Provision in Heterogeneous Assistive Environments

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Abstract — Wireless hotspots are permeating the globe bringing interesting services and spontaneous connectivity to mobile users. In order to enable the elderly and disabled to be fully integrated into the society, it's of paramount importance to build a pervasive assistive environment where assistive services can be automatically discovered and easily accessed with the device-to-hand across the physical spaces. In this paper, we propose a framework that can support impromptu service discovery and context-aware service provision with mobile devices in heterogeneous smart assistive environments. Different from the existing approaches, the framework requires no specialized hardware or software installation in mobile client devices, and it can automatically discover and select appropriate services based on the user profile and situation context, and generate personalized user interfaces according to user preference and device capability. To demonstrate the effectiveness of the framework, we prototyped a set of assistive services in public spaces like shopping malls, leveraging the OSGi-based platform accessible from any WLAN enabled mobile devices.

Index Terms — Impromptu service discovery, service provision, smart assistive environment, user interface generation.

1. INTRODUCTION

The rapid growth of the world's older and dependent population calls for assistive services in various living

spaces such as home, office, hospital, shopping mall, museum, etc.. Mobile and pervasive technologies are opening new windows not only for ordinary people, but also for elderly and dependent people due to physical/cognitive restriction. As wireless hotspots are permeating the globe bringing interesting services and spontaneous connectivity to mobile users, one trend is to gradually transform various physical environments into "assistive smart spaces", where dependent people can be supported across all the heterogeneous environments and be fully integrated into the society with better quality of life and independence.

In order to provide services in various assistive environments, impromptu service discovery and provision with heterogeneous mobile devices become critical. There are two possible ways to make the services accessible to mobile users. One way is to get connected to a global service provider and access the location-based services through the service provider. In this case, the service provider needs to aggregate all the services in the smart spaces and have the indoor/outdoor location of the user. Due to the evolutionary nature of the autonomous smart spaces, it is unlikely to have such a powerful service provider in the near future. The other way, which we are in favor of, is to enable the mobile user interact with individual smart space directly when the mobile user physically enters the space, that is, the mobile user can automatically discover and access the services provided by the smart spaces. In the latter case, the mobile user needs to get connected directly to the individual smart space using short range wireless connectivity, appropriate services are provisioned to users with consideration of user preference and the constraints of mobile devices.

There are three key challenges to achieve impromptu

service discovery and access. The first challenge is how to automatically discover the relevant services upon entering a smart space; the second challenge is how to automatically provide appropriate services to the right person with the right form with the consideration of user and situation context; the third challenge is how to generate a personalized user interface for the specific mobile device based on user's preference and device capability. To address the first challenge, various software [1][2][3] and hardware [4][5][6] "plug-in" methods have proposed. The key idea was to embed specialized software or hardware components in both the mobile device and the environment which follow the same service discovery protocol, however, there is still no dominant solution that was standardized and accepted by the whole community. To address the second challenge, existing approaches are either location based or user preference based, they seldom consider the multi-dimensional contextual information, and are often limited to key-value based semantic matching to select appropriate services to the user [15]. To address the third challenge, various device-independent user interface generation mechanisms [7][8][9][3] have proposed. The key idea was to separate the definition of a user interface from that of the underlying service, however, the user profile and interaction style were not well studied for impromptu generation of user interfaces for dependent people.

In this paper, we aim to design a new framework for dynamic service discovery and provision in heterogeneous smart assistive environments, using a wide spectrum of mobile devices ranging from smart phones, PDAs to Tablet PCs. The proposed framework is designed to achieve the goal of impromptu service discovery, context-aware provision, and personalized device-independent service access. While the framework makes minimum assumptions on the mobile devices, it is capable of capturing and aggregating contexts about the users, devices and environments, which in turn can facilitate the service discovery and provision considering the user profile and situation context. It is also capable of generating appropriate user interfaces in mobile devices, according to the user preference and device context.

