# An Alignable User Profile Ontology for Ambient Intelligence Environments

I. Panagiotopoulos, L. Seremeti, and A. Kameas

***Abstract*—One of the principal objectives of today's ambient intelligence environments is to provide users with services according to their activity, i.e. preferences in order to accomplish a specific user goal. For this purpose, miscellaneous user information must be collected and structured into user profiles. These profiles offer the advantage of being easily enriched and exploitable by the environment, in order to deliver to the user, at any moment and at any place, the best fitted service, with regard to his activity. In this paper we present an ontology-based user profile model which provides the static data about a user but also the context of the user in a given situation in real time.**

***Index Terms*—activity spheres, ambient intelligence, ontologies, user profile**

## I. Introduction

THe notion of "activity sphere" can be used in order to describe the aim-dedicated conglomeration of entities and the collective knowledge surrounding the user living in an ambient ecology [1]. An activity sphere is both the virtual description of the resources (e.g., devices, services, agents, and users) required to achieve a user's single aim, as well as its fulfillment in the context of a specific ecology. An activity sphere in general consists of ontologies as primary knowledge and information repository, the user itself as the task owner (and possibly the environment's occupant) and various entities (devices, services, etc) that realize the services necessary to carry out the tasks. Each entity profile maintains a local ontology. In other words, the local ontology, which represents the complete set of knowledge associated with this entity.

This paper focuses on the issue of describing the profile of a user-owner of an activity sphere, in a way that supports sphere adaptation to the user's changing context. Such a profile should firstly represent important permanent user traits like personal information, interests, capabilities etc. In addition, there is the need of representing the user role in each specific activity sphere and the user's preferences defined for the sphere tasks at any moment. When the user and the associated spheres move to a different ambient ecology, context (time, location, state, etc.) changes; it is essential to also represent the changes taking place. Finally, another requirement the user profile should fulfill is the ability to align with all the other entity profiles, in order to semantically describe a user specific activity within an ambient ecology.

This paper presents an ontology for modeling user profiles. The purpose was to create a generic extendable ontology capable of encompassing and representing user needs and preferences regarding every activity sphere he participates in, while maintaining at the same time a general common structure, so as to satisfy portability and communication between different activity spheres. Moreover, the user profile ontology should be align-able, that is, it should be possible to match its concepts and relations with concepts and relations of the other entity profile (local) ontologies that participate in the realization of the same activity sphere. This ability supports dynamic and scalable semantic integration.

The rest of the paper is organized as follows: in Section II, we review the existing work in the area of ontology-based user profiling and classify it in two categories. Then, the method for creating our user profile ontology is presented, followed in Section IV by a representation of the ontology itself. Section V gives a brief discussion over ontology alignment. Finally, the last section presents the conclusions and briefly outlines future work.

## II. Related work

Ontologies have been proven to be an effective means for modeling user profile, because they can present an overview of the domain related to a specific area of interest and they may be used for browsing and query refinement. They model concepts and relationships in a high level of abstraction, providing rich semantics for humans to work with and the required formalism for computers to perform mechanical processing and reasoning.

Using an ontology to model the user profile has already been proposed in various applications, like web search [2], personal information management [3] and context-aware systems [4]. We are interested in the ontology-based user profile in context-aware systems. The notion of user profiling in this area of ubiquitous computing has been introduced in order to record the user context and personalize applications so as to be tailored to the user needs.

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The available approaches in ontology-based user profile modeling, each one following a different hierarchy of concepts, can be distinguished as describing either static user information, or dynamic user information. Static user information is referred to the permanent characteristics, preferences, interests and context of the user, while the dynamic profile of the user includes matters pertaining to temporal conditional preferences and interests, according to specific situations. Representative examples of the first category are the following:

FOAF [5] is an ontology-based RDF vocabulary which describes user profiles, friends, affiliations, etc. The profile contains mostly static data, like personal information, work history, links to contacts and services.

