IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received February 25, 2021, accepted March 5, 2021, date of publication March 10, 2021, date of current version March 25, 2021.

Digital Object Identifier 10.1109/ACCESS.2021.3065274

Development of an Ontology for the Inclusion of App Users With Visual Impairments

MARÍA ISABEL TORRES-CARAZO, MARÍA JOSÉ RODRÍGUEZ-FÓRTIZ, AND MARÍA VISITACIÓN HURTADO TORRES
Department of Lenguajes y Sistemas Informáticos, ETSIIT, University of Granada, 18071 Granada, Spain

Corresponding author: María Visitación Hurtado Torres (mhurtado@ugr.es)

This work was supported by the Spanish Ministry of Economy and Competitiveness (Agencia Estatal de Investigación) under Project PID2019-109644RB-I00/AEI/10.13039/501100011033.

ABSTRACT Approximately 15% of the world's population have some form of disability and the majority use apps on their mobile devices to help them in their daily lives with communication, healthcare, or for entertainment purposes. It is not, however, easy for users with impairments to choose the most suitable apps since this will depend on their particular personal characteristics or circumstances in a specific context, and because such users require apps with certain accessibility features which are not always specified in the app description. In order to overcome such difficulties, it is necessary to obtain a user profile that gathers the user's personal details, abilities, disabilities, skills, and interests to facilitate selection. The basis for our research work is to develop an app that recommends a set of apps to users with disabilities. In this respect, the focus of this paper is to obtain a semantic user profile model on which more precise search requests can be performed. The disability we have chosen to concentrate on is that of visual impairment. We propose an ontology-based user profile that matches users' characteristics, disabilities, and interests, and which not only simplifies the classification process but also provides a mechanism for linking them with existing disability ontologies, assistive devices, accessibility concepts, etc. Moreover, thanks to the inclusion of semantic relations and rules, it is possible to reason and infer new information that can be used to make more personalized recommendations than a simple app store search.

INDEX TERMS Ontology, disability, ICF, accessibility, user profile, inclusion, apps, mobile device.

I. INTRODUCTION

Mobile apps enable users to select suitable content or functions according to their preferences, interests, abilities, context, culture, etc. The huge, ever increasing number of apps which are available on the most famous online app stores (Apple App Store and Google Play) have been designed for almost every imaginable possible task: entertainment (e.g. listening to music, watching videos, or playing games), sharing photos, or expressing opinions on social networks (e.g. Instagram or Facebook), shopping (i.e. Amazon, eBay, Wish or Aliexpress), etc. The categories of Medicine or Health & Fitness include a variety of m-Health or health-related mobile apps such as pill reminders, and physical activity, weight or diet trackers and recommenders.

A number of studies have explored the need for support apps for activities such as going to the beach [1], doing physical exercise [2], working [3], or keeping fit, and consequently app store categories (e.g. Lifestyle, Food & Drink, Medical, Health & Fitness or Beauty) include apps that can help users improve their lifestyles with new health routines, activities, or sports (e.g. yoga, relaxation, stretching, or diets). Users therefore have access to an increasing number of applications for almost any task imaginable by searching the various categories.

One further difficulty is that of deciding between apps in the app store. By way of example, a Play Store search for the term ''video'' returns more than 250 apps. In order to decide which app to download, the user must obtain more information by reviewing the app description and reading reviews in order to determine whether it meets their needs before they install it. This is by no means an easy task and further complicated by the fact that names, descriptions, or reviews might be written in a foreign language or perhaps the descriptions are not available, are incomplete, or are in an inaccessible format. For example, the results of an

The associate editor coordinating the review of this manuscript and approving it for publication was Resul Das.

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/

app store search might provide information that could only be presented in a pictorial or visual way, e.g. screenshots with no alternative textual descriptions or descriptive audios which means that visually impaired users might not be able to access all the app contents in order to take advantage of all the app functions and purposes (e.g. edit, create or watch) in addition to the accessibility features, which may not always be specified [4].

It is important to mention the fact that most apps are developed for the general public and do not consider whether it is possible for people with disabilities to use them. In 2020, the world population had reached 7.8 billion people [5] with 1150 million of these having some form of disability [6]. It is therefore possible to say that a large proportion of the population are unable to access certain apps [7]. Our motivation and commitment behind this work is to solve problems relating to the search, selection, and installation of apps for people with disabilities on their mobile devices.

A great deal of research has focused on developing apps to help people with different types of disabilities [8]–[12]. Although a small number of apps have been specifically designed for people with special needs or disabilities, it would be possible for them to use some of the apps developed for the general public if these contained certain accessibility features according to the users' needs.

In terms of usability and accessibility, many mobile devices and apps are not always easy to use, and they might be impossible for people with any functional difficulty to use. The possible access barriers might even result in a digital gap and the exclusion of certain users, particularly for people with visual disabilities.

Existing initiatives such as the World Wide Web Consortium (W3C) [13] and advancing assistive technologies such as screen readers or voice input, however, have already helped to break down some of the barriers by providing users with special needs with adapted access to mobile devices [14]. Technology, therefore, plays a crucial role for people with disabilities and facilitates the social integration of people with visual disabilities [15] since the tools provide better accessibility in their daily activities [16].

To sum up, problems arise from the results obtained after the app search process since these might be inaccessible for people with disabilities, and such problems relate to the way the information is presented. In order to solve these issues, it is necessary to identify the user's personal characteristics, their current context, and the technology available. By considering the user profile at a specific time and location for a particular mobile device, we can search the app stores for the most suitable app for the user by including their disabilities. This will ensure that all users have the same opportunities when searching and using apps and this will in turn improve both their satisfaction and well-being [17].

The main objective of this work is to use ontologies to model user profiles for app users by considering their disabilities and capabilities. A previous version of this model was presented in [18] but this has been improved in this paper with the inclusion of new features and relationships between concepts in order to obtain better results for the query requests. Each and every stage of the model will be described in order to provide a more thorough understanding of it. In order to handle the user's personal details, abilities, disabilities, skills and interests, we define, design, and implement an ontology to build the user profile and this is called the *User Profile Ontology*. In this process, existing ontologies modelling user characteristics, disabilities, and interests have been analyzed so that they may be reused, and this is one of the benefits of using ontologies. We also define relationships and properties to enable reasoning about the user data and information that had not been explicitly modelled to be inferred and this would allow richer answers to the queries.

Additionally, we have chosen the option of ontologies to take advantage of the possibilities that they offer in terms of reducing the effort involved in the initial learning phase of a recommender system [19]. Although our paper focuses on the *User Profile Ontology*, other ontologies are also being developed as part of our research (e.g. Apps Ontology, Accessibility Features Ontology, Devices Ontology, Languages Ontology, and Context Ontology). This series of finished ontologies will comprise the knowledge base for a recommender system which will suggest more personalized recommendations about the most suitable apps for the user [20] and which is better than a simple app store searcher due to the additional knowledge obtained [21].

The rest of the paper is organized as follows: Section 2 details related work; Section 3 presents and explains our integrated ontology for compiling user profiles; Section 4 shows examples of the answers to queries obtained by reasoning with the ontology; and, finally, Section 5 outlines our conclusions and future lines of research.

II. RELATED WORK

The user profile is a set of characteristics and preferences that define a person. Some of these possible features concern personal data such as gender, age, religion, or country, and other terms can be added to the list such as personal tastes, interests, or disabilities. All these terms can help to define a person's profile more precisely.

Disabilities can affect people's daily lives due to the variety of activities that they may want to perform although some of these tasks can be completed using aids that have been specifically adapted to the user's disability. Mobile devices can represent one such tool since they are portable, cheap and incorporate apps for performing almost any task. The problem arises, however, when a user needs to select an app to perform a specific task from the vast number of apps available on the app store.

It might be interesting for there to be a system that recommends the most suitable app for performing a task according to each user's needs. In order to build a user profile, it is necessary to consider certain aspects that can be gathered such as disability and personal information. The following subsections analyze various existing user profile ontologies to check whether any fits our purpose, and to classify the disabilities that may be included in the user profile.

A. CLASSIFICATION OF DISABILITIES: ICF

In view of the various aspects affecting disability and the high number of professionals involved in all the related fields of research (psychology, social services, education, medicine, etc.), there is a wide range of disability-related terms, definitions, and classifications. In these times of globalization, it is necessary for there to be a clear idea of the implied concepts and their classification so that a global and common language may be used.

For this reason, the WHO approved the International Classification of Functioning, Disability and Health (ICF) [22] which aims to approximate, simplify and unify terminology, and identifies disability-related problems. The ICF is supplementary to the International Statistical Classification of Diseases and Related Health Problems (ICD-11) [23] that was previously published by the WHO.

