TOWARDS AN ONTOLOGY-BASED CUSTOMIZATION APPROACH FOR SUPPORTING PEOPLE WITH SPECIAL NEEDS

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Abstract

People with disabilities encounter serious limitations in interacting with their home environment since their requirements are not met properly. Personal assisting devices interacting with the services offered by smart home environments can help to improve the quality of their lives. A major prerequisite for this is to provide an appropriate customization architecture which allows to reason about the person's current situation in terms of personal, technical and natural context and to adapt the home environment's services accordingly. This paper proposes a customization approach based on an ontology which comprehensively represents the situation of persons with special needs for the purpose of adapting their home environment's services.

1. Introduction

People suffering from physical or mental disabilities often have problems in interacting with their home environment and thus are constrained in supporting themselves as independently as they often would wish. They encounter limitations when using existing of the shelf home equipment like lights, telephone, TV-sets or VCRs. The reason for these difficulties is that there exists a mismatch between the equipments capabilities designed for standard users only and the abilities of persons with disabilities in terms of motion, recognition, and perception.

Those difficulties differ for each person individually, dependent on the kind of disability one is suffering from. The spectrum may reach from slight difficulties in operating these devices not likewise skilfully as people not encountering disabilities to severe disabilities making it impossible for such persons to interact with traditional equipment without additional help at all. Some users might have difficulties in reading, while others have severe problems when using standard keyboard interaction to interact their home equipment. Currently, persons with disabilities need to adapt themselves to their home environment, meaning that the human need to adapt to the machine.

Such systems should rather be intelligent in that they adapt themselves to the individual constraints and current situation of persons to provide a service most likely in the line with the user's intentions

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and goals. Pervasive computing research envisions promising developments towards smart home environments which are equipped with various networked sensors/actuators such as cameras, microphones, location sensors, etc. (cf., e.g., [27]) and are able to provide services which can be realized on basis of Web service technologies (cf., e.g., [34]). In such scenarios, so-called personal assisting devices (PADs) [23], which are specialized towards the user's disabilities, can be used as interfacing devices to the home environment's services. We claim that such PADs should interact on the user's behalf with the home environment and - by collecting additional contextual information - act intelligently in assisting the user in performing tasks easier and enabling tasks previously not possible.

To achieve a comprehensive support, it is important to combine contextual information like *personal aspects* (e.g., disabilities and preferences), *technical aspects* (e.g., equipment services and network) and *natural aspects* (e.g., location and time) in a way that the smart home environment's services can adapt to the user more or less automatically while keeping the user in control. Semantic Web technologies in general and ontologies in particular, offer a promising mechanism to describe the people's situation and the required adaptations in a machine comprehensible way, thus paving the way for supporting them with appropriately adapted services.

According to this vision, the paper is structured as follows. Section 2 discusses domain-specific requirements for assisting persons with special needs in a pervasive home environment scenario. Section 3 presents largely domain-independent context and adaptation issues which should be considered in the realm of customization. Based on these prerequisites, Section 4 proposes the use of ontologies as a main basis for customization, gives an overview on related work and illustrates the overall architecture of our approach. Finally, Section 5 summarizes the main achievements of the paper.

2. Requirements for Assisting Persons with Special Needs

Pervasive computing systems [7], focusing primarily on the aspects of sensors, networking and device interaction, have essentially different interaction modes since computers are disappearing. The same holds for the application area of supporting people with special needs in a home environment - interaction modes are often different to the ones traditionally used (e.g., visual output is of course not appropriate for persons suffering sight disabilities). Most importantly for this domain is that the smart home environment needs to serve the user by particularly regarding her/his situation.

The influencing requirements on a user's current situation, which need to be considered when supporting users with special needs, can be categorized into personal, technical and natural ones (see also [28]). These three requirements categories which are also depicted in Figure 1, are described in detail in the following.

2.1. Personal Requirements

Personal requirements, comprise on the one hand the person's *disabilities* and on the other hand the person's individual *preferences*.