The rest of the paper is organized as follows: Section 2 starts with a use scenario for assisting a disabled person in a shopping mall environment, from the use case six system requirements are identified for supporting impromptu service discovery and access

in heterogeneous smart assistive environments. After presenting the overall system design for impromptu service discovery and access framework in Section 3, a context-aware service provision process based on semantic similarity measure is described in Section 4. Section 5 presents an automatic service user interface generation mechanism according to the user context and device capability. Finally, Section 6 gives the implementation details about the service framework and some assistive services in a shopping mall environment, some concluding remarks are made in Section 7.

2. USE CASE SCENARIO

Before elaborating technical details about the system, we would like to provide a use scenario motivating the assistive services which need impromptu discovery and access in smart environments. From the scenario, system requirements can be derived.

Bob, a person with disability on wheelchair, would like to buy some movie DVDs in a new shopping mall. Upon entering the mall, he is presented with a navigation service on his wireless PDA so that he finds that one DVD shop is located in third floor. When approaching the nearest lift, he finds a lift control service in his PDA as he is not able to push the button in the lift. He accesses the lift control service and sees a user interface with big fonts as it's difficult for him to touch small icons. He then selects level 3 and finds the DVD shop. In the shop, he is presented with 2 services : one is the DVD finder which helps him locate the DVD in a specific shelf, the other is a movie recommendation service that recommends movie DVDs based on his preference.

Apparently, in the above use scenario, impromptu service discovery and context-aware service provision with mobile devices are critical requirements ; the automatic generation of user interface of the selected services is also needed, based on the user's preference, physical constraints as well as the device capability. Concretely, the following requirements need to be satisfied:

2.1. Minimum Assumption on Mobile Devices (R1)

The pervasiveness of web-enabled mobile devices, such as smart phones, PDAs, laptops and Ultra-Mobile

PCs, provides a convenient interface for accessing services through wireless network and web browsers. A spontaneous service discovery and access framework should leverage on this existing minimal requirement to provide access to services rather than on technologies, such as proprietary beacons that are not ubiquitous.

By relying on basic wireless capabilities and web browser functionality, the framework should allow services to be easily reachable to customers who use currently available mobile devices. They would not need to buy specialized hardware or install any software, thus spurring rapid adoption of services.

2.2. Spontaneous Service Discovery in Heterogeneous Smart Spaces (R2)

In the future, with places such as home, office, shopping mall, and museum transformed into “*smart spaces*”, people would like to access the services at each location in the same way through their personal mobile devices. However, each service provider would have their own agendas and it may be difficult for a universal service provider to emerge.

We anticipate an ecosystem of distributed local service providers, where local spaces are controlled by individual entities, each providing their own set of services. Such services across heterogeneous spaces need to be discovered automatically by the users.

2.3. Heterogeneous Service Aggregation (R3)

Service aggregation in heterogeneous spaces is a heavily researched field, leading to many implementations and standards. Each has their strengths and weaknesses, but none of them have yet to become the dominant standard used in industry. Furthermore, many proprietary services exist that do not follow any standards, causing the problem of devices and services that are incompatible. Customers would have to either accommodate multiple platforms or stick to one, constraining their options. We seek to develop a flexible framework that integrates many of these platforms, rather than creating a competing implementation. Our system would have adaptors that will allow these platforms to easily fit into the framework.

Other than just aggregating device-based services, the framework should also handle web-based services that are independent of devices and locality. For example, the del.icio.us and flickr websites aggregate web bookmarks and online photos, respectively. Aggregators can be built over these web services to incorporate into the framework to offer more services.

While the aforementioned mechanism allows dynamic discovery of services, some services can be installed during configuration of the local server. These would be static and location dependent. With all these services available, our framework would be a hybrid system providing dynamically and statically available services. Furthermore, the user would interact with each service equally without the need to be aware of the aggregation that occurs.

2.4. Context-aware Service Provision (R4)

In a smart environment, mobile users might discover various kinds of services in which majority of them are not relevant to the current task. Therefore, service provision and selection are required to provide right services to the right person in the right form.

Formally, Context is the kind of semantic description of entities in the smart environment such as the user, device, activity and services. It's obvious that the context (e.g. location, user preferences, device capability) plays an important role in service provision and selection, because they provide appropriate constraints for the service provision process.