According to the ICF, ***body functions*** are physiological functions of body systems (including psychological functions), and ***body structures*** are anatomical parts of the body such as organs, limbs, and their components. The ICF also defines some important terms relating to disability and people's performance. An ***activity*** is the execution of a task or an action by an individual, and ***participation*** is the involvement in a life situation. The term ***functioning*** is an umbrella term for body function, body structures, activities, and participation, and it denotes the positive or neutral aspects of the interaction between a person's health condition(s) and that individual's contextual factors (environmental and personal factors). Additionally, the ICF defines ***impairments*** as problems in body functions and structure such as significant deviation or loss, ***activity limitations*** as difficulties an individual may have in executing activities, and ***participation restrictions*** as problems an individual may experience in involvement in life situations. The term ***disability*** relates to impairments, activity limitations, and participation restrictions. It denotes the negative aspects of the interaction between a person's health condition(s) and that individual's contextual factors (environmental and personal factors).

The Red Cross [24] accepts the ICF definition of disability and establishes its own three-group classification, but also considers the heterogeneity that exists in each one:

- Physical disability: a disability that affects locomotion or limbs
- Cognitive impairment: a decline in higher mental functions (intelligence, language, learning, etc.) and motor functions
- Sensory disability: this includes individuals with visual and auditory problems, and deficiencies in communication and language deriving from these

It is useful to know what disabilities a user might have so that the necessary technologies (i.e. software and hardware) or resources (i.e. mobile devices or accessibility devices) can be selected.

From the perspective of information and communication technologies (ICT), disabilities affect how information, services, and resources are accessed in terms of perception and interaction [25], and disabilities such as upper limb motor impairment will obviously affect the user's ability to use the mouse, keyboard, or touchpad [26]. In addition to their disabilities, users also have skills (i.e. things they do) and capabilities (i.e. things they are physically able to do) and both should be included in their user profile.

B. USER PROFILE ONTOLOGIES

A number of projects have developed interfaces and ontologies in order to create the user profile, and some of these have been reviewed. The ontologies address the three main scopes of the user profile: personal details, interests, and disabilities. In this section, we will present a brief description of the ontologies on which this work is based.

The ICF classifies health and health-related domains according to body functions, body structures, activities, and participation. As the life of an individual occurs in a context, the ICF also includes environmental factors. A number of ontologies [27], [28] model the ICF with the same structure and the same coding. Any domain covered by the ICF ontology can also be described in detail and graded according to severity (i.e. severe impairment of 50%-95%, or partial or total absence of body structure). These ICF ontologies [27], [28] are used as the basis for other ontologies [29], [30] to model a user's disabilities and this will be shown in the following paragraphs.

The general user model ontology (GUMO) [31] models a user's profiles in terms of the four dimensions of basic user, context, domain dependent, and sensors: Basic User contains information about demographic data and personality; Context represents the user's current environment; Domain Dependent stores the user's computing preferences, interests, and knowledge; and Sensor collects the user's biometric data, speech parameters, and typing behavior.

Although the GUMO ontology contains interesting data for building a user profile such as the user's contact information, email, address, birthday, gender, mood (whether they are sad, happy or excited, for example), personal interests (whether they like going to museums or are interested in science), and abilities (whether they are able to drive), it does not model information about the user's disabilities or capabilities.

The Open Accessibility Everywhere: Ground-work, Infrastructure, Standards Ontology (AEGIS) has been developed as part of the AEGIS project [32]. Its main purpose is to associate accessibility concepts and accessibility scenarios. Consequently, the AEGIS Ontology provides support for the formal and unambiguous definition of accessibility domains, and the possible semantic interactions between them. It also aims to formalize conceptual information about the following aspects:

1. The characteristics of users with disabilities, functional limitations, and impairments (personal aspects)

2. The technical characteristics of input and output devices, general and functional characteristics of web, desktop, and mobile applications, and other assistive technologies
3. The natural aspects of users, such as user actions and logical interactions while using applications

Since the AEGIS ontology categorizes the user's disabilities, functional limitations, and impairments as a list of individuals rather than classes, reasoning is difficult. The Abilities and Disabilities Ontology for Enhancing Accessibility (ADOLENA) [33] was created in 2008 to improve the National Accessibility Portal of South Africa (NAP), to provide information about disabilities and assistive devices (i.e. wheelchairs or talking thermometers), and to empower people with any disability. The second version of this ontology works with four main interrelated concepts: ability, disability, device, and functionality.

The Rat Genome Database Disease Ontology (RGD-DO) [34] models sensory organ diseases associated with the five human senses. This database was created in 1999 and is the first data repository and the first platform with genetic data obtained from rat research into genomes, phenotypes, and diseases. It also enables human and rat data to be compared. Part of this ontology is dedicated to eye diseases that include vision disorders that limit one or more basic functions of the eye.

We have found that none of the ontologies (ICF, GUMO, AEGIS, ADOLENA, or RGD-DO) is capable of modelling every user feature (i.e. personal details, interests, and disabilities) at the same time. We have been able to make this assertion by analyzing not only how the ontologies make classifications but also how they include diseases that may cause visual disabilities and the severity of these (i.e. moderate or severe). While GUMO does not provide any information about disabilities, AEGIS and ADOLENA do not support personal information. The RGD Disease Ontology does not model personal information, and although it includes terms relating to disabilities and human diseases, it is constructed from an exhaustive medical viewpoint.

For these reasons, we have selected various concepts and relationships from each of the analyzed ontologies. We have extracted personal information and user interests and abilities from GUMO. We have also extracted the class structure for classifying user disabilities from ADOLENA and ICF, and we will also include new concepts to create a more complete user profile. Finally we have selected individuals to populate the ontology from AEGIS, RGD-DO, and ICF.

III. PROPOSAL OF AN ONTOLOGY FOR USER PROFILES

One objective of our work is to develop a system that allows information to be gathered from diverse fields so that it may be collected, stored, and used in a near future by an app that will make recommendations about the apps that best match user needs and preferences. Since our aim is to combine this information and treat it as a set, we will follow the Bravo, Hoyos, and Reyes methodology [35] which defines

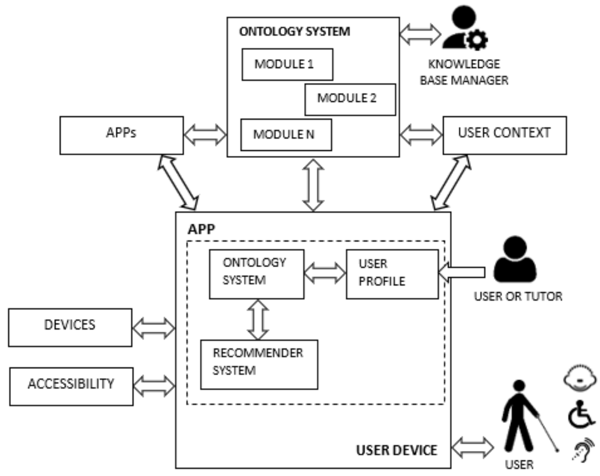

FIGURE 1. System operation.

an ontology system comprising individual ontologies (called modules) which are interlinked. Figure 1 shows how the full system will work.

The users should first install an app on their devices [18] which includes the ontology system and the recommender system. The ontology system comprises a number of modules, one for each ontology: *User Profile*, *Context*, *Devices*, *Languages*, *Apps*, and *Accessibility Features*. In order to improve efficiency, a local copy of the ontology system is stored on the device once the app has been installed and configured. The app needs to request and gather information (e.g. user's profile, context and device, and accessibility devices or features if required) in order to make personalized recommendations. The first time the app is used, the user profile is configured by the user or the user's tutor using the app interface.

Once the requested information has been collected, new instances are created with the data provided and these are added to their corresponding ontologies (i.e. personal information to the module *User Profile Ontology*, device information to the module *Device Ontology*, etc.) and all the ontologies will form the knowledge base (with relationships and rules relating the information of the ontologies) that will be used by a recommender system to provide the recommendations. Finally, the recommender system will generate recommendations using the ontology system and it will show possible apps that match the user profile.

The Bravo, Hoyos, and Reyes methodology provides methods and techniques to support the construction of ontologies. It is based on the creation of an ontology system which is a global ontology that imports individual ontologies (or modules) which are semantically interrelated within the global ontology. In our case, we want to create and link various ontologies from different scopes such as user profile, context, or apps, which will form an ontology system.

This methodology comprises four steps that guide developers through the construction of the ontology system:

Step 1. Ontology requirements
Step 2. Ontology design

Step 3. Ontology construction
Step 4. Ontology evaluation

The following subsections of this paper present and describe the steps of the process for obtaining the ontology system and also the individual ontologies and their classes, subclasses, properties, and instances. The methodology also includes the reasoning process and the inclusion of inference rules.

Although we have followed the methodology for obtaining the ontology system, in this section we only examine the *User Profile Ontology* since this is the target of this paper.

A. STEP 1: ONTOLOGY REQUIREMENTS

The first step of the Bravo, Hoyos, and Reyes method involves establishing the *ontology requirements* by identifying the scope and defining possible scenarios, users, and capacity of the ontology in order to provide answers and quality characteristics. This phase is completed once the following tasks have been completed:

a) Specify the motivation: the motive for creating an ontology system is to gather a series of characteristics about users, apps, contexts, devices, accessibility features, and languages that enable a recommender system to obtain personalized recommendations for a particular user by considering on account of their personal circumstances.
b) Specify the competency of the ontology: the ontology should answer questions about its stored and linked information, such as the most suitable app for a user with a specific severe visual disability, or the best device for a user who is missing a limb and cannot speak English. It should also make queries on the basis of the user's abilities in terms of what accessibility devices and features are required by a user with a particular mobile device, who can read but cannot hear. In this way, the ontology system should cover the spheres of user, apps, context, accessibility features, devices, and languages.