The user profile model proposed by Von Hessling et al. [6] is a simple ontology consisting of the union of user interests and disinterests. The system is peer-to-peer where the profiles are stored on the mobile devices, which guarantees better privacy.

Mendis [7] proposed a user profile ontology containing semantic contact information encoded in RDF. The ontology is structured in three parts: *Person Ontology* containing classes relevant only to the user, *Organization Ontology* containing business oriented information and a *Common Ontology*, containing information relevant to both persons and organizations.

Golemati et al. [8] also represent an application-independent user profile ontology, which deals only with the static profile of the user and not the dynamic or contextual one.

APO (Actor Profile Ontology) [9] is another example of this category. It is devoted to contain all the knowledge about the different kind of actors involved in a Home Care assistance system and their potential functionalities and possible interactions.

Vildjiounaite et al. [10], on the other hand, offer an ontology-based user profile model, where static and dynamic profiles are distinguished. The model is separated into two components: the static user profile, which comprises preferences, personal data, interests, and disinterests and the context-aware dynamic user profile, which learns user behavior from history of activities.

Another user profile ontology addressing both static and context-aware aspects is the UPOS (User-Profile Ontology with Situation-Dependent Preferences Support) [4]. This ontology, defined in OWL, allows creating situation-dependent sub-profiles. A user has a profile and a context associated. The profile is structured into sub-profiles, each containing user preferences that correspond to a specific situation.

Stan et al. [11] proposed a user model that allows users to have a situation-aware social network by controlling how reachable they are for specific categories of other people at any moment.

Existing user profile models allow the specification of a great variety of static data such as preferences, interests, personal data, but they do not allow expressivity for real-time context changes. [10] while supports dynamic aspects, it is limited in the logging of the user's activity enriched with context. On the other hand [11], adapts static and dynamic concepts to represent the current situation of the user but focuses on the social network of the user and how he can be reached by other people (family, colleagues, etc.) at any moment. UPOS while addresses both static and context-aware aspects, it refers generally to a single context dimension (e.g. location). The user profile that will be presented in this paper extends the UPOS ontology by the conjunction of multiple context dimensions (location, time, state, and mood); in order to better represent the current situation of the user.

In the context of EU research project ATRACO [12], we have developed an architecture that can realize activity spheres as adaptive ubiquitous computing applications. Each sphere is modeled as a workflow of tasks and managed by the Sphere Manager (SM), a software module that ensures the binding of tasks to intelligent agents and resources in the ambient ecology [1]. As mentioned already, each resource maintains its local ontology; then, for each sphere, a Sphere Ontology (SO) is formed by the Ontology Manager (OM), which aligns all resource ontologies. When the sphere moves to a different ecology, all which is required to make the sphere functional is a new alignment. User adaptation is achieved by including the user profile ontology in the alignment. Consequently, the user profile ontology plays a key role in modeling and realizing user centered activity spheres, which are realized in Ambient Intelligence environments.

The scope of the proposed user profile ontology, is to model an active entity, such as the user, by describing the user's characteristics, his/her relationships with other users, his/her temporary/permanent preferences, interests, disinterests, capabilities and current/permanent state within continuously changing environments, that is, to describe his/her static and dynamic profile. Since the domain of profile is so broad, an attempt to model it in a detailed manner would produce a huge and cumbersome ontology. From another point of view, there is no single correct way to model a domain: there are always viable alternatives. The best solution depends on the application area and the possible extensions. Having this in mind, the domain of user profile is modeled in a non-exhaustive, yet sufficient way, adopting the definition of generic concepts that can be easily extended by aligning them with concepts of other entity profile ontologies.