In our framework, we need to identify the context entities that enable the service provision and propose an efficient service provision mechanism to filter services according to user needs.

2.5. Adaptive User Interface Generation (R5)

The design and complexity of the user interface determines the ease with which users can access the services in the smart environment. As the users and access devices vary, adaptive user interface generation should be supported to facilitate the access of appropriate services.

In our framework, the adaptive user interface needs to be generated to different users by considering user preferences and device capabilities, providing personalized experiences to end-users in mobile client devices.

2.6. Security and Privacy for Service Access (R6)

Security and privacy are critical issues for service access in a mobile environment. When the mobile users access certain services, the information security and privacy should be guaranteed during the interaction process between the mobile client device and the system. The information exchange should be secure to avoid malicious attacks. In the meanwhile, user privacy should be guaranteed so that he might choose

not to reveal his identity during the service access process.

3. SYSTEM ARCHITECTURE FOR IMPROMPTU SERVICE DISCOVERY

To address the above-mentioned requirements, we have proposed an impromptu service discovery and provision framework which enables the services in heterogeneous environments accessible to any WLAN enabled mobile device, according to individual user's preference, situation and device capability. The system is designed according to the six identified requirements as follows:

- R1 : In order to facilitate the interaction between users and the smart space, we assume that the mobile devices should have at least the built in WiFi chipset to allow wireless connectivity and a web browser to access the web server hosting the services of the smart spaces. The requirement on mobile devices is minimum as it doesn't rely on any specialized software or hardware.
- R2 & R3 : Following the minimum assumption on mobile devices, it requests that the services are associated with a specific "smart space" like a shopping mall, a lift, or a DVD shop. When the mobile devices are detected within a certain smart space, the services can be automatically discovered and presented in the mobile devices. To enable the service aggregation and automatic discovery, a captive portal and service portal mechanism is proposed. We adopted the open standard-based service platform such as OSGi [10] to aggregate various services and provide the service portal in a specific smart space as such various devices and communication protocols are already supported. The main function of captive portal is to direct the web browser of the mobile device to the service portal of a specific smart space, it enables the automatic discovery of the services available in the smart space. The automatic service discovery process is shown in Fig. 1. When the user connects to a wireless hotspot, his browser is detected by the Captive Portal (1), and forwarded to the Service

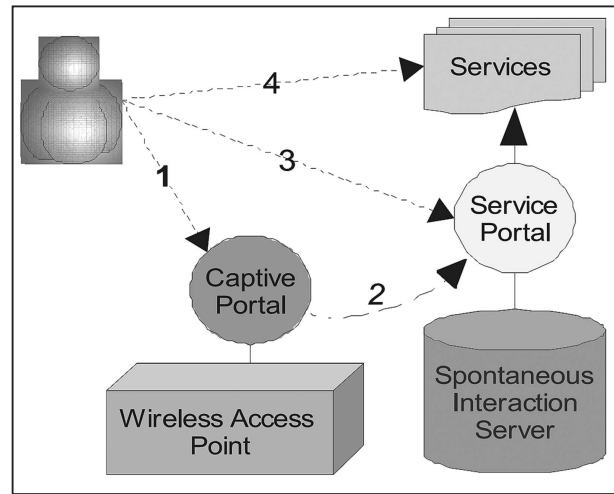


Fig. 1. Service discovery process

Portal (2). He can then browse the available services (3), and invoke a service through his mobile device (4).

- R4 : The relevant contexts that might facilitate service discovery/provision include the user preference, user identity, location, orientation, and the device context such as screen size and input/output constraints. Leveraging on our previous work on "Semantic Space" [11], the context model and the service provision process based on semantic matching of context are described in Section 4.
- R5 : Separating the user interface from the service functionality is the key for the generation of user interface to different targeted platforms. The user constraints and device constraints have given new impetus to the need for personalized user interface generation. The detailed user interface generation mechanism is given in Section 5.
- R6 : As the web browser is the user interface shown in the mobile device and connected with the services in the smart space, thus certain security mechanisms and information exchange profiles need to be defined and agreed upon. In the system design, the user authentication and information exchange profile are associated with individual service. When a service gets accessed, it will invoke the associated authentication and information exchange process. The W3C Composite Capabilities/Preferences Profile (CC/PP) [12] has been adopted to exchange information between the personal device and the environment services.