B. STEP 2: ONTOLOGY DESIGN

The second step is to design the ontology to obtain a formal model. In order to achieve this, three steps are required to build the ontology modules as part of the model (i.e. individual ontologies):

a) Term elicitation: we identify elementary concepts for the knowledge domain such as user, apps, disability, mobile device, accessibility features, accessibility devices, languages, skills, or abilities. This list of concepts will be analyzed to identify which belong to each ontology module.
b) Module identification: with the elementary concepts of the previous list, we will model the relevant domains that will be transformed into individual ontologies. Initially, there are two relevant domains: the user, which is a profile of a person, and the app, which is a set of characteristics that comprise the app profile. However, these are not enough to make a personalized recommendation since the user's background plays an important role in decision-making, and so background must also be considered and is modelled using ontologies. This has been split into four parts so that the ontologies may be reused. The first of these is *context*, in terms of the user's circumstances, date and location; the second is *mobile device*, with information about the features of the mobile device; the third is *accessibility features*, which are the desirable or available characteristics for apps and for users with disabilities according to the accessibility guidelines as recommended by WCAG 2.0 [36] and MWABP [37], as well as additional devices that enable people with special needs to access information; and the fourth is *languages*, both in terms of the languages the users can speak and the app language.
These domains will be transformed into various individual ontologies or modules so that they can be modeled (*User Profile Ontology, Apps Ontology, Context Ontology, Mobile Device Ontology, Accessibility Ontology, and Language Ontology*). Since the sole focus of this paper is the *User Profile Ontology,* although we will mention the remaining ontologies, they are beyond the scope of this paper.
c) Individual ontology design: for each identified ontology module, its hierarchy, data properties and object properties are described using description logic notation (DL).

1) CLASSES AND SUBCLASSES

This subsection provides a more detailed description of the design, the classes, and the subclasses of the *User Profile Ontology*. The main classes arise from the user dimensions e.g. disabilities, skills to acquire or improve, abilities, evaluation of disabilities, personal details, and interests.

The *User Profile Ontology* is defined in DL in Figure 2.

a: DISABILITY

The first user dimension is *disability*, together with its classification, degree, and the diseases that may cause it. Based on WHO, ADOLENA and Red Cross proposals, we propose a new organization for disability-related terms so that they may in turn be associated with mobile devices and apps. Since our work focuses on visual disabilities, this classification will be more detailed than others and may well be extended in the future. There are four main types of disability:

- Physical disability: impairments that affect body and limb mobility
- Cognitive disability: intellectual and mental impairments
- Communication disability: all impairments relating to language and speech, either acquired, congenital, or caused by other disabilities
- Sensory Disability: this is divided into visual and hearing disabilities because of their influence on the use of ICTs.

TBox

UserProfile ≡
Disability ⊆ UserProfile,
Disease ⊆ UserProfile,
Impairment ⊆ UserProfile,
Skills ⊆ UserProfile,
UserAbilities ⊆ UserProfile,
UserDisabilityEvaluation ⊆ UserProfile,
UserPersonalDetails ⊆ UserProfile,
UserPersonalInterests ⊆ UserProfile,
∀ userHasName.xsd:string,
∀ userHasAge.xsd:int,
∀ userHasDisabilityPercentage xsd:float,
∀ userHasGender ∈ {male, female},
∀ userHasIQxsd:int,
∃ hasAbilities.UserProfile,
∃ hasDisability.UserProfile,
∃ hasDisabilityPercentage.UserProfile,
∃ hasDisease.UserProfile,
∃ hasEducationalLevel.UserProfile,
∃ hasEvaluationDegree.UserProfile,
∃ hasEvaluationMagnitude.UserProfile,
∃ hasEvaluationTest.UserProfile,
∃ hasImpairment.UserProfile,
∃ hasRangeOfAge.UserProfile,
∃ hasADevice.UserProfile,
∃ hasInterests.UserProfile,
∃ hasRangeIQ.UserProfile,
∃ hasRecommendedAccessibility.UserProfile,
∃ hasRecommendedAge.UserProfile,
∃ hasRecommendedApps.UserProfile,
∃ hasRecommendedCategory.UserProfile,
∃ hasRecommendedDevice.UserProfile,
∃ hasSpokenLanguage.UserProfile,
∃ wantsImproveSkills.UserProfile

FIGURE 2. User profile ontology in DL.

The disability class hierarchy is shown in Figure 3.

b: DISEASE

It is also possible for certain diseases to cause disability and impairment according to their severity [22]. For example, Stage 4 glaucoma could be considered as blindness. We have included classes for modeling possible diseases which might cause certain disabilities according to the disability classification. This severity of the disease and the disability percentage will also be modeled. Figure 4 shows the diseases class hierarchy.

c: SKILLS

It is possible to improve, develop, or acquire certain skills to replace the disabilities that a user may have, such as, for example, improving the sight of users with myopia, or improving the hearing of users with impaired hearing.

We will classify the skills relating to the parts of the body or functions that we want to develop or train. In order to do so, we begin with the ICF since this provides a classification of human functioning and disability. By identifying the problem, we can then try to improve it.

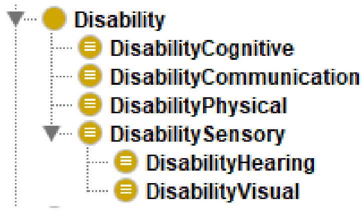

FIGURE 3. Disability class hierarchy.

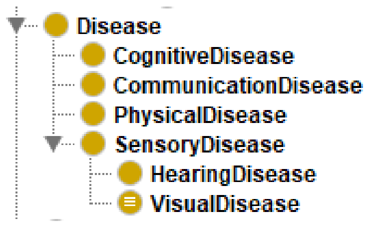

FIGURE 4. Disease class hierarchy.

The ICF helps with the creation of a user profile on account of functioning, disabilities, and health using three levels of classification: body structures, activities, and participation, and specific values extracted from other levels. Each level is then split into more detailed categories.

The first level gathers the disability classification proposed in Section II.A according to body structure (physical, cognitive, communication, and sensory). In the second level, the domain activities and participation are divided into new areas relating to any of the body structures (i.e. visual and hearing, or attention and memory functions). In the third level, specific examples are obtained from the previous levels. We will use these values as the skills that people could train, acquire, or improve (e.g. visual acuity or hearing stimulation). This three-level classification is shown in Table 1, where Level 1 corresponds to the column Disability, Level 2 to the column Functioning, and Level 3 to the column Skills.

We have modelled the user's skills using the same organizational structure as Table 1. It is therefore possible to classify the appropriate skills and link these with the classifications in the disability class. The skills class hierarchy is shown in Figure 5.

d: USER ABILITIES

User abilities are the capabilities for performing a task. Unlike skills, abilities tell us whether a person is able to perform a task, such as riding a bicycle for example, even if their disability was loss of mobility in both legs as the user could use an adapted bicycle and possessed other abilities required to ride it. It would therefore be possible to recommend certain apps or perform certain tasks instead of others according to the user's abilities. For example, if a user has a visual disability but is able to hear and wants something to read, the system will recommend audiobooks. This feature will be extracted from the Abilities class which is a subclass of the basic user dimensions in the GUMO ontology. The abilities class hierarchy is shown in Figure 6.

TABLE 1. Created structure for skills.

DISABILITY	FUNCTIONING		SKILLS
Cognitive	Mental functions	Attention functions	Attention stimulation Divided attention Selective attention Visual spatial attention
		Calculation functions	Calculations Learn math
		Consciousness functions	Alertness
		Memory functions	Figural memory Long-term memory Memory stimulation Short-term memory Learn colors
		Orientation function	Spatial situation Know environment Learning time
		Thought functions	Logical reasoning Cause-effect
	General tasks		Organization of information Task planning
	Self-care		Look after skills
	Domestic life		Acquisition of goods and services Preparation of meals
	Interpersonal interactions and relationships	Emotional functions	Avoid phobias Recognize moods Personal well being
		Energy and impulse functions	Avoid eating disorders
		Global psychosocial functions	Social interaction Social rules Use social networks
	Major life areas		Economic self-sufficiency Education Employment
	Community, social and civic life		Community life Recreation and leisure Religion and spirituality Political life Citizenship
Physical	Neuromusculoskeletal and movement-related functions		Bimanual stimulation Eye-hand coordination Improve mobility ankle Improve mobility arm Improve mobility both legs Improve mobility hand fingers Improve mobility knee Improve mobility shoulder Improve mobility trunk Improve mobility wrist Manual coordination stimulation Voluntary movements coordination
Communication	Voice and speech functions		Expression of sign language Improve fluency of speech Improve oral expression Improve rhythm of speech Improve speech Learn alphabet Learn writing
Sensory	Sensory functions	Hearing	Hearing stimulation Hearing Hear-hand coordination
		Visual	Eye-acuity Eye tracking Visual stimulation Watching

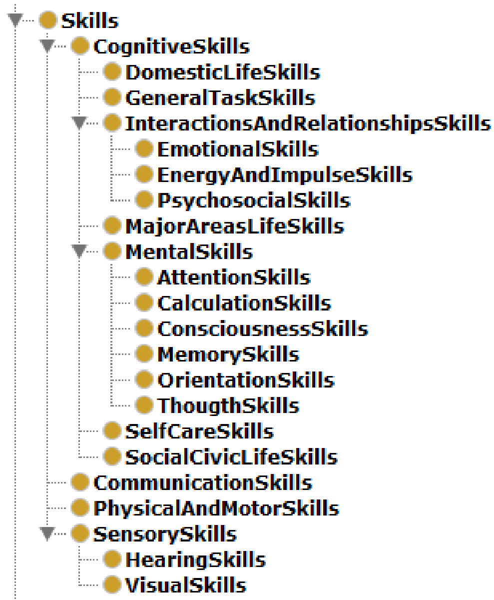

FIGURE 5. Skills class hierarchy.