Personal Disabilities. It is of paramount importance to consider the users personal capabilities determined by her/his impairments. Categories of disabilities are, amongst others [29]:

- *Visual impairments.* Disorders in the functions of the eye ranging form reduced capability of sight, color-blindness to total disability to see (e.g., cataracts or retinal detachment).
- *Physical impairments.* Disorders in the musculoskeletal condition and connective tissue having impact on the coordination of movement, movement accuracy, grip power, etc. up to the state of not being able to use hands or feet at all willingly (e.g., cerebral palsy or arthritis and rheumatism).
- *Hearing impairments.* Disorders in perceiving audio, ranging from problems in understanding normal conversations to complete deafness (e.g., high or low tone hearing loss).
- *Specific learning impairments.* Disorders manifested by significant difficulties in the acquisition and use of listening, speaking, writing, reading, reasoning, or mathematical abilities.
- *Speech impairments.* Disorders of language, articulation, fluency, or voice which interfere with communication.

The degree of the users disabilities determines the extent of adaptations necessary, ranging from fine-grained adjustments like enlarging font size of text to coarse-grained changes like switching the I/O modality, completely.

Personal Preferences. In addition to considering the users personal capabilities it is important to respect the user's personal preferences. Each user may have individual preferences of which services of the home environment to use and how to interact with the home environment. The user may be able to express those preferences explicitly like, e.g., the preferred TV channels available via a quick list, the crispness of the toast produced by the toaster, the setting of the heating / cooling system. In contrary other preferences might be hard to express explicitly and thus should be learned dynamically. Whereas some preferences may increase the convenience level others may be of vital importance like for example setting an emergency number which can be easily accessed by the user. Some of those preferences may be very stable over time while others may change frequently or evolve constantly during time.

Everybody develops certain routines and reoccurring activities, e.g., getting the morning news before having day's first coffee, having the shades pulled down and the light dimmed before starting a night TV session. These should not be superimposed by the home environment or somebody else but shall develop on bases of the user's preferences and the daily usage scenario. This requirement also derives from the necessity of keeping the user in control. By considering each user’s preferences individually, the user is given the impression that the home environment responds to her/him not the other way around. In the very end it is that the home environment should respect the user's wishes and foresees in an intelligent way the users intentions and future activities.

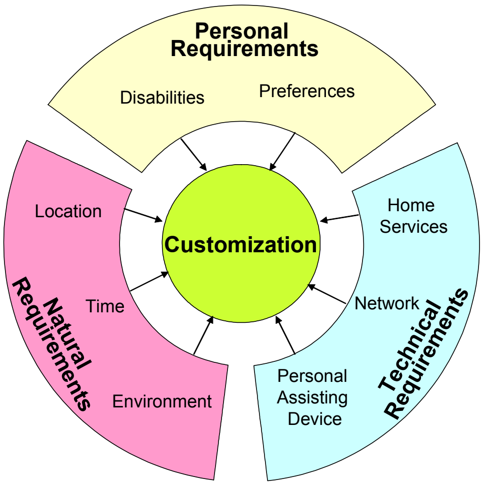

Fig. 1. Influencing Requirements

2.2. Technical Requirements

The technical requirements include information about the *PAD*, the *services provided by the home equipment* and the *network*.

- *Personal assisting device.* The user's PAD (which might be specialised towards the person's disabilities) possess certain abilities and restrictions which need's to be considered. Abilities may comprise various I/O-modes (e.g., visual, audio, Braille output). Restrictions may include the PAD's battery power, memory, CPU speed, etc.
- *Home Services.* Services provided by the home equipment may have different functionality, along with different content, presentation and handling options. Some home equipment services like a microwave oven or a motor-adjustable bed have fundamentally different functionalities, whereas, e.g., home entertainment equipment offer comparable functions like play, pause and skip and thus may be treated as a group of services.
- *Network.* Networking is essential for the scenario considered, since communication and coordination between the PAD and the home environment as well as the environment sensors may be conducted by various networking technology means. Whereas some home equipment may require broadband wireless LAN connection, for, e.g., streaming multimedia to the PAD, other's like sensors may encounter a less small bandwidth and inaccuracy of transmission.

