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LONG PAPER

An integrated semantic framework supporting universal accessibility to ICT

Vassilis Koutkias · Nick Kaklanis · Konstantinos Votis · Dimitrios Tzovaras · Nicos Maglaveras

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Abstract As we are moving rapidly to a digital economy, accessing and effectively using Information and Communication Technologies (ICT) in everyday life is widely recognized as an important requirement. However, the accessibility technologies that we have up to date are meeting the needs of only some, at a very high cost and, as a consequence, accessible ICT for all people still remains a major research and development goal. This work presents an integrated ontological framework for the semantic representation of terms and concepts (i.e., related to user needs and preferences (N&P) with respect to ICT use, as well as solutions, platforms and devices) that are required for addressing the universal accessibility in the scope of the Cloud4all project and the Global Public Inclusive Infrastructure (GPII). Cloud4all aims at advancing and building upon the concept of GPII through the development of the necessary tools and models for making ICT accessible for all by exploiting the cloud computing paradigm. The main goal of the proposed framework lays in the separation between generalized accessibility concepts, user interaction mechanisms and N&P with the particular details of different ICT artifacts. Thus, the framework aims at integrating concepts related with user N&P, as well as ICT solutions, platforms, devices and their customizable settings along with information concerning their vendors or implementers, in order to (a) offer the necessary expressiveness for defining/representing personal N&P across applications, platforms and devices, (b) link N&P with the conditions/context according to which these shall be applicable for (e.g., considering the user activity and the physical environment), (c) link interaction requirements (originated from user characteristics) with N&P and (d) support the Cloud4all matchmaking process through the mapping between N&P and application-specific settings based on semantic rules and automatic reasoning techniques.

Keywords Universal accessibility · User needs and preferences · Accessible ICT · Ontologies · Semantic modeling · Cloud computing

V. Koutkias (✉) · N. Maglaveras
Institute of Applied Biosciences, Center for Research and Technology Hellas, 6th Km Charilaou-Thermi Road, P.O. BOX 361, 57001 Thermi, Thessaloniki, Greece
e-mail: vkoutkias@certh.gr

N. Maglaveras
e-mail: nicmag@certh.gr

N. Kaklanis · K. Votis · D. Tzovaras
Information Technologies Institute, Center for Research and Technology Hellas, 6th Km Charilaou-Thermi Road, P.O. BOX 361, 57001 Thermi, Thessaloniki, Greece
e-mail: nkak@iti.gr

K. Votis
e-mail: kvotis@iti.gr

D. Tzovaras
e-mail: dimitrios.tzovaras@iti.gr

1 Introduction

While Information and Communication Technologies (ICT) are getting more sophisticated, adaptable and personalized, there are still major obstacles toward achieving accessible ICT for all people according to their specific needs and preferences (N&P), i.e., the most appropriate and favorable way for interacting with ICT artifacts. Addressing this goal currently remains an important research and development theme, especially considering that each user has their own specific characteristics (e.g.,

abilities, knowledge), and thus, the accessibility of each ICT artifact differs from user to user. In this respect, an international coalition of organizations and individuals has come together and proposed the development of the Global Public Inclusive Infrastructure (GPII) [1], aspiring to simplify the development, delivery and support of access technologies and provide users with a way to instantly apply them as they need/prefer, automatically, on any computer system or other ICT they encounter.

Cloud4all [2], an EU-founded international project established in the context of the Seventh Framework Program (FP7), explores and develops some of the key techniques, technologies, and standards needed to implement GPII by elaborating on the cloud computing paradigm [3]. Its focus is on core GPII components such as (a) personal N&P profiling, (b) federated repositories of accessibility solutions[1] and (c) auto-personalization of ICT. Cloud4all is based upon the explicit and implicit definition of user N&P sets that are kept either locally (i.e., in a USB stick or a digital tag, e.g. RFID-based), or stored in the cloud for ubiquitous—anytime–anytime—access. Via the Cloud4all system, these N&P sets will automatically match mainstream products and services with the necessary access features and imply their configuration taking also into account the context of use, anywhere (any device the person encounters in any location), on any device (desktop computer, tablet, mobile phone, iTV, etc.), seamlessly and holistically (configuring both the content and the user interface). In order to achieve this goal, there is a major gap that has to be overcome that originates from the lack of common terminologies and models enabling the semantic description of both N&P and available ICT artifacts, which will in turn enable their subsequent association dynamically toward personalized user interaction (matchmaking).

In this respect, the current paper presents an integrated ontological framework for the semantic representation of concepts that are required for addressing universal accessibility in the scope of Cloud4all and GPII. Ontologies are defined as explicit specifications of conceptualizations [5] and are considered as the backbone of the Semantic Web. They play an important role in ICT research through a variety of applications, e.g., providing the controlled vocabulary and the shared meaning required for the annotation of data; facilitating the retrieval of and, more generally, access to information; offering a source of computable domain knowledge [6]; supporting hypothesis generation and knowledge discovery in data-driven approaches [7].

[1] In the scope of this work, the term *solution* refers to a standalone application, an application offered as a service, a service or an assistive technology (AT) that "allows the user to perform an activity in a given environment, overcoming existing barriers" [4].

In the current case, the proposed ontological framework encapsulates various concepts from the domain of user interaction with ICT, in order to provide the basis for expressing knowledge that reflects the linkage among user characteristics, interaction requirements and personal N&P, considering the context of ICT use. It also incorporates concepts related to solutions, platforms, devices and their customizable settings along with information concerning their vendors or implementers. The main design principle is separating generalized accessibility concepts, user interaction mechanisms and N&P from the particular details of different ICT artifacts that users may want/have to use. Thus, this principle dictates the introduction of new semantic models to cope with the particular Cloud4all requirements, despite the availability of various ontologies and formal information models in the field accessibility. Nevertheless, the proposed design takes into account relevant standards devoted to user N&P profiling, such as the ISO/IEC 24751 [8], the ETSI TS 202 746 [9], as well as new standardization efforts [10], and classifications of assistive products, such as the ISO 9999:2011 [11], aiming to reinforce the exploitation potential and generalization of the proposed ontological framework, and facilitate possible synergies with the respective scientific community.

The paper is structured as follows. Section 2 presents related works concerning the formal representation of user N&P and the semantic description of ICT solutions, devices and platforms. Section 3 presents the proposed ontological framework by highlighting the design considerations and presenting its structure, main concepts and content. Section 4 illustrates the integrative perspective of the framework within the Cloud4all architecture. Finally, Sect. 5 discusses the current approach and our future work directions, while Sect. 6 concludes the paper.

2 Related work

2.1 Formal models for describing users, their needs and preferences

Several approaches targeting at formal user modeling have been presented in the literature for a variety of application domains. For example, Heckmann et al. [12] proposed an architecture for decentralized user modeling having its basis on the user model markup language (UserML) and the general user model ontology (GUMO). UserML is an exchange language for user modeling between decentralized systems based on the Resource Description Framework (RDF) [13], while GUMO is a top-level ontology expressed in OWL (Web Ontology Language) [14]. The study aimed to address uniform interpretation of

decentralized user models, and the integration of ubiquitous applications with a user model service.