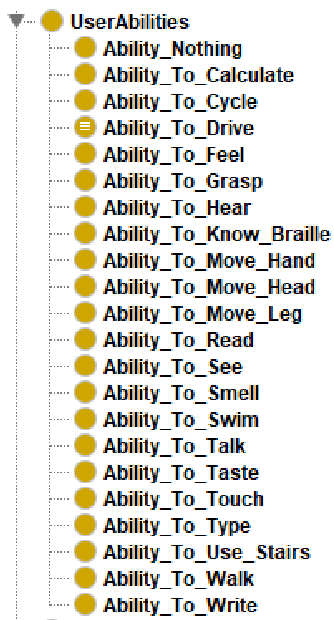

FIGURE 6. Abilities class hierarchy.

e: EVALUATION OF THE USER'S DISABILITY

Disabilities are graded in the ICF [22] by using a generic scale to denote the magnitude of the disability in an individual. This must be applied using the most significant adjective to a particular situation as indicated in Table 1. As we have mentioned, diseases or disabilities can be graded according to ICF classification for body functions. This degree is shown in Table 2.

The ICF uses Table 2 to classify the three first-level components (i.e. body functions, structures, and activities and participation) that are coded with a letter (b for body functions, s for structures, and d for activities and participation), followed by a series of 3-5 numbers, represented by xxx in the ICF coding column of Table 2.

The xxx indicates the coding of the second and third levels in terms of the user's difficulties or abilities in these

TABLE 2. ICF scale qualifier (extracted from ICF [22]).

ICF Coding (Degree)	Disability Magnitude	Qualifier	Percentage
xxx.0	NO problem	(none, absent, negligible, etc.)	0-4%
xxx.1	MILD problem	(slight, low, etc.)	5-24%
xxx.2	MODERATE problem	(medium, fair, etc.)	25-49%
xxx.3	SEVERE problem	(high, extreme, etc.)	50-95%
xxx.4	COMPLETE problem	(total, etc.)	96-100%

FIGURE 7. User disability evaluation class hierarchy.

domains. For example, in the coding b21020, b represents body functions, the first 2 refers to Chapter 2 in the ICF entitled ''Sensory Functions and Pain'', 10 refers to *Seeing Functions*, the second 2 represents *Quality of vision*, and the final 0 stands for *Light sensitivity*. This coding according to level (or *degree* as we have called it) enables quantification since it is possible to assign a value from 0 to 4 which can then be converted into words (e.g. 0 to NO problem, or 3 to Severe problem) to indicate the *magnitude* of any problem. To be more concise, we have added certain words as qualifiers such as slight or severe. There is also an association with the *percentages* that can be used in cases where the problem can be measured. The ranges are calibrated according to population standards and expressed as percentiles (e.g. 25-49%). Table 2 enables us to compare data and to provide more information when the user cannot explain their situation exactly but can provide some words to classify it.

We also include the format of the methods used (i.e. test or interviews) and the obtained evaluation results for the user's disabilities. This information enables us to calculate the percentage of disability recognized for an individual user. This percentage corresponds to a value that will be in one of the ranges listed in Table 1, and so it is therefore possible to grade the users' diseases and then consider the level of disability.

In the case of visual disability, professional opticians use a series of tests to evaluate a person's visual disability by considering visual acuity, visual field, or chromatism. The Wecker Scale [38] is used in Spain to calculate visual acuity by calculating the percentage of disability according to law. The disability evaluation might suggest the need for additional support so that a person can perform a task.

The hierarchy of the user disability evaluation class is shown in Figure 7.

TABLE 3. Classification by age range.

Group	From (age)	To (age)
Baby	0	3
Child	4	9
Teenager	10	17
Adult	18	59
Elderly	60	-

f: USER'S PERSONAL DETAILS

We will reuse the following information which has been extracted from GUMO in the Basic User Dimension class: name, age, age group, education level, first language, gender, and highest level of education.

We consider personal characteristics to be *gender* and *age*, and the age group to include *baby*, *child*, *teenager*, *adult*, and *elderly*, and education-related characteristics to include IQ (Intelligence Quotient), spoken or known languages, and the highest education level (low, basic, medium and high in order to standardize the various educational systems in each country).

We have chosen these data because they are connected with some of the information provided by the app stores and so they may indicate which kinds of apps should be recommended for these users, or the appropriate level of difficulty for them. For example, an adult with a low educational level or a foreigner with a non-Romanic language might need an educational app to learn how to write vowels in English, and this may well be the same app as that used by a 4 or 5-year-old child.

In this case, age classification is key because one of the ways app stores classify apps is by using the recommended age. Although categorization may differ according to the app store used, we use the following classification in this work: *baby* for 0 to 3-year-olds, *child* for 4 to 9-year-olds, *teenager* for 10 to 17-year-olds, *adult* for 18 to 59-year-olds, and *elderly* for people over the age of 60. The data are summarized in Table 3.

The user's age is modelled as a number rather than a class in order to have the real value and not a range or class. Additionally, we have considered languages as an individual ontology but in order to link the *User Profile Ontology* with it, we have inserted various relationships as object properties. New information can be added in order to obtain more extensive knowledge about the user to improve the quality of the recommendations. For example, information about the user's profession or interests could help to recommend apps which best suit the user.

The hierarchy of the User Personal Details class is shown in Figure 8.

g: USER'S PERSONAL INTERESTS

Possible typical user interests have been added as subclasses and these are extracted from the domain dependent dimension of the GUMO ontology: environmental topics, film, museum, music genre, musical instruments, PC-games, recreation, science, and sports. We have also included two new categories

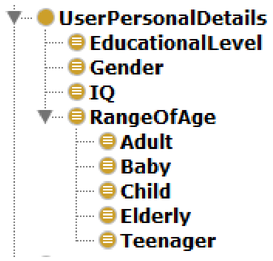

FIGURE 8. User personal details class hierarchy.

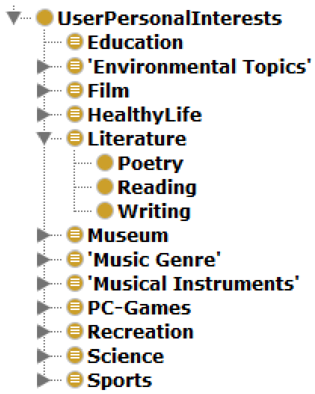

FIGURE 9. Hierarchy of user personal interests class.

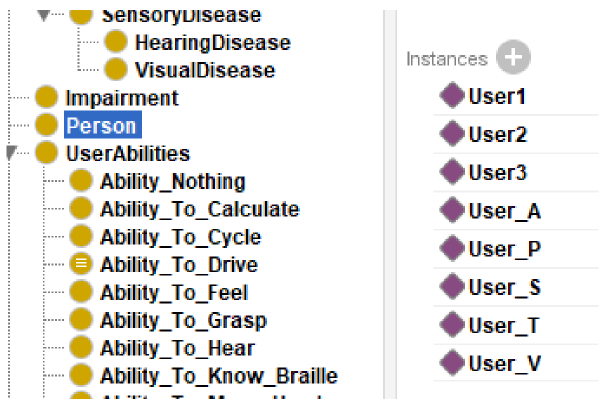

FIGURE 10. Person class hierarchy.

called healthy life and literature as these terms are connected with app categories and do not appear in the GUMO ontology. This is a wide list in order to cover most user interests regardless of their disability. The presence of any of these interests in a user profile can determine the recommendations of one app that belongs to one category if it is closer to the user's tastes or preferences than another.

The hierarchy of the User Personal Interests class is shown in Figure 9.

h: PERSON CLASS

We have added a class *Person* which includes the created user profiles and which is the main domain for the relationships between the remaining classes. Figure 10 shows the class Person and its instances.