2.3. Natural Requirements

Natural requirements comprises *location*, *time* and other *environmental* factors.

- *Location.* Location copes with the need for mobility of the user together with location-aware services and captures information about the location from which a home equipment's service is accessed, since movement between rooms will occur. This information can be provided by various means (cf. e.g., [14]).
- *Time.* Timing requirements may have major influence on the home environment's available services. It would allow to make some services scheduled automatically on a certain time of day, e.g., pulling down the shades at night.

– *Environment.* There are several other environmental requirements which are meaningful to consider within our scenario, e.g., room temperature for the heating/cooling system, sunlight for setting the brightness of a display and background noise for adjusting the volume of the home entertainment system.

It is obvious that the above mentioned natural requirements are only a small subset of those possible.

3. Customization Issues for Assisting Persons with Special Needs

The requirements listed above form the information which needs to be considered by the home environment to adapt the services accordingly. The pre-requisite for realising such home environments is awareness of the user's *context*. One must understand what context is to determine its relevancy and how it can be exploited for adaptation purposes [1], [26].

Knowledge about the personal disabilities would e.g. allow to chose an input and output modality which can be perceived by the user. Information about location and time of access together with user preferences would allow providing more accurate services taking into account the current situation of use. In the following we use the term *customization* to denote the adaptation of a home environment's services towards its context (cf. Figure 2).

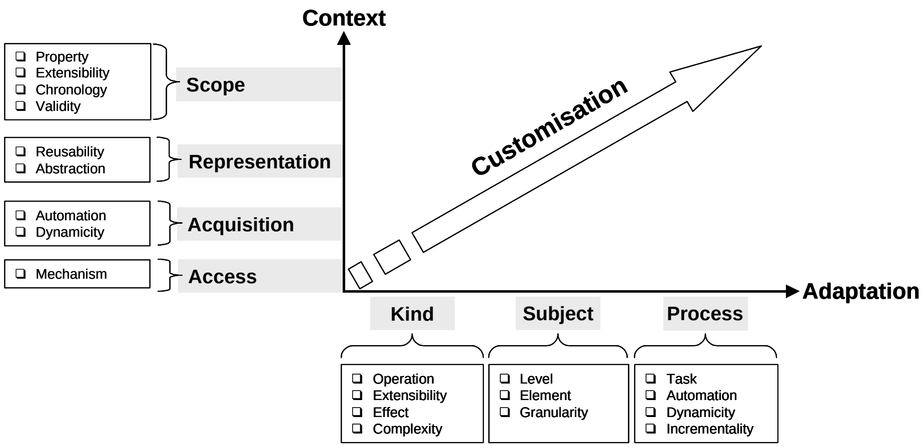

Fig. 2. Customization Issues in terms of Context and Adaptation

The roots of customization are manifold and can be found in user interfaces being either adaptive [11] or even intelligent and advisory [8], information filtering and recommender systems [21], adaptive hypertext and hypermedia [6] and mobile computing [2]. For supporting persons with special needs in a home environment scenario, the classical user model employed for personalization purposes (cf., e.g., [12], [20]) needs to be generalized to a comprehensive context model, extended by additional information about the technical and natural context as discussed in the previous section.

3.1. Context

The notion of context can be found in various different fields of computer science, for an overview, cf., e.g., [5]. As *context* we subsume all information that can be used to characterize the situation of the user and from which adaptation of the home environment's services can be inferred. Note that this understanding of context is broader than traditionally regarded in context-aware systems focusing mainly on sensory context information [14]. In [18] some general criteria for customization have been introduced. Although primarily dedicated for customization in the domain of web applications, they can be reused to a large extent for conceptualizing the issue of context for the domain of supporting disabled persons, too[4]:

Scope of context comprises the *considered context information*, the *extensibility* to introduce new context information, the *chronology* of context information over time, and the *quality* of the context information in terms of validity and availability. As pointed out in the previous section, a large variety of context information is relevant in the envisioned scenario spanning across personal, technical and natural requirements. Chronological information is necessary to allow adaptation to take into account, e.g., regular habits and process patterns. Since people may depend on the home environment, it is necessary to assume an imperfect system and that context information may not be accurate.