## III. Creating the User Profile Ontology

We consider the following ATRACO scenario as a starting point, in order to create our user profile ontology:

*Suki has been living in this new apartment for the past 10 months. It is no ordinary house; it is not a commonplace first generation smart house: it is a brand new adaptive house! When he returns home at night, he wants to sleep and for this reason the smart house should adapt the temperature (Suki prefers a cold bedroom), lower the level of brightness and* *switch off his TV set. The next day, Suki has to stay the night at a hotel in the city close to his office, due to a public transportation strike. When Suki enters the hotel room he wants to go to bed and sleep. Then, the hotel smart room should also adapt the temperature, the level of brightness and TV set to Suki's preferences.*

Using the above scenario, we can limit the scope and the domain of our user profile ontology, as well as sketch the competency questions in which our ontology should be able to answer. Examples of competency questions are: What is the current activity of the user and how is it affected by any possible changes of context? What are the user's preferences depending on the current activity? Which are the environmental conditions in order for the user to perform a specific activity? Does the user's emotional state depend on his activity or context? From these competency questions we elicit the main concepts which will be included in our user profile ontology. Moreover, existing applications and ontologies related to the domain of user context and profiling have been taken into account in order to design it. For the creation of the proposed ontology, we adopted a top-down approach, firstly selecting important general concepts, which are later, enriched and specialized. Our user profile ontology has been defined in OWL, the Web Ontology Language [13], and we have used Protégé 3.1 [14], as the ontology editor.

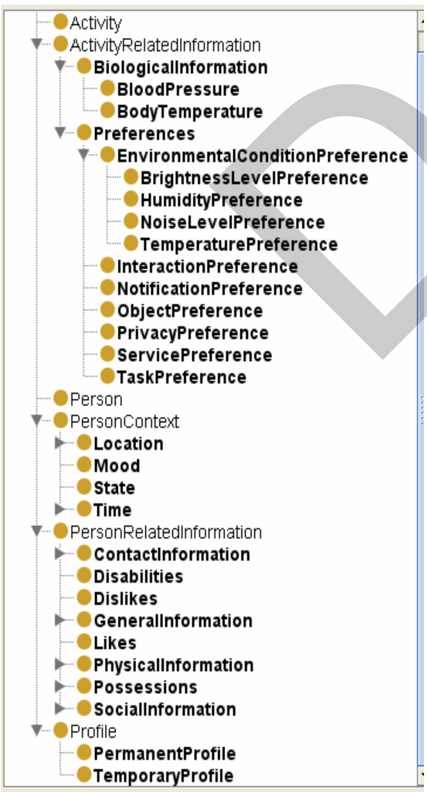


Fig. 1. Class hierarchy of the ontology

## IV. THE USER PROFILE ONTOLOGY

In this section, we will shortly describe some of the created classes and properties, and visualize their relations by means of the TGVizTab plug-in of Protégé. Fig. 1 shows the class hierarchy of the most general concepts included in the ontology, whereas Fig. 2 shows the list of the created properties.

Describing the ontology in a nutshell: An *Activity* defines what the user wants to do in a given time and context, while the class *Preferences,* defines the environmental and other activity sphere preferences. The *Activity* concept allows describing the current state of interaction between the user and his environment. The user profile (*PermanentProfile*), which contains general information about the user for expressing static aspects of the user (personal information, interests), has a set of associated *TemporaryProfiles*. Each of them is linked to an *Activity* (*isDescribedBy* property) and a *ServicePreference* (*hasServicePreference* property) containing a list of user preferences. A *Preference* is divided to an *EnvironmentalConditionPreference* (temperature, lighting, wind, humidity, noise), an *ObjectPreference* (e.g. air-condition, lamp, TV) and other preferences (Fig. 1) related to the environment of the activity sphere.