2) PROPERTIES OF THE ONTOLOGY

This section establishes the properties of the objects and data.

a: OBJECT PROPERTIES

Object properties connect two classes through a semantic link which can be restricted by domain and range. In the *User Profile Ontology,* a relationship can be established between the different domains of their classes to extend the knowledge required for the application of the system. In this case, for example, we have a relationship called *hasDisability* that is used to connect a user with one or more disabilities they may have. Another object property is called *userHasInterests*, where its domain is the user and its range is the *User Personal Interests* class. The domain of every case in this ontology is the Person class, however there are three relationships with different domains:

- *languagesHasUser* with domain Languages from the *Languages Ontology*, that will be linked later
- *topicsBelongsToUserInterest* with domain Categories from the *Apps Ontology*
- *userInterestHasTopic,* which has the class UserPersonalInterest as its domain

In several cases, object properties have an inverse relationship, as in the case of *userHasSpokenLanguage* and *LanguageHasUsers*.

It is necessary for us to include several object properties for any type of disability in order to distinguish between them when a user might have more than one, such as the magnitude qualifier for each disability because they may have a mild, cognitive disability but a severe, visual disability. It also allows us to complete the equivalence values of Table 2 once we have one of them (i.e. degree, magnitude, and percentage).

Figure 11 shows the object properties of the ontology.

b: DATATYPE PROPERTIES

A data type property connects an individual to a value. They are used to describe the following basic characteristics for a user in the class Person:

- *userHasAge*: the user's current age
- *userHasDisabilityPercentage*: the user's disability percentage according to law provided by an optician using the Wecker Scale [28] to calculate visual acuity
- *userHasGender*: the user's gender
- *userHasIQ*: the users' intelligence quotients (IQ) can affect recommendations
- *userHasName*: the name that identifies the user

The data type properties of the ontology are shown in Figure 12.

C. STEP 3: ONTOLOGY CONSTRUCTION

The third step is to construct the ontology and this includes coding and integrating the ontologies into the ontology system.

a) Implementation of the ontology modules using the Protégé editor [39] and OWL [40]: *User Profile Ontology*, *Apps Ontology,* and *Languages Ontology* have been implemented.
b) Implementation of the ontology module using the Protégé editor [39] and OWL [40]: *User Profile Ontology*,

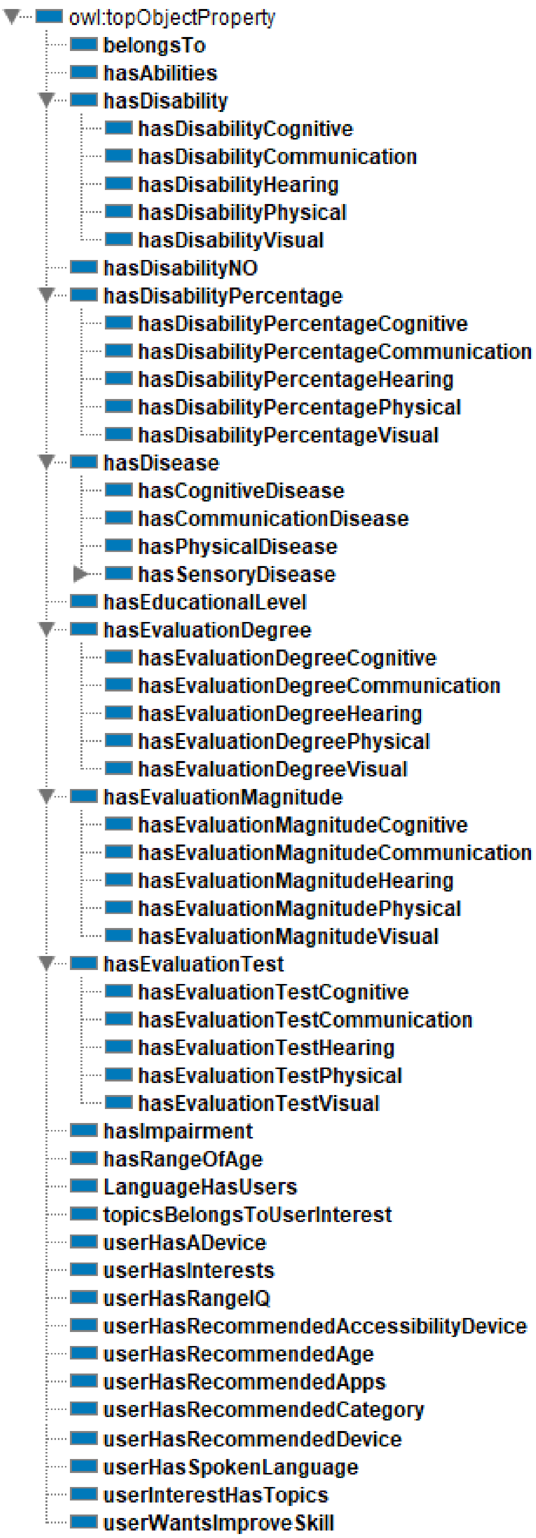

FIGURE 11. Object properties of the user profile ontology.

Apps Ontology, and *Languages Ontology* have been implemented.

c) Population of the ontology module: we populated and integrated the ontology modules into the ontology system.

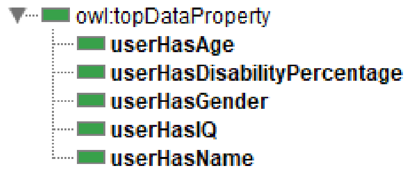

FIGURE 12. Datatype properties of the user profile ontology.

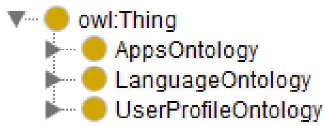

FIGURE 13. Ontology system integration.

d) Integration of the ontology system: the ontology system comprises a series of ontologies. The ontology system now consists of the *User Profile Ontology*, *Apps Ontology*, and *Languages Ontology*. The ontology model is shown in Figure 13.

e) Integration of the ontology system: the ontology system comprises a set of ontologies, and currently includes the *User Profile Ontology*, *Apps Ontology*, and *Languages Ontology*. The ontology model is shown in Figure 13.

As we have already mentioned, we will only describe the process for populating the *User Profile Ontology*. The ontology has been populated with instances that are objects with real, specific values, most of which have been obtained from the ICF, AEGIS and RGD-DO ontologies.

The **Cognitive** (Disability) class, therefore, includes the instances of academic skills disorders, Alzheimer's, Asperger's syndrome, attention deficit hyperactivity disorder, autism, dementia, Down's syndrome, learning disabilities, Rett syndrome, and traumatic brain injury. The class ***Communication*** (Disability) includes the instances of expressive language disorder, non-verbal learning disorder, and speech and language disorders. The class ***Physical*** (Disability) includes the instances of limb absence, arthritis, cerebral palsy, dystrophy, multiple sclerosis, Parkinson's disease, quadriplegia, reduced limb function, tic disorders, and Tourette syndrome. The class ***Hearing*** (Disability) includes the instances of deafness, mixed hearing loss and sensory neural hearing loss. The class ***Visual*** (Disability) includes some typical visual disabilities which will be graded using the terms from the Evaluation Magnitude class (i.e. no problem, mild problem, or severe problem). This class includes common visual disabilities that can be corrected with optical help such as astigmatism, farsightedness and myopia, blurred vision, cataracts, color blindness, light sensitivity, loss of central vision, loss of peripheral vision, and night blindness and blindness.

In the ***Visual Disease*** class, we have included some real diseases that may cause blindness or visual disability, such as lack of vitamin A, amblyopia, cataracts, diabetic retinopathy, glaucoma, macular degeneration, onchocerciasis, optic neuropathy, trachoma, etc.

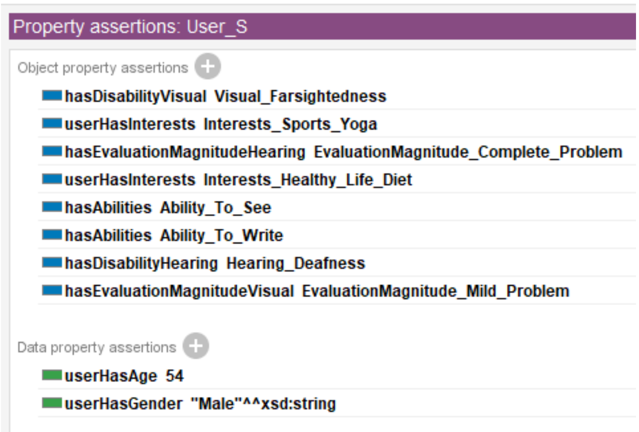

FIGURE 14. Object properties of user S.

For the class ***Person***, we have created four typical users based on real people and their characteristics:

- User_P is a 12-year-old teenage boy who has been diagnosed with a learning disorder and disability, and whose main interests are puzzle apps. He wears glasses for his blurred vision.
- User_T is a 17-year-old teenage girl with optic neuropathy and loss of peripheral vision and blurred vision. She is a secondary school student and loves classical music.
- User_V is a 72-year-old elderly woman with age-related cataracts and physical difficulties caused by arthritis. She is also in the early stages of Parkinson's disease.
- User_S is a 54-year-old man with age-related deafness and farsightedness who is able to see and write. The details for User_S are shown in Figure 14.