Sutterer et al. [15] proposed a user profile ontology that is dedicated to describe situation-dependent sub-profiles, aiming to support context-aware adaptive service platforms for mobile communication and information services, so as to automatically trigger the situation-dependent personalization of services. The design took into consideration recommendations from a human factors engineering viewpoint, enabling the specification of situational conditions and situation-dependent user sub-profiles.

Yurchyshyna et al. [16] elaborated on the adaptation of domain ontologies to different contexts and user profiles. The authors highlighted the need to reduce the gap between the expert knowledge primarily captured in a domain ontology and the end-user knowledge and, consequently, proposed a method to contextualize the initially acquired ontological knowledge and adapt it to different user profiles.

Panagiotopoulos et al. [17] presented an ontology for modeling user profiles capable of encompassing and representing user N&P regarding every "activity sphere" the user participates in, in a way that supports sphere adaptation to the user's changing context. Such profiles represent important permanent user trails such as personal information, interests, and capabilities, as well as the user role(s) in each sphere and the user preferences associated with the sphere tasks. The approach is explicitly targeting ambient intelligence (AmI) environments and applications.

Overall, ontology-based user profile modeling involves the definition of concepts that correspond to either static user information or dynamic features pertaining to temporal conditional preferences and interests, according to specific situations. A study aiming to explicitly assess the reusability of user profile models has been conducted by Hella et al. [18]. The study was based on a systematic review of existing (publicly available) ontologies from a reusability perspective, having the SEQUAL quality framework as the basis for the evaluation. Interestingly, the study concluded that none of the evaluated ontologies satisfied the requirement of reusability. This particular study indicates the need to build user profile models that are generic and not tightly coupled with the application of discourse, as it has been typically elaborated.

In addition, in practical terms, the need for formal modeling of user profiles is illustrated by Kobsa [19], in a review devoted to generic user modeling systems. It describes the purposes of such systems, their services within user-adaptive systems, and the different design requirements for research prototypes and commercial deployments.

Standardization activities have also targeted at user profiling through information models, aiming to provide a generalization perspective and a formal representation of a user's profile. For example, Part-2 of the ISO/IEC 24751 specifies a model dividing the personal N&P of the user into three categories [20]: (a) *Display*, i.e., how resources are to be presented and structured; (b) *Control*, i.e., how resources are to be controlled and operated, and (c) *Content*, i.e., what supplementary or alternative resources are to be supplied. Furthermore, Part-6 of the ISO/IEC 24751 introduces a model of accessibility as a basis for understanding access issues with the interactions between users and systems in various environments [21]. The model is built upon the idea that users and systems can share capabilities of communication through a framework specifying a profile of common access capabilities (the so-called CAP) of interactive systems, users, and their environment that are necessary for accessibility to be possible. This latest effort encapsulates rather rich semantics and has been realized as an ontology by Sala et al. [22] in the scope of an AmI framework.

Recently, the term "virtual user modeling" was introduced by the VUMS cluster of relevant FP7 research projects [23] (namely GUIDE [24], myUI [25], VERITAS [26], and VICON [27]), targeting people with disabilities and the elderly. Virtual user models can be considered as explicit representations of the properties of an individual user including user's N&P as well as physical, cognitive and behavioral characteristics. Thus, by following a declarative approach the user is described by a set of one-graded properties defined in a shared hierarchical meta-model (a taxonomy of physiological and cognitive variables). Finally, the ACCESSIBLE [28] and AEGIS [29] FP7 projects have developed large ontologies targeting users with functional limitations.

The current work elaborates on ontology-based modeling of user N&P concerning their interaction with ICT without profiling the users per se. This modeling is generic, i.e., without focusing on a particular, application-specific context, contrary to the majority of the above-mentioned approaches [18]. Furthermore, N&P are conceived as personal interaction requirements, thus embracing equally all individuals, which comes in opposition to traditional approaches in e-Inclusion which cluster users according to their disabilities. In addition, existing and emerging standards in the field aiming to reinforce the generalization potential of our approach are taken into account (and employed when applicable).

2.2 Formal representation of ICT solutions, devices and platforms

There are several efforts toward the direction of defining ontological concepts and architectures for the semantic representation of ICT solutions, devices and platforms

within the area of e-Inclusion. These efforts try to cover adequately the personal requirements of the end users, under an ICT artifact specific perspective. For example, besides user modeling, the ontologies developed in ACCESSIBLE [28] and AEGIS [29] incorporate the semantic description of solutions, applications and user interaction terms targeting users with functional limitations.

A major contribution to the field of ontologies for disabilities was also made from the FP6 ASK-IT project [30]. Within ASK-IT, ontology modeling and mapping produced a collection of shared sub-ontologies, which reflect the user needs of mobility-impaired people, and relationally map the available services along with the accompanying data sources to them. The ASK-IT ontology defines the interrelationships that may rationally hold between user groups of people with disabilities and various user information needs of different content types. This ontology provides a unified view of data and data flows; both internal to each ASK-IT application and in data interchange between ASK-IT applications as well, covering different domains such as transportation and multi-modal content.

Castro et al. [31] propose a repository of ontologies aimed at raising metadata interoperability across AT open repositories by means of a vocabulary without considering the user's needs or AmI aspects. Also the INREDIS Knowledge Base stores all the ontologies that collect formal descriptions of the elements in the INREDIS domain (e.g., users, AT, devices, software requirements) and its instances [32]. This ontological knowledge provides appropriate mechanisms for reasoning with and querying all this knowledge that enables the intelligent behavior of other modules of the INREDIS architecture.

Systematic efforts on device modeling were initiated as ubiquitous and mobile computing became mainstream. The most relevant industrial application has been the User Agent Profile (UAProf) [33], which provided a framework for describing capabilities of mobile devices until the middle of the previous decade. The relevant vocabulary became obsolete, because its applicability to the recent generations of smartphones is minimal. On the basis of a classification of input devices [34], it uses device models to categorize interaction problems that occur because of wrong use of devices. However, this categorization is at a functionality meta-level and has no applicability for user interface adaptation. Other strands of work focus on the adaptation of the device to the content, like in the Universal Remote Console (URC) standard [35].

In the field of AT standardization, the ISO 9999:2007 domain classification establishes a categorization and terminology of assistive products, including also assistive solutions [11]. Based on this categorization, some organizations, such as the European Assistive Technology Information Network (EASTIN) [36], have developed databases in which a set of assistive products that are currently available in the market is registered.