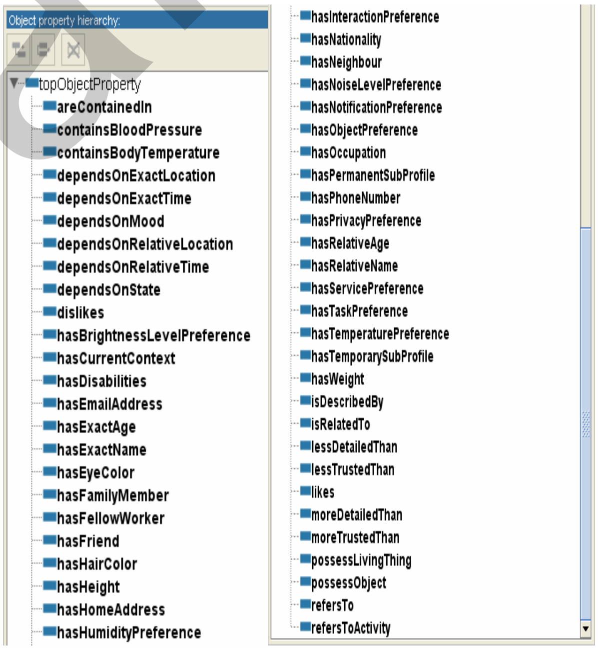


Fig. 2. List of properties

The values of context dimensions which are defined in the class *PersonContext* may change, but the user activity can still be the same. A good example for this is when Suki wants to sleep at home and the next day, he wants to sleep at a hotel room. The *Location* changes, but the user still wants to sleep. The purpose of the activity has also been changed. In our model, we bind a *TemporaryProfile* to an *Activity*. This subset of the *Profile* will contain user preferences that need to be applied when the context of that activity changes. In the example, the same activity of sleeping can be observed but with different location: the first is when Suki wants to sleep at home and the second is when Suki wants to sleep at a hotel room. For the same activity, Suki's preferences are defined in the *TemporaryProfile*. In Fig. 3 the instance *TemporaryProfile:Sleeping_Subprofile* corresponds to the activity *Activity:Sleeping*. The advantage of this ontology structure is that sub-profiles can be easily added or removed.

Let's refer again to Fig. 1. An Activity is related with a *Person*, a *PersonContext* and a sub-profile (*TemporaryProfile*) that describes preferences defined for this activity. This gives a dynamic aspect to the user-profile. The context is a set of multiple contextual dimensions, such as: *Location* (e.g. office, home, hotel room); *Time* (working day, night, weekend, morning, evening); *User emotional state* (sadness, anger, anxiety, happiness).