We have defined four educational levels for the user's personal details (low, basic, medium, and high) according to the user's level of studies (no studies, primary studies, secondary studies, or higher studies). The age range contains *baby*, *child*, *teenager*, *adult*, and *elderly*, according to the age range classification in Table 3.

Finally, the user's personal interests contain a list of the predefined user interests obtained from the GUMO ontology. These are related with their subclasses (e.g. environmental topics, film, museum, music genre, musical instruments, or PC-games): classical music, pop music and rock music, poetry, puzzles, sports games, etc.

D. STEP 4: ONTOLOGY EVALUATION

In the final step, the ontology evaluation attempts to obtain new inferred information from the ontology system created. One advantage of ontologies is that they allow users to reason [40], and once we have the user profile, we can reason about it in order to obtain new information. A reasoner is software that is able to deduce logical consequences from a series of facts and offer a larger set of mechanisms to work with them. The Pellet reasoner [41] works with OWL and can be used in Protégé.

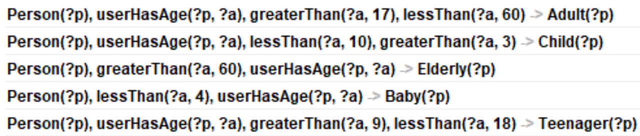

FIGURE 15. Classification rules according to age.

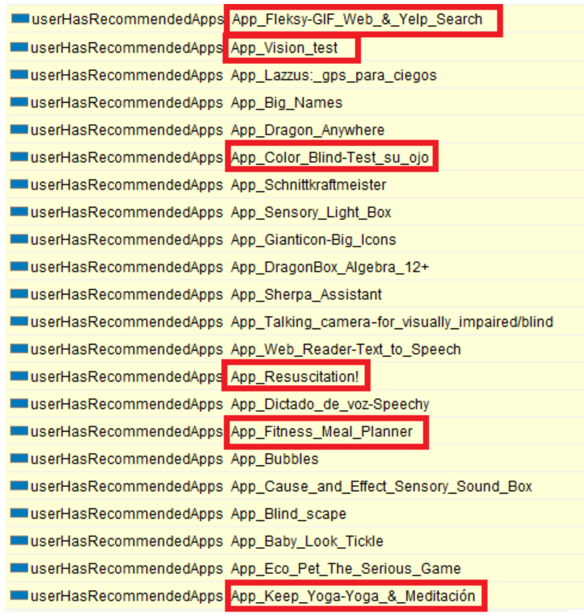

FIGURE 16. Recommendations for user S.

We have incorporated a number of inference rules to describe relationships that cannot be obtained in any other way. Inference rules are specified using a language of ontologies and a descriptive language. The Semantic Web Rule Language (SWRL) [42] is a rule-based language designed as an OWL extension that supports the writing of relationships that cannot be described using the OWL logic description since it is not sufficiently expressive. SWRL uses the same descriptive logic as OWL, and provides similar inferences and classifications of concepts and properties.

We have added five rules for grouping users according to the age ranges listed in Table 2: a child under 4 is classified as a baby; a user between the ages of 4 and 9 is a child; a user aged 10 to 17 is a teenager; a user between the ages of 18 and 59 is an adult; and, finally, users over the age of 60 are elderly. This information is shown in Figure 15.

Five further degrees of impairment have been included to indicate the different levels of disability that a user may have, and this degree scale follows the ICF categorization presented in Table 2. The following five rules can be applied to visual impairment:

- A person with a degree 0 is not considered to be visually impaired.
- A person with degree 1 has slight visual impairment and this is considered a mild visual disability.

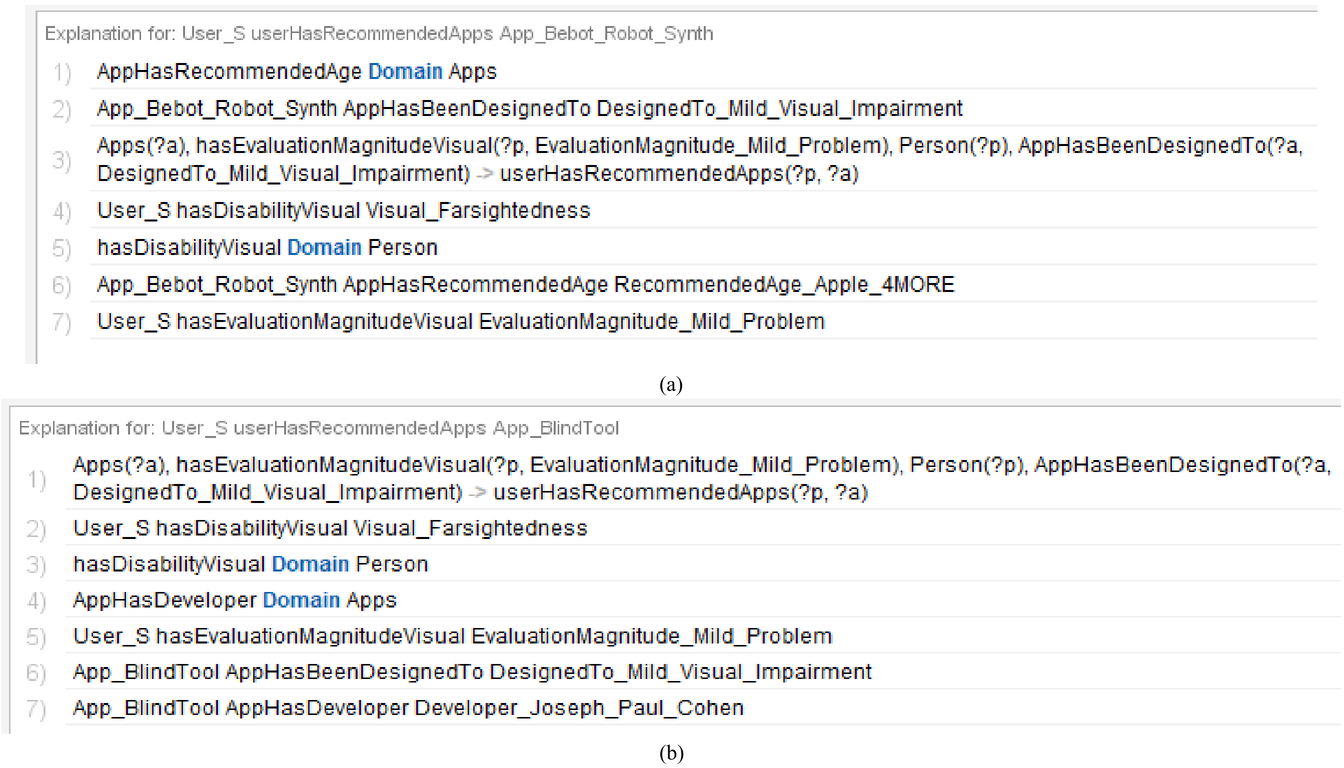

FIGURE 17. (a) Explanation for inferences. App BlindTool. (b) Explanation for inferences. App Bebot robot Synth.

- A person with degree 2 has moderate visual impairment
- A person with degree 3 has severe visual impairment.
- A person with degree 4 has complete visual impairment or is blind.

The aim of these rules is to convert the degree of visual impairment into the standard classification provided by the ICF. Further rules will be included once the ontology system has been created. In this way, we can link domains from different modules such as age range and apps when we want to identify the most suitable apps for a certain age. We could also deduce additional information from that which we already have in the inference process.

IV. RESULTS

In this section, we will show some of the possible results that can be obtained by reasoning with the ontology.

Once we have created the *User Profile Ontology* and incorporated various inference rules, we need to merge the *User Profile Ontology* with the *Apps Ontology* to obtain new information about the recommended apps for a user. The *Apps Ontology* gathers a series of basic features (e.g. name, category, file size, or store) and other complementary ones (e.g. recommended age, mode of play, apps designed for specific users, and skills that users can acquire or improve) and this constitutes the app profile. One example of user profile might be: User_S who is a 54-year-old man who suffers from farsightedness and deafness, who is interested in yoga, and wants to go on a diet, and the system must identify the apps to recommend to this user. This example written in SWRL is:

Person(?p) ^ RangeOfAge(?p, Adult) ^ hasVisualDisability (Disability_Farsightedness) ^ hasHearingDisability(Disability_Deafness) ^ userHasInterests(Yoga) ^ userHasInterests(Diet) -> Apps(?app) ^ userHasRecommendedApps(?app)

From the *Apps Ontology* instances, the reasoner infers that certain apps are suitable for User_S, and these are deduced according to the information. These are inferred according to the provided conditions of age, disabilities, and interests from the user profile. Apps such as "Fitness Meal Planner" and "Keep Yoga - Yoga & Meditation" are obtained, for example, since they match his personal interests. Other apps such as "Vision test" or "Color Blind – test su ojo" are also obtained because User_S has a hearing disability, or "Fleksy-GIF Web & Yelp Search" and "Resuscitation!" due to his age. The examples are shown in Figure 16.