In the current work, the main purpose is to provide a high-level modeling of context-related information of ICT solutions, platforms and devices by extending and integrating the previous ontological implementations that have been proposed by other projects such as AEGIS, ACCESSIBLE, INREDIS and EASTIN. This framework will be able to support and provide appropriate input to the matchmaking tools that are being implemented in the Cloud4all project. In this respect, an appropriate semantic representation mechanism will be created, in order to encourage and enable all potential stakeholders to use the same terms when describing the same things (the same concept and value range) with regard to the N&P sets and the offered ICT solutions and their customizable settings that will be hosted in the cloud.

3 The ontological framework for universal access to ICT

3.1 Overall design considerations

The proposed ontological framework may be discriminated into two parts, the N&P part and the ICT Solutions part. In the scope of this work, a user N&P set is a user-specific collection of needs/preferences either directly confirmed by a user or inferred by other means. A need/preference is a construct containing semantic information about a specific topic of application, identified by a property. In addition, a need/preference may be associated with conditions according to which it should be applicable. Conditions may vary and be relevant with applications, devices, operating systems, the user's activity/status, spatial features, temporal aspects, etc. Thus, the framework incorporates domain concepts that are applicable for (or relevant with) the expression of user N&P also providing the means to associate them with technical aspects related with user interaction with ICT.

Thus, the N&P part of the framework involves a semantic model aiming to (a) offer the necessary expressiveness for defining/representing personal N&P independently of solutions, platforms and devices, (b) link N&P with the conditions/context according to which these shall be applicable for (e.g., considering the user activity, the physical environment), and (c) link interaction requirements (originated from user characteristics) with N&P.

The input for defining the N&P part of the ontological framework originates from surveys (i.e., literature surveys, interviews with users and experts), relevant standards, e.g., ISO/IEC 24751 [8], ETSI ES 202 746 [9], and available

ontology/information models, e.g., VUMS [23], AEGIS [29], ACCESSIBLE [28]. Influential for developing the design presented was the AccessForAll standardization group [10], which aims to propose and standardize an updated version of the ISO/IEC 24751:2 standard [20]. Specifically, the N&P part of the framework has as its core part the AccessForAll Registry of Common Terms for expressing the so-called atomic N&P. Various conceptual views of the Registry may be applied, in order to organize/annotate its contents. The authors have elaborated toward this direction via the introduction of concepts like interaction channels and user interface elements (as remarked in Sect. 3.2).

The ICT Solutions part should be understood as an ontology representing in a semantic and hierarchical manner solution-aware information (i.e., about solutions, platforms, devices on which solutions run, customizable settings of solutions, platforms, devices and information on solutions', platforms' and devices' vendors and implementers). Thus, its aim is to provide the semantic representation of application-specific aspects (e.g., settings, platforms, devices, solutions) that should be exploited by

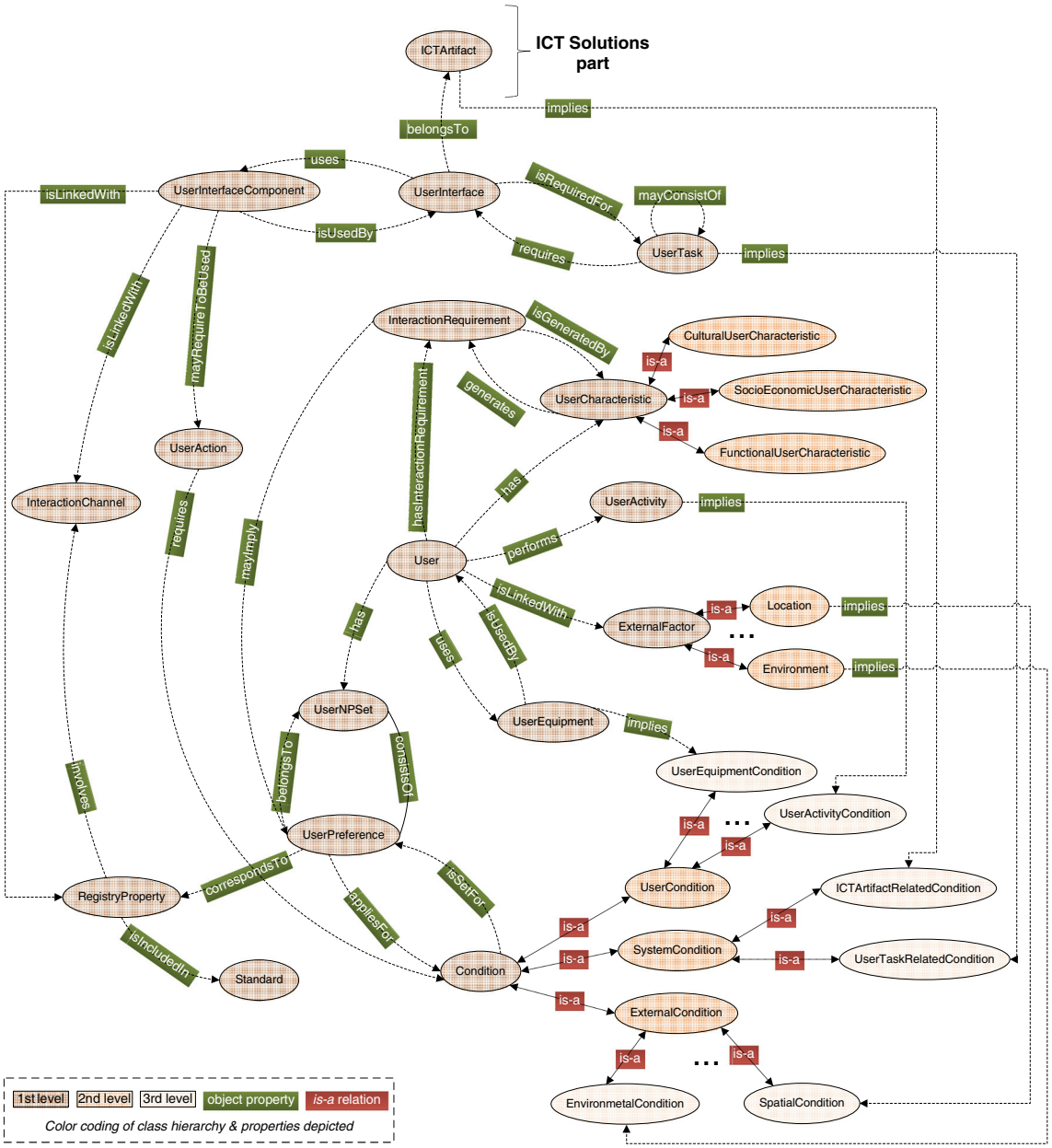

Fig. 1 Overview of the N&P part of the ontological framework (note the link with the "ICT Solutions" part of the framework in the upper part of the Figure)