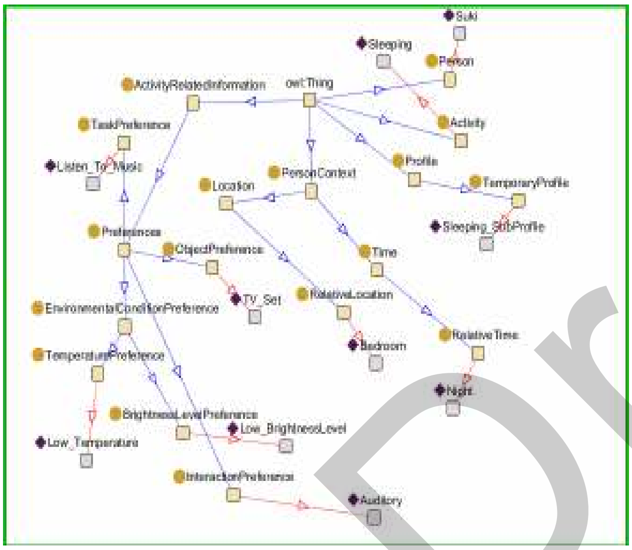

Fig. 3. A fragment of the user profile ontology

To facilitate understanding the core structure of the ontology, we describe an instance of it (Fig. 3). *Person:Suki* has the following *PersonContext*: he is situated in *RelativeLocation:Bedroom*, at *RelativeTime:Night*. He wants to *Activity:sleeping*. This activity involves *Pereference:Low_temperature*, *adjust_TV*, *Low_BrightnessLevel*, which concern the *ObjectPreference: TV*. In his corresponding sub-profile (*TemporaryProfile:Sleeping_SubProfile*), he defined the *Listen_To_Music TaskPreference*. According to the scenario of Section III, Suki has to stay at the hotel. Thus the *PersonContext* changes. Now, Suki is situated in *RelativeLocation:Hotel_room*, while time remains the same (*RelativeTime:Night*). In this concrete scenario Suki wants to sleep again and so the *Activity:Sleeping* is the same and it is described in *TemporaryProfile:Sleeping_Subprofile*. In this case the activity sphere (hotel room), has to be adapted to meet Suki's preferences as described above. So every time the context changes, the whole profile ontology changes also.

In order to test our ontology a number of queries (competency questions) have been applied to it. For this purpose a number of instances have been included in the ontology as shown in Fig. 3. For the application of the queries the SparQL tool [15] of Protégé has been used. In Fig. 4 we can see an example query and its results. With this query we ask the ontology what are the preferences defined by a specific person for a specific object, in order to carry out a specific activity.

According to the results of the query depicted in Fig. 4, Suki in order to sleep, wants only auditory interaction with his TV set (listen to music) and low brightness level in the environment. This query retrieves information from Suki's profile ontology only. Similar queries can be posed to this ontology, in order to retrieve Suki's personal information, preferences and current context. However, this information is not associated with any running activity sphere, therefore it cannot be directly usable. In the example of Fig. 4, we can find out that Suki, when trying to sleep, generally prefers low levels of brightness, but we cannot know the real devices that should be adjusted to achieve this. To extract this information, we have to combine Suki's user profile ontology with the local ontologies of the devices of the ambient ecology Suki is situated in. This can be done by aligning these ontologies, as we shall explain in the following section.

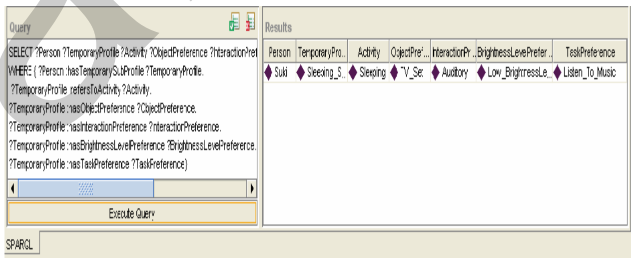

Fig. 4. Example of application and result in SparQL tool

## V. Ontology Alignment

In this section we will briefly discuss ontology alignment and its importance in the activity sphere adaptation. As a result of the alignment process. interoperability between different ontologies is achieved. In this case the aim is to combine all (possibly heterogeneous in terms and structure) sources of knowledge within each activity sphere. An alignment is defined as a set of correspondences between entities (classes, properties, individuals) of the ontologies. The alignment process can take place using a number of predefined algorithms and also different parameters (e.g. use of a threshold in order to get more accurate correspondences), depending each time on the development needs.

In the scenario we are examining in this paper, the "Sleeping" activity sphere is instantiated in Suki's home. For the sphere to operate properly, Suki's user profile ontology has to be aligned with the ontologies of the TV set and any heating device or lamp in the room; these devices participate in the activity sphere (you can refer to Fig. 5 and Fig. 6 for fragments of resource ontologies). Firstly, the SM of the "Sleeping" activity sphere "discovers" all ambient ecology devices that provide the services mentioned in the sphere workflow, that is, light, heating and TV programme. Then, the sphere OM aligns their local ontologies with Suki's profile ontology (we suppose that the OM can access the resources local ontologies). After the alignment, the activity sphere manager will be able to bind the sphere workflow to the real devices available in the ambient ecology and use their services to adjust the TV set, the room lamp and the air-condition according to Suki's preferences, as they are defined in his profile.