Representation of context refers to the need of context information reuse and abstraction. An explicit representation of the context would allow for reusability of the context throughout the home environment. Another requirement for achieving reusability is that context provided by the customization approach should be *generic*, that is independent of the individual home equipment involved.

Acquisition of context relates to the automation and dynamicity of context information collection. Concerning the acquisition of context, first it has to be defined *who* is in charge for gathering appropriate context information, be it either a human *(manual acquisition)* or the system *(automatic acquisition)* or a combination thereof *(semi-automatic acquisition)*. Particularly, a suitable balance has to be found between not burdening the user and the demand of privacy and keeping the user in control. Considering when context needs to be updated and considered, context can be either *static*, i.e., certain disabilities will not dramatically change or *dynamic*, i.e., determined on every change during runtime like location, since movement between rooms will occur.

Access to context falls into polling context information as soon as it is required and pushing context information to the interested "clients" in case of a subscription mechanism, as soon as a context change occurred. Certain adaptations may require contextual information not before the user invokes a certain service from the home environment, thus polling would be appropriate. Other adaptations like health state monitoring, certainly requires a permanent propagation of the health related sensor information to the monitoring service.

3.2. Adaptation

Adaptation refers to the capability of the home environment to take into account the context and to adjust its services accordingly. Following [18], adaptation can be characterized by the following properties:

Kind of adaptation subsumes which adaptations *operations* the home environment is capable to perform. These adaptation operations may include e.g. text-to-speech conversion to support blind people, resolution adaptation and changing screen colors for high contrast to support short-sighted people or functional guidance in form of a guided tour reducing complexity for people just capable

[4] Note that certain criteria have been adjusted for the domain and the "overall characteristics of customization" have been omitted since not being appropriate.

of very restricted manual selections due to physical handicaps. Additionally, *extension* mechanisms to incorporate new adaptations as new equipment is introduced into the home environment need to be foreseen. The *effect* of adaptation may either to add new services to the home environment, to remove currently non-preferable services allowing concentration on the relevant ones, and transformation, e.g., from one access mode to another. Considering the effects, it is interesting to reason about the *semantic value*, which is provided by an adapted home environment. The semantic value describes the quality of the service for the user. The adaptation of the home environment may seek to provide semantic equivalent services despite the user's handicaps. Often it will not be possible to provide an equivalent experience for the user. In that case, the semantic value for the user will be reduced (*semantic reduction*) with respect to the service as provided for not handicapped people. Beyond "just" striving for semantic equivalence, context-awareness enables to provide *semantically enhanced* services e.g. like automatic light and audio control as the person moves along. Furthermore, *complexity* refers to the fact that some adaptations will effect a single service, whereas complex adaptations will effect multiple services simultaneously.

Subject of adaptation can be characterized by looking at the service *level* which is affected by the adaptation, i.e., content/function, presentation, and handling. Furthermore, the concrete *elements* like, e.g., the elements for controlling the play, stop, forward etc. on a VCR, determines the adaptation. Finally, adaptation can be viewed from the number of elements which are affected termed *granularity*.

Process of adaptation characterizing how adaptation is performed comprises the *tasks* which are supported by context-awareness in order to allow a fine-grained control of the adaptation of the home environment falling into *initiation*, *proposal*, *selection*, *production*, *presentation* and *reversion* of the adaptation. For a certain adaptation, all these tasks may be applied either fully *automatically*, so that the human cannot take influence on the adaptation, *manually*, i.e., the user is responsible for the tasks or *semi-automatically* meaning that the user controls if one (or more) of the tasks is (are) performed automatically by the home environment or not. In general, it can be distinguished between *static* and *dynamic* adaptation, meaning the tasks are performed either at design time, e.g., by pre-configuring parts of the home environment or at runtime.

4. Ontology-based Customization

This section discusses our envisioned approach of ontology-based customization in order to support disabled persons in a smart home environment.