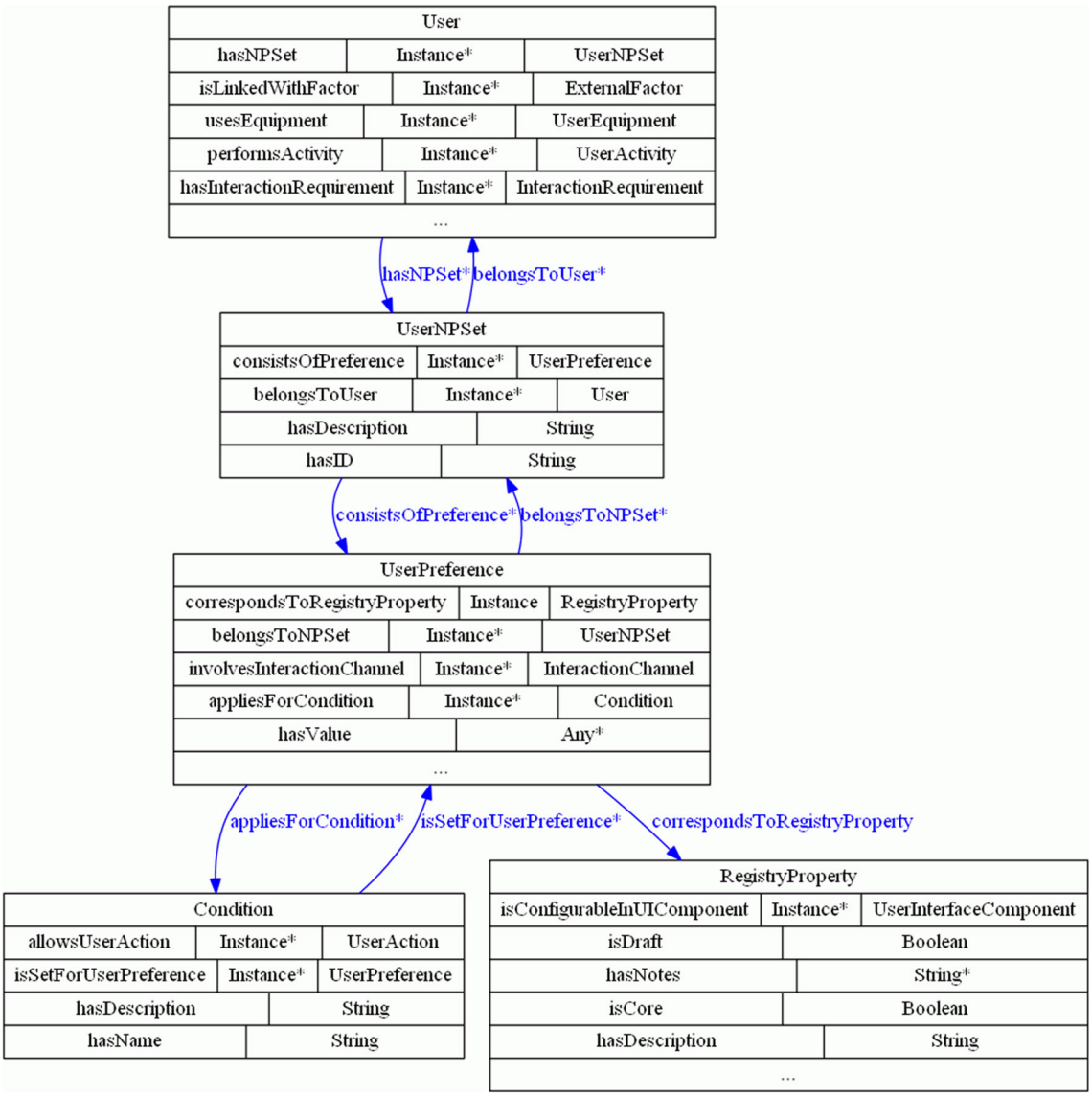

Fig. 2 Association among the *Core user N&P*-related concepts (*User*, *UserNPSet*, *UserPreference*, *Condition* and *RegistryProperty*). Representative datatype properties (name and type) are illustrated per concept, along with the object properties linking *Core user N&P*-related concepts

the components of Cloud4all (e.g., the Matchmaker), in order to incorporate in their functionalities semantic-aware information. This part of the framework is partially based on ISO 9999 [11], as explained in Sect. 3.3.

In the following subsections, both parts of the framework are presented, while Sect. 4 presents their linkage and interaction with the components of the Cloud4all architecture.

3.2 Semantic representation of user needs and preferences

An overview of the N&P part of the ontological framework is depicted in Fig. 1. It involves the following groups of concepts:

A. *Core user N&P-related concepts*, comprising of the following classes: *User*, *UserPreference*, *UserNPSet*, *Condition* and *RegistryProperty*. The semantic associations between these concepts are depicted in Fig. 2 and correspond to the following predicates expressed in natural language:

A User has (multiple) UserNPSet(s)
A UserNPSet consists of (multiple) User Preference(s)
A User Preference applies for specific (multiple) Condition(s)
A User Preference corresponds to a specific RegistryProperty.

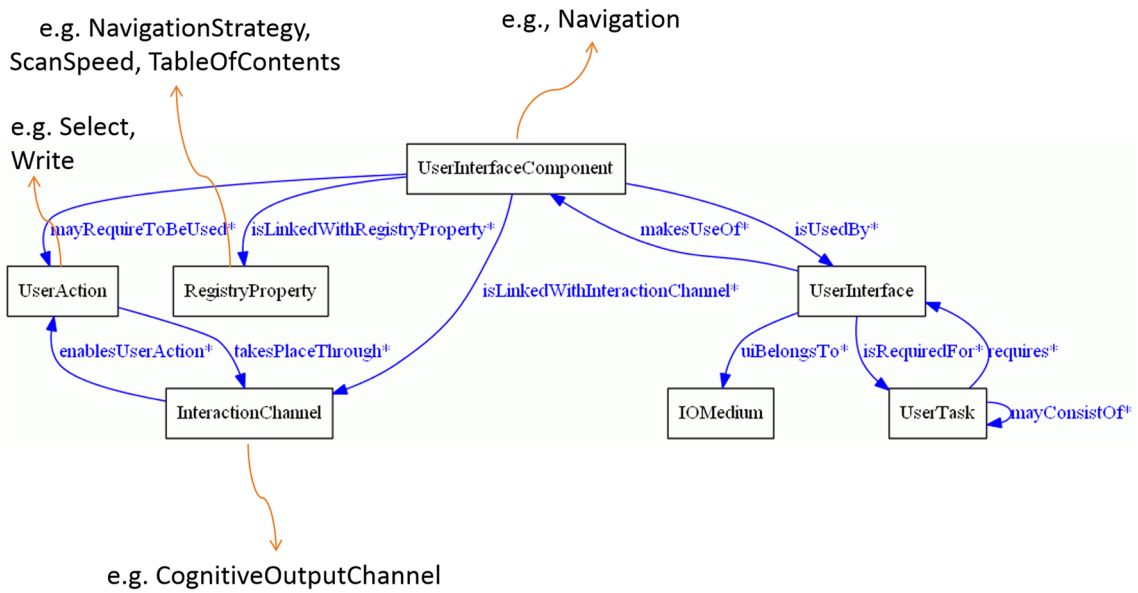

Fig. 3 Associations among the *User Interaction*-related concepts, illustrated via an example

Instances of the *RegistryProperty* class correspond to entries defined in the AccessForAll Registry of Common Terms (note that Fig. 2 depicts the properties comprising the current structure of the Registry [10]). Instances of the *User* class correspond to users of the Cloud4All platform for whom a UserNPSet is defined.