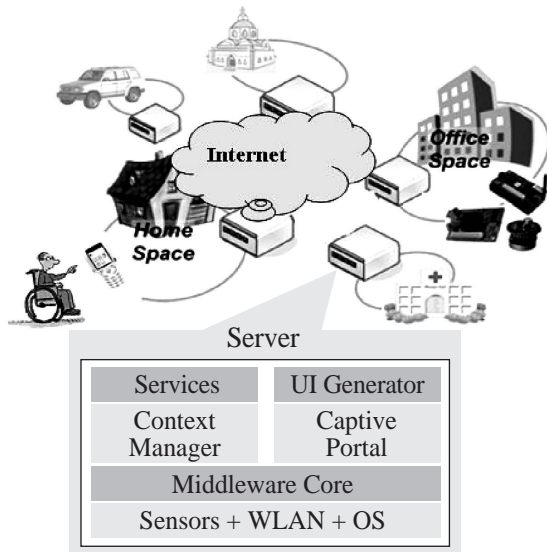


Fig. 2. Impromptu service discovery and access framework for multiple spaces

The overall system architecture is shown in Fig. 2 where each smart space has an impromptu service discovery and access framework embedded as a server. When the dependent people move from one space to another with a WLAN enabled mobile device, his mobile device’s web browser will be directed by the captive portal in the framework to the service portal of the new smart space which aggregates and hosts the services offered. The middleware core refers to the OSGi-based service platform. The context manager is responsible for

context representation, aggregation, reasoning, storage and query processing, which will facilitate service discovery and access with mobile devices. Based on the user preference and device capability, UI generator automatically generates the appropriate user interface for the service accessed on the device-to-hand.

4. CONTEXT-AWARE SERVICE PROVISION PROCESS

The context-aware service provision process needs to handle two main issues: context modeling and semantic matching. The former is to give a formal representation of user profiles, situation context and service description with the ontology-based context model ; the latter is to give semantic similarity measure to select appropriate services considering the user profile and situation context.

4.1. Context Modeling

Since user profiles, environmental contexts and device capability are key factors affecting the service provision process in smart assistive environment, the context model should consider context information ranging from user profiles, location, time, activity to environment and situation context as shown in Fig. 3.