4.1. Purpose and Benefits of Ontology-based Customisation

In compliance with [31] we believe that Semantic Web technology can be exploited to enhance the utilization of context information in pervasive computing environments in general and in supporting persons with special needs in their home environment in particular. A pre-requisite for the Semantic Web is a shared understanding of the domain in question, which is often conceived as a set of concepts, relations, properties, axioms, and instances – referred to as an ontology [13], [22]. Representing the relevant information for supporting the envisioned domain in terms of an ontology offers various benefits. Particularly an ontology facilitates (cf. also [31]):

– *Knowledge sharing:* The use of a common ontology enables the acting instances, i.e., the home equipment and the PAD to have a common set of concepts about the context and the adaptation possibilities when interacting with each other.

– *Knowledge reuse:* The reuse of existing domain ontologies allows composing large scale ones from existing domain ontology reducing development time.
– *Logic inference:* The employment of existing logic reasoning mechanisms allows to deduce further information on bases of the raw context information and to infer the appropriate adaptation to support the user. According to [31] one can distinguish between *ontology reasoning* and *user-defined reasoning*. The former provide various standard reasoning possibilities with respect to consistency, equivalence, instantiation and subsumption structure checks [15]. The latter allows for the introduction of user-defined reasoning mechanisms, e.g., in terms of customization rules [17].

4.2. Related Work

A main goal of our approach is not to develop a completely new context ontology from scratch, but rather to base our work on already existing ones. Several ontologies for supporting context-aware smart environments have been already proposed. The most relevant ones with respect to our application domain are described in the following.

CoOL. CoOL [30] propose a formal context model based on an ontology to address issues including semantic context representation, context reasoning and knowledge sharing, context classification, context dependency and quality of context. It uses the OWL (Web Ontology Language) [32] which is part of W3C's effort towards the Semantic Web [3] to provide richer and explicit descriptions of Web resources. The main benefit of this model is the ability to reason about various contexts. Based on CoOL, a service-oriented context-aware middleware architecture for the development of context-aware services is built. The focus of this ontology is on a low level of sensor information only.

COBRA-ONT. COBRA-ONT [9], [10] is an ontology for supporting pervasive context-aware systems. It is expressed in OWL and is a collection of ontologies for describing places, agents, events and their associated properties in an intelligent meeting room domain. The ontology serves for a broker-centric agent architecture that provides knowledge sharing, context reasoning, and privacy protecting for pervasive context-aware systems. It models context in an intermingled manner with the domain model.

CONON. CONON [31] is a context ontology encoded in OWL for modelling context in pervasive computing environments and for supporting logic-based context reasoning. As a prominent feature, CONON offers a separation of general concepts about basic context from domain specific context. The latter can be included since the ontology provides extensibility for adding an domain-specific ontology. CONON offers a rich context model but does not foresee the important aspect of time within the basic ontology.

Khedr et al. Khedr et al. [19] define a context ontology comprising generic context types needed in pervasive computing. The ontology is motivated by the need to share knowledge, so that context-aware applications can trigger actions and infer outcome. Aim of this ontology is to provide a unified context model that is flexible, extensible and declarative to accommodate a wide variety of context features and dependency relations. This ontology offers a wide spectrum of context information but at a generic level only, not including application-specific concepts.

SOUPA. SOUPA [11] - short for Standard Ontology for Ubiquitous and Pervasive Applications - consists of two distinctive, but related set of ontologies: SOUPA core and SOUPA extension.

SOUPA core intends to define generic vocabularies that are universals for different pervasive computing applications comprising concepts for person, agent, belief-desire-intention, action, policy, time, space and event. SOUPA extension ontologies allows to capture domain specific concepts. This ontology bases on existing ontologies including: FOAF [4], DAML-time [24], COBRA-ONT [10], MoGATU BDI [25], and the Rei policy ontology [16].

All those ontologies share common concepts and structures. Among those, however, SOUPA incorporates most concepts of previously defined ontologies and currently seems to be the most elaborated one of the listed ontologies. Nevertheless, a specific support for persons with special needs and for a comprehensive customization support as envisioned by our approach is not supported.