B. *Condition-related concepts*, comprising of the following classes: *ExternalFactor* (with subclasses: *CulturalFactor*, *Economic*, *EnvironmentalFactor*, *Location*, *SocialFactor* and *Time*), *ICTArtifact* (provided by the ICT Solutions part of the framework), *UserActivity*, *UserEquipment* and *UserTask*. These classes constitute all diverse sources of conditions for user N&P. In this regard, the subclass hierarchy of the Condition class has been defined to explicitly link these sources with types of conditions, e.g., *UserCondition* (with subclasses *BehavioralCognitiveCondition*, *UserActivityCondition*, *UserEquipmentCondition*, *UserFunctionalCondition*), *SystemCondition* (with subclasses *ICTArtifactRelatedCondition* and *UserTaskRelatedCondition*) and *ExternalCondition* (with subclasses *EnvironmetalCondition*, *SpatialCondition* and *TimeCondition*).

The semantic association between the various condition-related concepts and the Condition class per se corresponds to the following predicate expressed in natural language:

A (Typeof)Condition isApplicableFor a ConditionalFactor.

C. *User Interaction-related concepts*, expressed through the classes: *InteractionChannel*, *IOMedium*, *UserAction*, *UserInterface*, *UserInterfaceComponent* and *UserTask*. The association between these concepts is illustrated in Fig. 3 along with an example.

In essence, a UserTask (i.e., a concrete usage scenario that provides specific output, e.g., printout, calculation, alert) requires a UserInterface (offered through an ICTArtifact) to be performed. The UserInterface makes use of UserInterfaceComponents (e.g., Navigation, in this case). Each UserInterfaceComponent is linked with a RegistryProperty (e.g., "NavigationStrategy," "ScanSpeed" "TableOfContents"). A UserInterfaceComponent may require a UserAction (e.g., "Select" and "Write") to be used that is enabled by an InteractionChannel (includes the InputInteractionChannel and the OutputInteractionChannel, along with consecutive subclasses, e.g., AuditoryInputInteractionChannel, HapticOutputInteractionChannel; in our example the CognitiveOutputChannel). Also, a UserInterface may belong to an IOMedium (an external/peripheral medium, e.g., an external keyboard) which may be attached or embedded to a device.

D. *User-related concepts*, expressed through the classes: *InteractionRequirement* and *UserCharacteristic*. Interaction requirements (e.g., increased size of icons) may be generated for a user from his/her characteristics (e.g., low vision) and may in turn imply specific N&P (e.g., icon size preference). Figure 4 illustrates the relation between the above concepts, and how they may imply user N&P via an example. Specifically, "Low Vision" is a FunctionalUserCharacteristic of a specific user, which generates the InteractionRequirement "easy to read fonts"; this InteractionRequirement

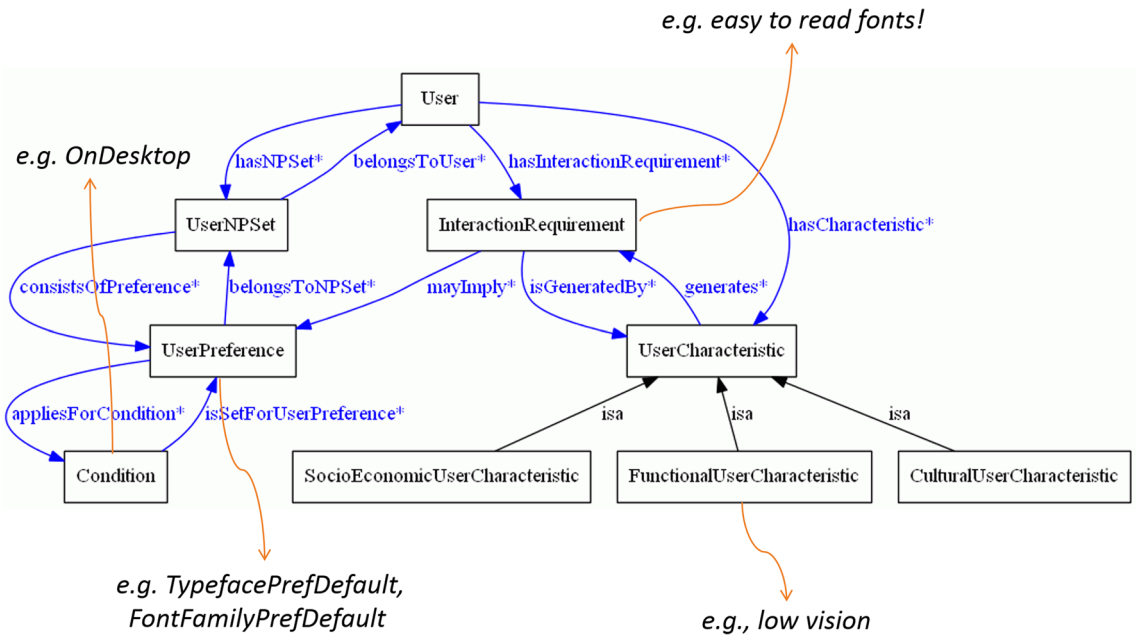

Fig. 4 Association of user characteristics and functional requirements with user N&P illustrated via an example

implies N&P such as specific values for the TypefacePrefDefault and FontFamilyPrefDefault properties (contained in the Registry of Common Terms), and these have to be applicable when the user uses his desktop computer.

E. *Standards-related* concepts, expressed through the classes:

- *PropertyInStandard*: Corresponds to a set of UserPreference instances that are defined/included in relevant Standards. This class enables keeping provenance information concerning well-established terms that have been introduced in the presented ontology.
- *Standards*: Refers to Standards that are relevant to user profiling, e.g., ISO/IEC 27451.

Figure 5 illustrates the relation between the standards-related concepts for the RegistryProperty instance corresponding to "AbsolutePointing." As it is shown, AbsolutePointing is included in the ISO/IEC 24751:2 standard [20].