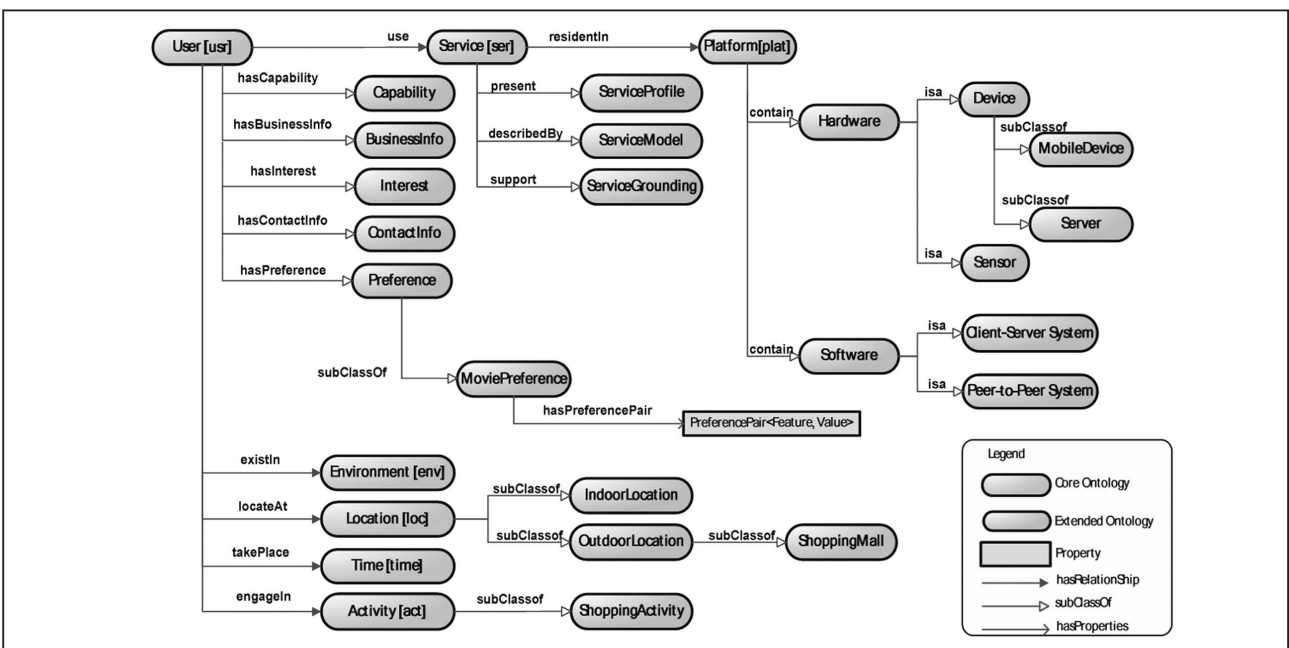


Fig. 3. A context ontology for service provision

Based on our previous work in context modeling [16, 17], we divide context ontology into two parts : core context ontology for general conceptual entities in smart assistive environment and extended context ontology for domain-specific environment, e.g. shopping mall domain. The core context ontology attempts to define the general concepts for context in smart environment that are universal and sharable for building context-aware applications. The extended context ontology attempts to define additional concepts and vocabularies for supporting various types of domain-specific applications. The core context ontology comprises seven basic concepts: *User, Location, Time, Activity, Service, Environment and Platform*, which are considered as the basic and general entities in smart assistive environments.

In order to select the appropriate services according to the user profile and situation context, the user profile and situation context need to be matched against the service descriptions. If the attributes of the user profile and situation context match well with the attributes of the services, then the corresponding services are selected and provisioned to the end user in the mobile devices. In the system design, we use Ontology to represent the user profile, situation context and service as follows:

- *User profile* : it refers mainly to user's static information such as *Interest, Preference, Device Capability, Business info, Contact info*, etc.. The user profiles can be stored in the mobile device or a home server updated accordingly.
- *Situation context* : It refers mainly to user's dynamic information such as *User location, User activity, Time and Physical Environment* which is often derived from sensors in the environment.
- *Service description* : it describe the features of service instance including *UUID, Service Name, Service Provider, Category, Precondition, Input Parameter, Output Parameter*, etc.

4.2. Semantic matching based on similarity measure

The goal of semantic matching is to determine how much the user profile and situation context match with the services available, which are described by the ontology model.

We use the *Pearson's Correlation Coefficient* to calculate the similarity measure between two vectors

with their rating values. The similarity of vector C_1 and C_2 is formally defined as

$$Similarity(C_1, C_2) = \frac{C_1 \cdot C_2}{\|C_1\| \times \|C_2\|} = \frac{\sum_{i=1}^n \alpha_i \beta_i}{\sqrt{\sum_{i=1}^n \alpha_i^2 \sum_{i=1}^n \beta_i^2}} \quad (1)$$

where $C_1 = (\alpha_i)$, $C_2 = (\beta_i)$, $i \in 1..n$ and *Similarity* (C_1, C_2) returns the relevance value of two vectors over all the items ratings.

Given the user profile vector $U^* = \{u_1^*, u_2^*, \dots, u_m^*\}$ and situation context vector $C = \{w_1, w_2, \dots, w_n\}$, we can get the composite vector $CC = \{u_1^*, u_2^*, \dots, u_m^*, w_1, w_2, \dots, w_n\}$. Then based on the service description vector $S = \{s_1, s_2, \dots, s_p\}$, where $p = m + n$, we can compute the cosine similarity between the composite user context and the service profile as follows:

$$Similarity(S, CC) = \frac{S \cdot CC}{\|S\| \times \|CC\|} = \frac{\sum_{i=1}^p v_i s_i}{\sqrt{\sum_{i=1}^p v_i^2 \sum_{i=1}^p s_i^2}} \quad (2)$$