4.3. Overall Architecture of our Approach

The overall architecture of our ontology-based customization approach for supporting disabled persons is depicted in Figure 3. The architecture illustrates the real-world requirements as discussed in Section 3 and their reification within the machine in terms of the ontology base.

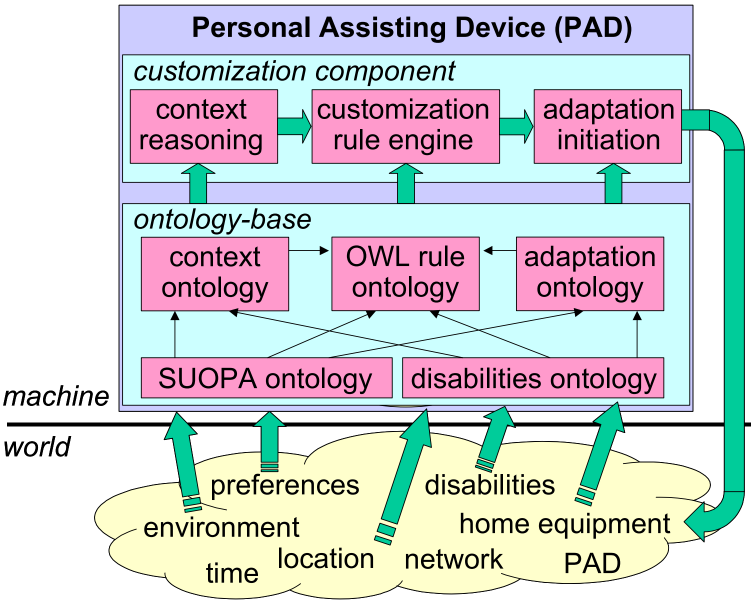

Fig. 3. Overall Architecture of Ontology-Based Customization

Ontology Base. The ontology base of this architecture should cover comprehensively the situation of persons with special needs for the purpose to utilize this information for customization of their home environment's services. In line with [11] and [31] we favor a separation of concerns separating the ontology into an *application dependent part* and an *application independent part*. The application dependent part of the ontology comprises concepts which are specific for the application domain of supporting people with special needs in their home environment as discussed in Section 2. The application independent part of the ontology comprises concepts related to context-aware systems per se like, e.g., location, time, and computing capabilities of the system as discussed in Section 3. They together form the common ontology base for the customization by the PAD. The ontology base can be used to answer questions about the person's abilities and disabilities as well as about the technical and natural capabilities and constraints, thus forming the context for the customization. In addition, the ontology base comprises the service's adaptation capabilities and the customization rules used by the semi-automatic customization component. The ontology base will be maintained partly manually by pre-configuration and partly automatically through content-capability negotiation [33].

Customization Component. The customization component of the PAD comprises a context component, responsible for *context reasoning* on basis of the ontology base and the current context-information as provided during run-time. The *customization rule engine* also utilizes the ontology for supporting user-defined reasoning. First the customization rules themselves are represented within the ontology and second the customization rule engine can exploit the ontology to form an understanding of the interrelationships and dependencies between the customization rules. This allows for improved execution of customization rules. Finally, the *adaptation initiation* triggered by the customization rule engine derives the adaptation capabilities and interdependencies within the home equipment from the conceptualized description in the ontology. In turn the adaptation influences the home equipment by initiating the appropriate adaptations (cf. feedback loop depicted in Figure 3).

5. Conclusion

In this paper we have proposed an ontology-based customization architecture for supporting disabled persons in a smart, service-based home environment. The ontology should be structured into an application-independent part, covering various context and adaptation issues necessary for customization and an application-dependent part, comprising information about the domain in terms of personal, technical and natural properties. The customization rules and the adaptation capabilities are also conceptualized in the ontology, additionally to the context. This allows to reason about the context, the interrelationship between the customization rules and the effects of the adaptation with respect to functionality, handling and presentation of the home equipment's services.

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