3.3 Semantic description of ICT solutions, platforms and devices

The ICT Solutions part of the ontological framework consists of the five generic classes (highlighted in Fig. 6):

- The *Solutions* class, which classifies solutions according to their domain. The domain classification is based on ISO 9999 [11] and, more specifically, on class 22 "assistive products for communication and information"[2] and class 24 "assistive products for handling objects and devices"[3] of the standard. The reason for partially adopting the standard is that only these classes can categorize solutions, according to the definition of the term "solution" provided in Sect. 1. The proposed approach gives the ability to vendors or implementers to propose new classes that refine the existing classes of the standard, in order to allow new solutions to be classified in a more flexible manner.
- The *Platforms* class, which classifies resource execution platforms in a hierarchical manner. A platform refers either to an operating system or to a Web execution platform. As a platform can be adapted in order to fulfill users' N&P, each platform has platform-specific settings (i.e., aspects of a platform generally or of a specific Operating System that can be adapted). Thus, each platform instance is related to the Settings class via the *hasPlatformSpecificSettings* property. If a new platform needs to be incorporated in the framework, one has to specify the semantic class to which the platform belongs to, along with the *hasPlatformVendor* and *hasPlatformSpecificSetting* properties.
- The "*Devices*" class, which provides a hierarchy of devices on which applications run. A part of the Devices subclass hierarchy is depicted in Fig. 7. A device is

[2] http://www.eastin.eu/en-GB/searches/products/isoSearch/22.

[3] http://www.eastin.eu/en-GB/searches/products/isoSearch/24.

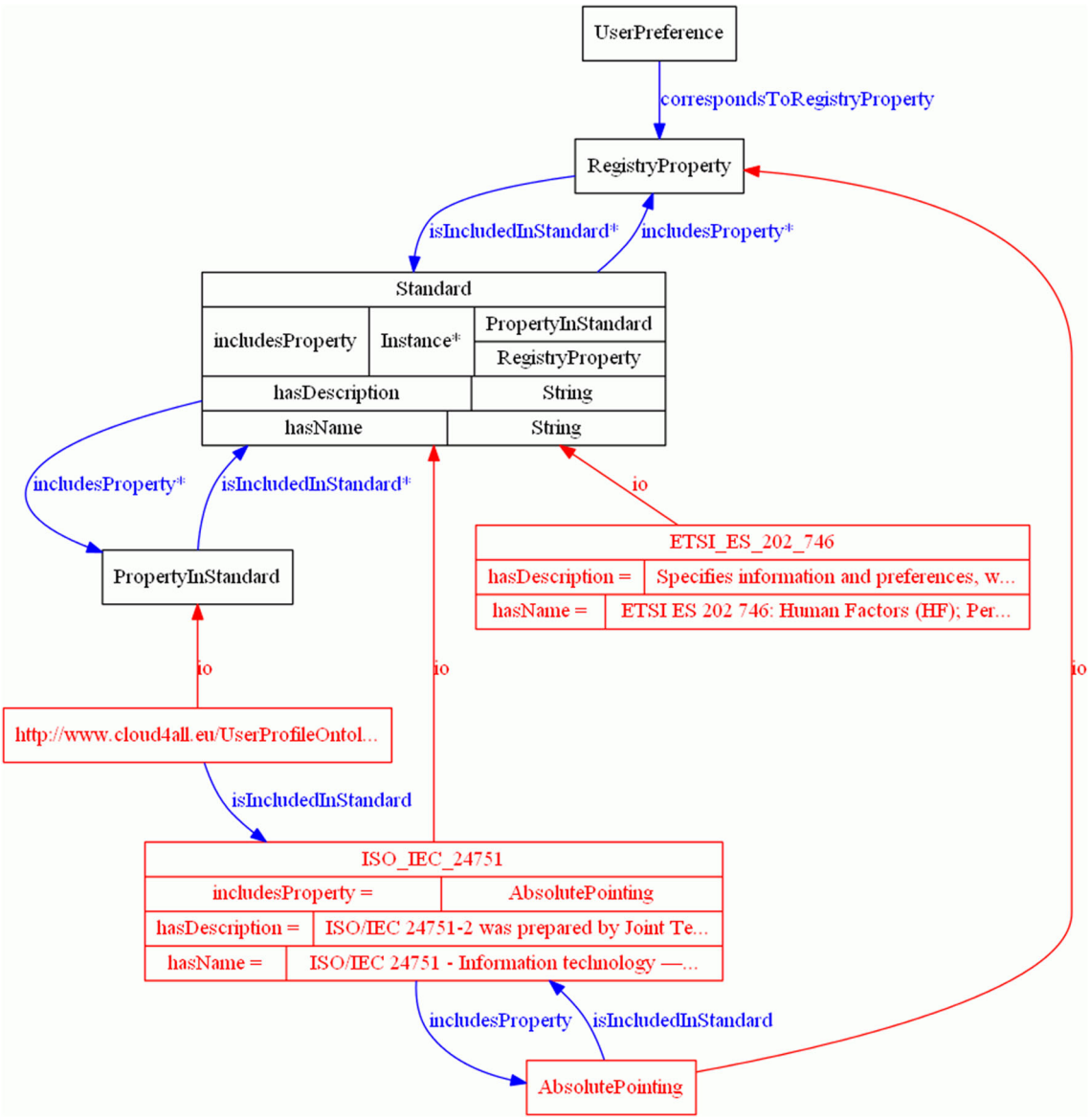

Fig. 5 Association among the *RegistryProperty*, the *Standard* and the *PropertyInStandard* classes (instances are depicted in *red)*

related to the appropriate settings via the *hasDeviceSpecificSetting* object property. Furthermore, a device is related to a specific device vendor via the *hasDeviceVendor* property. When a new device has to be incorporated in the framework, one has to specify the semantic class in which the device belongs and appropriately assign the hasDeviceVendor and hasDeviceSpecificSetting properties.

- The *Settings* class (Fig. 8), which classifies solution-specific, platform-specific and device-specific (user interface configuration) settings. Each setting is linked to a solution, platform or device via the *adaptingSolution*, *adaptingPlatform* or *adaptingDevice* property, respectively. Furthermore, each Settings instance has the following data properties: (a) *hasSettingDescription*: that relates each setting with a short description in English of what the setting is for, (b) *hasSettingName*: that relates each setting with the name of the correspondent setting, (c) *hasSettingRange*: that relates each setting with the range of the corresponding setting, and (d) *hasSettingDefaultValue*: that relates each setting with a default value of the corresponding setting.
- The *Vendors* class, which maintains and classifies information about solutions', platforms' or devices' vendors or implementers.