Based on the similarity result, the m services with high ratings are selected and presented to the end user. The number m depends on the UI design of user's client device, where

$$\{S^*\} = \{U_j \mid \max_m \{ Similarity(S, CC) \} \} \quad (3)$$

5. AUTOMATIC GENERATION OF PERSONALIZED USER INTERFACE

In order to facilitate adaptive user interface generation, services in the OSGi based service framework are decomposed into the following three parts [13]:

- *Program code* : it consists of the service logic and related methods.
- *Interface description* : it provides the template of input/output parameters as well as the device independent presentation of the service. It provides

a high-level abstraction of the user interface which takes the form of XML file. Different modalities such as visual, auditory, and tactile are also described in the file.

- *Service description* : it contains the description of the service properties as mentioned above. The service profile serves mainly for service filtering purpose.

With the service description as input, the UI generator is responsible for automatically generating the graphical user interfaces for different target platforms, taking into the following factors into consideration: interaction techniques, user preferences and device capabilities. The UI generation process is illustrated in Fig. 4.

Aligned with the current trends in web programming, XHTML now only presents structural data of the webpages, while all the layout styling is handled via Cascading Style Sheets (CSS). This dissociation of presentation from model allows us to handle the XHTML form structure separately from its layout.

Utilizing the standard procedure of transforming XML to XHTML, the XSLT processor uses the standard SidXML-to-XHTML XSLT stylesheet and a Service Interface Description (Sid) XML document as input to produce the XHTML user interface (UI) form. This is the basic version with no stylizing. The use of the XSLT processor and document allows for output to other formats than HTML, which can be used to generate UIs for non-browser-based devices, or web services.

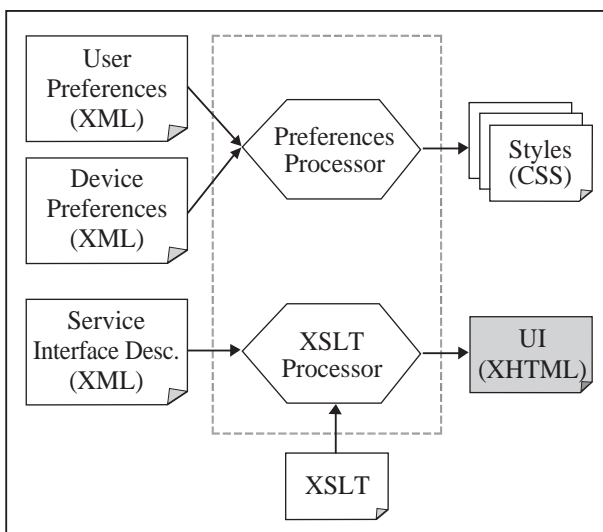


Fig. 4. Generation process of user interfaces according to user context

Our contribution involves providing a Preferences Processor to take user and device preferences in XML format and generating CSS that would style the output XHTML form appropriately. The system requires that the file for the CSS has a predefined name that the XHTML form knows to point to. Depending on the preferences of the user or device, a different CSS stylesheet would be generated. Since the XHTML file and the SidXML are not manipulated by the Preferences Processor, developers familiar with the XML-to-XHTML conversion can easily augment their user interfaces with preference-sensitive stylesheets.

By using HTML and CSS, we can also leverage on the accessibility features of these web standards to provide suitable UIs for the visually and aurally handicapped. The same documents would be served to accessible browsers.

6. IMPLEMENTATION OF THE PROTOTYPE

We have implemented a prototype of the impromptu service discovery and access framework using the ProSyst OSGi service platform as the middleware core.