The explanation given by the Pellet reasoner for the recommendations shows that User_S is interested in *diet* (and therefore also in healthy living) and *yoga* (and therefore also in sports). Both interests lead the system to obtain various apps for the user from the Health & Wellness app category. Both the "Fitness Meal Planner" and the "Keep Yoga – Yoga & Meditation" apps appear in the Health & Wellness category and so these are also inferred by the system.

The system also considered the user's visual disability (*Farsightedness*) as a mild visual disability according to the previously established rules which means that the user can lead a normal life by wearing glasses or lenses. Taking this into account, the system also infers apps intended for people with mild visual disability such as ‘‘ErgoVidrio’’ or ‘‘Blind Tool’’ (Figure 17a). Because of the user’s deafness, the system also infers the app ‘‘Bebot Robot Synth’’ (Figure 17b) which will help him improve his hearing. Figures 17a and 17b illustrate how the system makes app inferences on the basis of the rules established for the ontology. As we can see, in order for the system recommend suitable apps based on the profile of User_S, it is not necessary for the system to know much information since it is able to build a more complete profile and make inferences by generating new knowledge based on existing information and the added rules.

V. CONCLUSION AND FUTURE WORK

It is often difficult for people with disabilities to manage their mobile devices and their apps, and they may find it hard to find a suitable app in the app store. The app store has a section with the newest apps which can be searched according to age, key word, or category, and returns a list of apps that users must evaluate before deciding which best suits their needs. The decision-making process is a complex task due to the number of similar apps shown in the list, and one that is further complicated by factors such as inadequate information to help the user decide, the app only being available in a foreign language, text being too small, there not being any indication of who the app is intended for, or what the purpose of the app is. Users might have special requirements when it comes to using apps since the vast majority does not include their accessibility features in their description.

We have solved this situation by modeling an ontology system which includes user profiles with the intention of making personalized recommendations of suitable apps for users according to each user’s characteristics and needs. In order to build the user profile, we have created a new classification of disabilities and skills (Table 1) based on the ICF. We have also included personal details, personal interests, abilities, diseases, and the evaluation of the user’s disabilities to compile a complete user profile. Various rules have also been added to obtain new information that cannot be deduced in any other way.

Since the reasoning of the *User Profile Ontology* does not obtain any inference of apps, we have merged it with a previously developed *Apps Ontology* [4] so as to obtain more complete inferences.

In cases where the user profile might be incomplete, the new *User Profile Ontology* and the reasoner make it possible to obtain a more complete user profile and personalized recommendations about the most suitable apps according to the available personal information, disabilities, and interests by deducing new information based on existing information. As more information is added to the ontology, we could obtain more complete recommendations.

We have used the Bravo, Hoyos, and Reyes method to create the ontology system, and this models the information gathered by several ontologies and forms the knowledge base for a recommender system.

Although we have focused this work on people with visual disabilities, it can be extended to include other impairments, disabilities, and diseases by incorporating more subclasses and rules into the ontology.

We are currently completing the modelling of a series of ontologies that cover other domains, and this would enable more accurate recommendations to be made. These domains are: *Context* so as to identify the user’s environment, *Mobile Devices* so that can suitable apps be recommended for a specific device, *Languages* to identify those the user knows, and *Accessibility Features* that the user might require or that the app offers. All the proposed ontologies will also be merged with the *User Profile Ontology* and the *Apps Ontology*. This set of ontologies will effectively and accurately represent knowledge, and, by way of a secondary objective, will be used by a recommender system that will enable the user to interact with the system in an easy and usable way. The recommender system will also include a module that will enable us to improve the inferences.

The system will be able to infer and make recommendations as shown in the following examples:

- What are the best apps for training a user’s specific skills (e.g. attention or memory) on an iOS mobile device?
- Which device is suitable for installing a selected app that is specifically designed for people with visual disabilities?
- What accessibility features should be activated on a blind user’s Android tablet?
- How should the device be configured for a public place such as a cinema or museum?
- What apps are suitable for a specific visual disability?

By way of conclusion, it is worth mentioning that the creation of a more complete user profile with various features that are not present in other user profile ontologies will enable us in the future to tailor app recommendations to users with visual impairments.

REFERENCES

[1] D. Mayordomo-Martínez, J.-C. Sánchez-Aarnoutse, J. M. Carrillo-de-Gea, J. A. García-Berná, J. L. Fernández-Alemán, and G. García-Mateos, ‘‘Design and development of a mobile app for accessible beach tourism information for people with disabilities,’’ *Int. J. Environ. Res. Public Health*, vol. 16, no. 12, p. 2131, Jun. 2019, doi: 10.3390/ijerph16122131.

[2] G. R. Oviedo, N. Tamulevicius, and M. Guerra-Balic, ‘‘Physical activity and sedentary time in active and non-active adults with intellectual disability: A comparative study,’’ *Int. J. Environ. Res. Public Health*, vol. 16, no. 10, p. 1761, May 2019, doi: 10.3390/ijerph16101761.

[3] P. Litchfield, C. Cooper, C. Hancock, and P. Watt, ‘‘Work and wellbeing in the 21st century,’’ *Int. J. Environ. Res. Public Health*, vol. 13, no. 11, p. 1065, Oct. 2016, doi: 10.3390/ijerph13111065.

[4] M. I. Torres-Carazo, M. J. Rodriguez-Fortiz, and M. V. Hurtado, "Analysis and review of apps and serious games on mobile devices intended for people with visual impairment," in *Proc. IEEE Int. Conf. Serious Games Appl. Health (SeGAH)*, May 2016, pp. 1–8, doi: 10.1109/SeGAH.2016.7586263.

[5] United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision, Key Findings and Advance Tables. ESA/P/WP/248*. Accessed: Nov. 5, 2020. [Online] Available: https://population.un.org/wpp/

[6] *WHO. World Health Organization. Disability*. Accessed: Nov. 5, 2020. [Online] Available: https://www.who.int/disabilities/es/

[7] J. Lazar and P. Jaeger, "Reducing barriers to online access for people with disabilities," *Issues Sci. Technol.*, vol. 27, no. 2, pp. 69–82, 2011.

[8] J. M. Saez, F. Escolano, and M. A. Lozano, "Aerial obstacle detection with 3-D mobile devices," *IEEE J. Biomed. Health Informat.*, vol. 19, no. 1, pp. 74–80, Jan. 2015, doi: 10.1109/JBHI.2014.2322392.

[9] S. Harada, D. Sato, D. W. Adams, S. Kurniawan, H. Takagi, and C. Asakawa, "Accessible photo album: Enhancing the photo sharing experience for people with visual impairment," in *Proc. SIGCHI Conf. Hum. Factors Comput. Syst.*, Apr. 2013, pp. 2127–2136, doi: 10.1145/2470654.2481292.

[10] C. Yi, "Serious game design for auditory training of hearing-impaired children," *TECHART, J. Arts Imag. Sci.*, vol. 2, no. 1, p. 46, Feb. 2015, doi: 10.15323/techart.2015.02.2.1.46.

[11] G. P. Mahardhika, A. Kurniawardhani, and D. Yolhanda, "Mobile games interaction design for people with visual impairment using participatory design approach," *IOP Conf. Ser., Mater. Sci. Eng.*, vol. 482, Mar. 2019, Art. no. 012039, doi: 10.1088/1757-899X/482/1/012039.

[12] L. R. Milne, C. L. Bennett, R. E. Ladner, and S. Azenkot, "BraillePlay: Educational smartphone games for blind children," in *Proc. 16th Int. ACM SIGACCESS Conf. Comput. Accessibility - ASSETS*, 2014, pp. 137–144, doi: 10.1145/2661334.2661377.

[13] *W3C*. Accessed: Nov. 5, 2020. [Online] Available: https://www.w3.org/Consortium/

[14] S. Wu and L. A. Adamic, "Visually impaired users on an online social network," in *Proc. SIGCHI Conf. Hum. Factors Comput. Syst.*, Apr. 2014, pp. 3133–3142, doi: 10.1145/2556288.2557415.

[15] J. P. Pfeiffer and M. Pinquart, "Computer use of adolescents with and without visual impairment," *Technol. Disab.*, vol. 25, no. 2, pp. 99–106, Jul. 2013, doi: 10.3233/TAD-130373.

[16] R. Hewett, G. Douglas, and S. Keil. (2015). *Wellbeing of Young People With Visual Impairments*. Visual Impairment Centre for Teaching and Research. University of Birmingham. [Online]. Available: https://research.birmingham.ac.uk/portal/en/publications/wellbeing-of-young-people-with-visual-impairments(d574539f-2d15-4776-b6cb-c4ec15a83c94).html

[17] E. A. Pascoe and L. S. Richman, "Perceived discrimination and health: A meta-analytic review," *Psychol. Bull.*, vol. 135, no. 4, pp. 531–554, 2009, doi: 10.1037/a0016059.