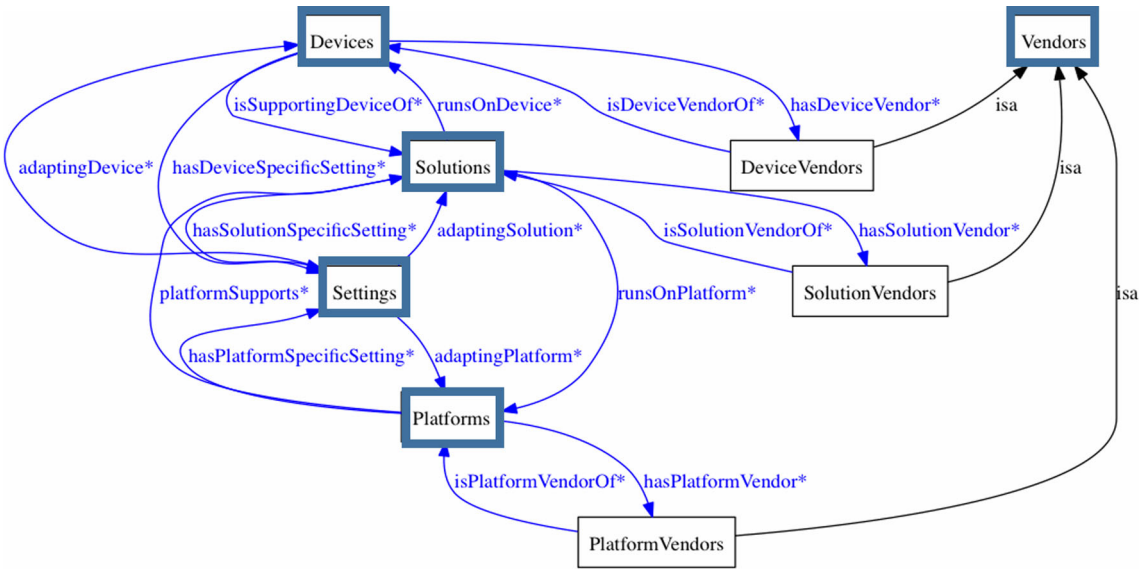

Fig. 6 The core of the "ICT Solutions" part of the ontological framework

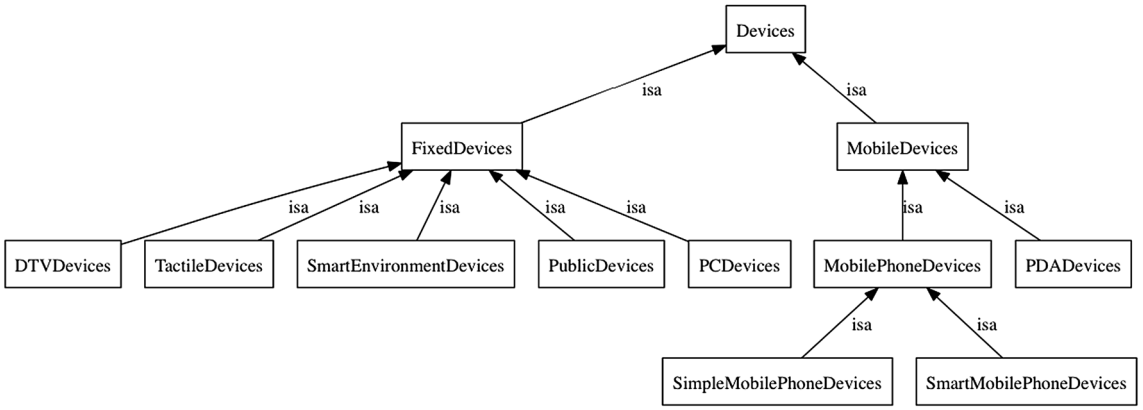

Fig. 7 Part of the "Devices" subclass hierarchy

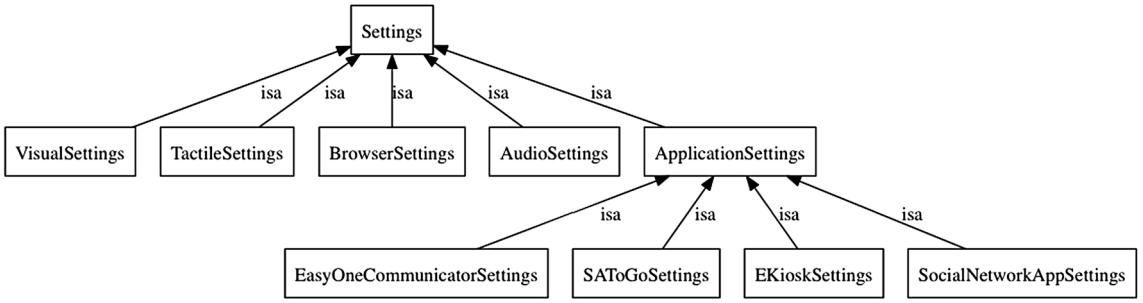

Fig. 8 Part of the "Settings" subclass hierarchy

4 Integration of the ontological framework in the Cloud4all platform: implementation aspects

The proposed ontological framework aims to provide semantic information about user N&P, solutions and content and will be located on the cloud. The N&P part (Sect. 3.2) and the ICT Solutions part (Sect. 3.3) of the framework have been integrated. Their linkage (via object properties) and interaction with components of the Cloud4all system is depicted in Fig. 9. Both parts of the

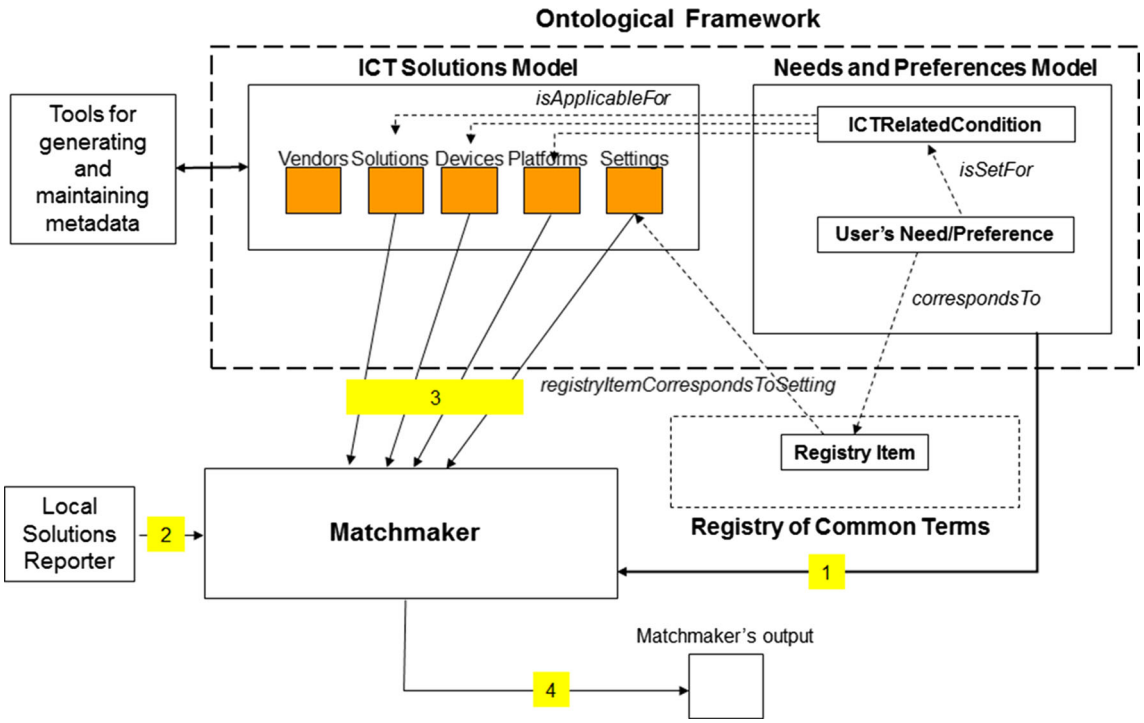

Fig. 9 The overall ontological framework and its interaction with components of the Cloud4all system