The UI generator, the context manager and the assistive services are wrapped as OSGi bundles in the framework. Each assistive service implements its specific interface, and each interface has to contain a common method called “getInterfaceDescriptionURL”. This method intends to be called by the UI generator when the user selects a service and pass the URL of the service description file to the UI generator. Upon loading the XML file, the UI generator will parse it to generate the corresponding GUI and associate the GUI with the service logic and methods. In each logical smart space, we install the captive portal on a Linksys WRT54GL WLAN router. On entering the smart space, the web browser of each mobile device is automatically directed to the service portal showing the selected services, whose profiles match with the user profile and situation context based on the similarity measure. For aggregation of devices, we implemented an UPnP wrapper service built over Kono’s CyberLink for Java UPnP library, providing web access capabilities. Links generated in



Fig. 5. Impromptu service discovery/access platform

the service portal point to the presentation URLs of the UPnP services. Fig. 5 shows the system set-up consisting of a Linksys WLAN router, a Samsung Q1 UMPC, a service platform, an Axis UPnP camera, and a set of assistive services in the shopping mall environment.

For the shopping scenario in a DVD shop, a DVD finder service and a movie recommendation service are chosen and provisioned to users when they enter the shop. Fig. 6 shows the snapshot of the selected shop services, he can then use the DVD finder to locate the DVD collections in a certain shelf and invoke the movie recommendation service to ask for an impromptu recommendation, based on the user preference and device capability. The detailed recommendation algorithm can be found in [14].

For the lift control use case in the shopping mall, Fig. 7 shows the automatic generated user interfaces of the lift control service for different users and different devices. Depending on the preferences of the user, he would see a different UI. For example, when invoking the lift control service, a young dependent man could

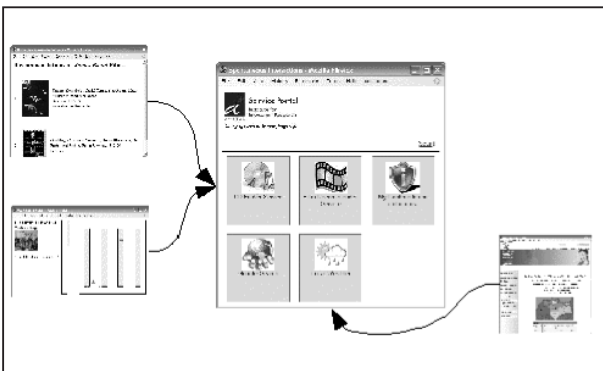
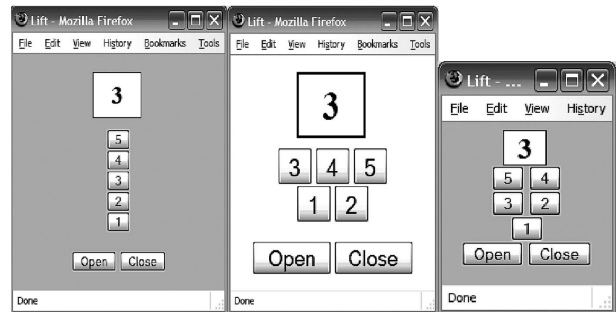


Fig. 6. DVD Shop-specific services: DVD finder and movie recommendation



(a) (b) (c)

Fig. 7. Generated user interfaces according to user and device context

see the UI in Fig. 7a with a vivid design. While an elderly person with poor eyesight access the service, the UI generated is shown in Fig. 7b with larger font and a higher contrast ratio. The UI generation is also adaptable to device context such as screen size. Fig. 7c shows the same lift control UI rendered for a smaller screen.

7. CONCLUSION AND FUTURE WORK

We have proposed and implemented a framework for impromptu service discovery and provision in heterogeneous assistive environments. The distinct features of the framework are:

- Achieving impromptu service discovery with a “minimum assumption” on mobile devices through a proposed captive and service portal mechanism.
- Service provision based semantic similarity measure combining with user profiles and situation context.
- Automatically generating personalized user interface according to the user preference and device capability.

While the framework developed showed encouraging results, there are several issues which we plan to address in the future work:

- Although OSGi service platform can support heterogeneous devices and services, proper tools still need to be developed to transform the other services, especially legacy services into OSGi service bundles.

- When more than one WLAN routers are put in vicinity, the user is still requested to manually select the appropriate access point.
- Security and privacy issues are not addressed in the current system set-up.
- The preferences of different type of dependent users need to be systematically understood and the usability issue of the assistive services and generated user interfaces need to be studied.

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