[18] M. I. Torres-Carazo, M. J. Rodríguez-Fórtiz, V. Espín, and M. V. Hurtado, "Ontology-based user profile modelling to facilitate inclusion of visual impairment people," in *Proc. Int. Conf. Model Data Eng. MEDI*, 2017, pp. 386–394, doi: 10.1007/978-3-319-66854-3_29.

[19] S. E. Middleton, H. Alani, N. R. Shadbolt, and D. C. De Roure, "Exploiting synergy between ontologies and recommender systems," in *Proc. 3rd Int. Conf. Semantic Web SemWeb*. vol. 55, 2002, pp. 41–50.

[20] M. I. Torres-Carazo, M. J. Rodríguez-Fórtiz, M. V. Hurtado, J. Samos, and V. Espín, "Architecture of a mobile app recommender system for people with special needs," in *Ubiquitous Computing and Ambient Intelligence. Personalisation and User Adapted Services—UCAmI* (Lecture Notes in Computer Science), vol. 8867, R. Hervás, S. Lee, C. Nugent, and J. Bravo, Eds. Cham, Switzerland: Springer, 2014, doi: 10.1007/978-3-319-13102-3_47.

[21] V. Codina and L. Ceccaroni, "A recommendation System for the Semantic Web," in *Proc. DCAI Distrib. Comput. Artif. Intell. 7th Int. Symp.*, Valencia, Spain, vol. 79. Sep. 2010, pp. 45–52, doi: 10.1007/978-3-642-14883-5_6.

[22] W. H. Assembly, *International Classification of Functioning, Disability and Health. ICF*. Geneva, Switzerland: World Health Organization (WHO). May 2001.

[23] WHO: World Health Organization. (2018). *International Statistical Classification of Diseases and Related Health Problems*. 11th Revision ICD-11. Accessed: Nov. 5, 2020. [Online]. [Online]. Available: https://icd.who.int/browse11/l-m/en

[24] *Red Cross*. Accessed: Nov. 5, 2020. [Online]. Available: http://www.redcross.org

[25] C. Rivas-Costa, L. Anido-Rifón, M. J. Fernández-Iglesias, M. A. Gómez-Carballa, S. Valladares-Rodríguez, and R. Soto-Barreiros, "An accessible platform for people with disabilities," *Int. J. Hum.-Comput. Interact.*, vol. 30, no. 6, pp. 480–494, Jun. 2014, doi: 10.1080/10447318.2014.888503.

[26] B. D. R. Marino, M. J. Rodriguez-Fortiz, M. V. H. Torres, and H. M. Haddad, "Accessibility and activity-centered design for ICT users: ACCESIBILITIC ontology," *IEEE Access*, vol. 6, pp. 60655–60665, 2018, doi: 10.1109/ACCESS.2018.2875869.

[27] V. D. Mea and A. Simoncello, "An ontology-based exploration of the concepts and relationships in the activities and participation component of the international classification of functioning, disability and health," *J. Biomed. Semantics*, vol. 3, no. 1, p. 1, 2012, doi: 10.1186/2041-1480-3-1.

[28] P. L. Whetzel, N. F. Noy, N. H. Shah, P. R. Alexander, C. Nyulas, T. Tudorache, and M. A. Musen, "BioPortal: Enhanced functionality via new Web services from the national center for biomedical ontology to access and use ontologies in software applications," *Nucleic Acids Res.*, vol. 39, pp. W541–W545, Jul. 2011, doi: 10.1093/nar/gkr469. [Online]. Available: https://bioportal.bioontology.org/ontologies/ICF

[29] B. D. Romero-Mariño, V. Espín, M. J. Rodríguez-Fórtiz, M. V. Hurtado-Torres, L. Ramos, and H. M. Haddad, "Ontology to profile user models with disabilities," in *Model and Data Engineering* (Lecture Notes in Computer Science), vol. 10563, Y. Ouhammou, M. Ivanovic, A. Abelló, and L. Bellatreche, Eds. Cham, Switzerland: Springer, 2017, pp. 372–385.

[30] D. Tzovaras, K. Votis, N. Kaklanis, T. Oikonomou, M. Kastori, R. Lopes, C. Michael-Loupis, M. Ringler, M. Papadopoulou, N. Partarakis, and P. Korn. (2009). *ACCESSIBLE EC Project.D3.3a—ACCESSIBLE System Architecture Specification (Beta)*. CERTH/ITI. Accessed: Nov. 5, 2020. [Online]. Available: http://www.accessible-eu.org/documents/ACCESSIBLE_D3.3a.pdf

[31] K. A. Basit and M. Matskin, "GUMO inspired ontology to support user experience based citywide mobile learning," in *Proc. Int. Conf. User Sci. Eng. (i-USEr)*, Nov. 2011, pp. 195–200, doi: 10.1109/iUSEr.2011.6150564.

[32] *AEGIS Project*. Accessed: Nov. 5, 2020. [Online]. Available: http://www.aegis-project.eu/

[33] C. M. Keet, R. Alberts, A. Gerber, and G. Chimamiwa, "Enhancing Web portals with ontology-based data access: The case study of South Africa's accessibility portal for people with disabilities," in *Proc. ISWC 5th OWLED Workshop OWL, Exper. Directions, Collocated With 7th Int. Semantic Web Conf.*, Karlsruhe, Germany. Oct. 2008, pp. 1–12.

[34] M. Shimoyama, J. De Pons, G. T. Hayman, S. J. F. Laulederkind, W. Liu, R. Nigam, V. Petri, J. R. Smith, M. Tutaj, S.-J. Wang, E. Worthey, M. Dwinell, and H. Jacob, "The rat genome database 2015: Genomic, phenotypic and environmental variations and disease," *Nucleic Acids Res.*, vol. 43, no. D1, pp. D743–D750, Jan. 2015, doi: 10.1093/nar/gku1026.

[35] M. C. Bravo Contreras, L. F. Hoyos Reyes, and J. A. Reyes Ortiz, "Methodology for ontology design and construction," *Contaduría y Administración*, vol. 64, no. 4, p. 134, Mar. 2019, doi: 10.22201/fca.24488410e.2020.2368. [Online] Available: http://www.cya.unam.mx/index.php/cya/article/view/2368

[36] *WCAG 2.0: Web Content Accessibility Guidelines 2.0*. Accessed: Nov. 5, 2020. [Online]. Available: https://www.w3.org/TR/UNDERSTANDING-WCAG20/

[37] *MWABP: Mobile Web Application Best Practices*. Accessed: Nov. 5, 2020. [Online]. Available: https://www.w3.org/TR/mwabp/

[38] *Wecker Scale*, WHO Study Group on the Prevention of Blindness. Wecker Scale, Geneva, Switzerland. Nov. 1973, no 518.

[39] *Protégé*. Accessed: Nov. 5, 2020. [Online]. Available: http://protege.stanford.edu

[40] G. Antoniou and F. van Harmelen, "Web ontology language: OWL," in *Handbook on Ontologies* (International Handbooks on Information Systems), S. Staab and R. Studer, Eds. Berlin, Germany: Springer, 2004, doi: 10.1007/978-3-540-24750-0_4.

[41] E. Sirin, B. Parsia, B. C. Grau, A. Kalyanpur, and Y. Katz, "Pellet: A practical OWL-DL reasoner," *J. Web Semantics*, vol. 5, no. 2, pp. 51–53, Jun. 2007, doi: 10.1016/j.websem.2007.03.004.

[42] I. Horrocks, P. F. Patel-Schneider, H. Boley, S. Tabet, B. Grosof, and M. Dean. (2004). *SWRL: A Semantic Web Rule Language Combining OWL and RuleML*. W3C Member Submission. Accessed: Nov. 5, 2020. [Online]. Available: https://www.w3.org/Submission/SWRL/

MARÍA ISABEL TORRES-CARAZO was born in Granada, Spain. She received the Bachelor of Science degree in computer engineering from the University of Granada, in 2003, and the master's degree in software development, in 2012. She is currently pursuing the Ph.D. degree. Since 2006, she has been a full-time teacher of computer science in several secondary and professional training schools. Her research interests include ontology-driven systems, recommender systems, mobile applications (apps), and assistive technologies for blind people.

MARÍA JOSÉ RODRÍGUEZ-FÓRTIZ was born in Granada, Spain. She received the B.S. and Ph.D. degrees in computer science from the University of Granada. Since 1990, she has been a Lecturer with the Department of Languages and Computer Systems, University of Granada. She has been a Lead Researcher and has participated in several research projects at national, regional, and local levels, and also in contracts with companies. Her field of work is related to the application of ICT to special needs and older people. Specifically, she is specialized and interested in accessibility, usability, and adaptation of software to users, considering its profile and context information.

MARÍA VISITACIÓN HURTADO TORRES was born in Granada, Spain. She received the B.S. and Ph.D. degrees in computer science from the University of Granada. Since 1996, she has been a Lecturer with the Department of Languages and Computer Systems, University of Granada, where she is currently responsible for the Modeling and Development of Advanced Software Systems Research Group. Her research interests include development of interactive and collaborative systems and their application in educational environments, assistive technologies, and ontologies.