framework interact with the Registry of Common Terms, which aims to register in a flat manner (i.e., without using any hierarchical structure) generic N&P terms. The term "generic setting/term" stored and maintained in the Registry refers to a setting that is solution-, platform- and device-independent as depicted in Fig. 9. The ICT Solutions part of the framework maintains and represents solution-, platform- and device-specific settings. A user's N&P may *applyFor* an ICTRelatedCondition which *isApplicableFor* specific Solutions/Platforms/Devices that are available from the ICT Solutions part of the framework. Each user's N&P *CorrespondsTo* a Registry item. Furthermore, each Registry item is related via the object property *registryItemCorrespondsToSetting* to a setting of the ICT Solutions ontology. Thus, each generic setting of the Registry is mapped to solution-, platform- or device-specific setting(s).

The ICT Solutions part interacts also with a rule-based Matchmaker tool for supporting the matching process between personal N&P and solution-, platform-, device-specific settings, and appropriately adapt those ICT artifacts. Thus, the framework is being used in the context of Cloud4all for

- Translating generic N&P terms that are stored in the Registry of Common Terms to solution-, device- or platform-specific settings;
- selecting the best solution for the user among semantically similar solutions;
- providing a framework for the Matchmaker in order to perform suggestions for customizable settings that are not explicitly stated in a user's N&P set based on the semantic categorization of settings, and
- providing a framework for the Matchmaker in order to suggest to the user new solutions, not yet installed by the user, that meet his/her personal N&P.

More specifically, the Matchmaker that is the basic decision support module of the Cloud4all architecture aims to match a user's N&P set to the customizable settings of the ICT solutions that are available in a given device. As depicted in Fig. 9, the Matchmaker receives input as regards:

- the N&P set of the user (step 1);
- who reports the solutions that are available on a local device through the Local Solutions Reporter (step 2), and
- the specific settings with respect to the available ICT artifacts as reported by the Local Solutions Reporter (step 3).

Having all this information, the Matchmaker infers a set of settings that should be customized according to the user's N&P set (step 4).

The development of the proposed ontological framework has been based on an iterative and incremental approach. The N&P and the ICT Solutions ontologies have been developed in Protégé [37], an open-source, knowledge modeling tool. The ontologies have been encoded in the Web Ontology Language (OWL) [20], since due to its Description Logic prevalence [38], automatic reasoning and inference is supported, which is an important requirement for the applications that will exploit the ontological framework (e.g., matchmaking).

For checking the consistency of the constructed model, the built-in ontology checking features of Protégé were employed during the entire development procedure. In the current stage, the ontological framework comprises of about 365 classes, 120 object properties, 3,350 datatype properties and more than 1,000 instances. Further information and detailed ontology documentation is available in the GPII wiki [39].

5 Discussion

There is a pressing need for a paradigm shift in access to ICT by people with disabilities as well as by the elderly. Existing approaches are not reaching but a fraction of those who need access technologies—yet access is rapidly becoming mandatory for participation in education, employment, commerce and health. Many individuals are excluded from various services, because they do not fit in the current definitions of disability and yet they face significant barriers to accessing ICT. Overall, accessible ICT is an issue exceeding the barriers that physical disabilities introduce, especially if the dynamic context and the ubiquity in which users require ICT access are considered. As new equipment and devices are developed at a rapid rate, choosing the AT and ICT that best matches the needs of an individual can be intimidating or impossible for many.

To cope with such challenges, GPII has been proposed, aiming to develop the necessary tools and models for making ICT accessible for all by exploiting the cloud computing paradigm. The proposed ontological framework provides the means to formalize domain knowledge based on various concepts that are related with user interaction and ICT use within Cloud4all, an R&D project developing parts of GPII. The main principle of the framework lays in the separation between generalized accessibility concepts and user interaction mechanisms, user N&P and the particular details of different ICT artifacts. The proposed modeling conceives user N&P as interaction requirements, embracing this way equally all individuals which comes in opposition to traditional approaches in e-Inclusion that cluster/stereotype users according to their disabilities.

The ultimate goal is linking user interaction requirements with user N&P, represented in a machine processable and interoperable format, while at the same time maintain a semantically rich and extensible framework for solutions, platforms and devices. To this end, standardization is of paramount importance. In particular, besides taking into account existing N&P profiling standards, the ontological framework has been designed in line with the proposed AccessForAll Registry of Common Terms for expressing N&P [10], as well as the ISO 9999 classification of accessible products [11]. The flat structure of the Registry may be exploited via semantic mappings as well as through automatic reasoning mechanisms.

The proposed ontological framework is constantly being populated with a large corpus of instances. Furthermore, its evaluation concerning its expressiveness and applicability is constantly being performed through a variety of use case scenarios coping with diverse, actual N&P. A preliminary analysis that was conducted concerning its virtue in expressing N&P corresponding to 36 use case scenarios defined for Cloud4all [40], revealed several interesting aspects. In particular, in various cases, high-level user requirements have been documented (e.g., "desktop environment gets simplified," "the user is able to manage documents and e-mails in the preferred way," "large most frequent option's buttons"). In such cases, it is evident that the application of a relevant mapping to atomic N&P terms as contained in the AccessForAll Registry of Common Terms is necessary. Thus, relevant domain knowledge has to be employed, in order to define the corresponding N&P set. Through the incorporation of key concepts in the domain, the N&P part of the framework supports the expression of such knowledge. Also, the need to address contextual aspects in the applicability of user N&P has been highlighted in various application scenarios. Thus, the Condition-related concepts that have been incorporated in the framework constitute a necessary component for expressing such N&P. Still, this part has to be further elaborated toward the establishment of a controlled vocabulary that will be introduced in forthcoming versions of the ontological framework.

Besides providing a representation formalism of N&P, the framework is currently being exploited in order to support the development of tools to facilitate effective N&P initialization and management, as well as matchmaking algorithms based on semantic rules.

6 Conclusions

This work has presented an integrated ontological framework for the semantic representation of concepts that are required for addressing the universal accessibility of ICT as

conceived in the scope of Cloud4all and GPII. In particular, the framework integrates concepts related with user N&P, as well as with ICT artifacts and their customizable settings, in order to express personal N&P across such artifacts. In this respect, it links N&P with the conditions/context according to which these shall be applicable for, as well as interaction requirements (originated from user characteristics) with N&P. The ultimate goal is to support the matchmaking process through the mapping between N&P and ICT-specific settings based on semantic rules and automatic reasoning techniques. To this end, the proposed framework aspires to facilitate auto-personalization of ICT artifacts from N&P, contributing this way toward more accessible ICT for all.

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