Another kind of adaptation must be realized when the "Sleeping" activity sphere has to be instantiated in the hotel, the night that Suki has to spend away from home. Let's suppose that in Suki's room in his home there is a floor lamp and in the hotel room a wall-mounted lamp. In this case the binding of the activity sphere workflow to actual devices changes and thus the ontologies to be aligned are different.

We shall now demonstrate how the above scenario can be realized using ATRACO technology. In Fig. 5 we can see a fragment of the floor-lamp ontology, while in Fig. 6 a fragment of the wall-mounted lamp ontology.

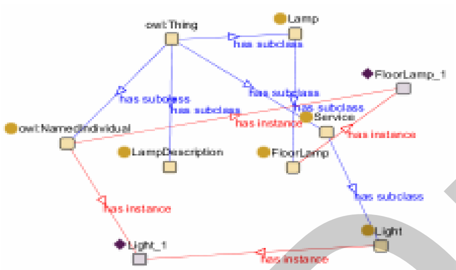


Fig. 5. Fragment of the floor-lamp ontology

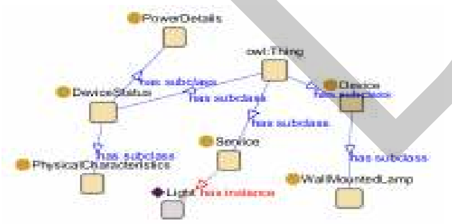


Fig. 6. Fragment of the wall-mounted lamp ontology

While the instantiation of the activity sphere changes, Suki's preferences remain the same in his user profile. For example, in both cases and according to Suki's preferences defined in his *TemporaryProfile:Sleeping_Subprofile*, he prefers *Low_BrightnessLevel*. That means that both editions of the activity sphere should be adapted to his preferences, by aligning each resource ontology with the user profile ontology. As mentioned before, the ontology alignment finds correspondences between two ontologies. Below it is shown the result of the alignment between user profile and floor-lamp ontologies, and user profile and wall-mounted ontologies respectively (Fig. 7 and Fig. 8), using the Alignment API [16]. Each alignment is itself exported as an ontology.

We can see from these alignments that in both cases the property *hasBrightnessLevelPreference* of the user profile ontology is matched with the corresponding properties of the two device ontologies (*hasBrightness* and *Brightness* respectively). The similarity measure between the alignments is approximately 0.89 for the first case and 0.76 for the second; both are considered "safe". In both cases and despite the fact that there are two different light emitting devices, they both get the information necessary from the user profile ontology, in order to adapt to Suki's preferences regarding the brightness level, which must be set to *Low*.

```
<Cell>
  <entity1 rdf:resource='http://www.owl-ontologies.com/Ontology1.owl#hasBrightness'/>
  <entity2 rdf:resource='http://www.owl-ontologies.com/Ontology2.owl#hasBrightnessLevelPreference'/>
  <relation>=</relation>
  <measure rdf:datatype='http://www.w3.org/2001/XMLSchema#float'>0.8902439024390244</measure>
</Cell>
```

Fig. 7. Alignment between user profile and floor-lamp ontology

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<Cell>
  <entity1 rdf:resource='http://www.owl-ontologies.com/Ontology1.owl#Brightness'/>
  <entity2 rdf:resource='http://www.owl-ontologies.com/Ontology2.owl#hasBrightnessLevelPreference'/>
  <relation>=</relation>
  <measure rdf:datatype='http://www.w3.org/2001/XMLSchema#float'>0.763157894736842</measure>
</Cell>
```

Fig. 8. Alignment between user profile and wall-mounted lamp ontology

However, the alignments must be made accessible to the SM, in order for the sphere to adapt to Suki's preferences. This is possible by matching the user profile ontology, the resources ontologies and the alignments between them. This new ontology model in reality represents a fragment of the activity sphere. This process will be repeated twice, for each version of the activity sphere (Suki's bedroom and hotel room). In order to verify that the activity sphere has been adapted to Suki's preferences according to his profile, a number of queries is applied to the new ontology. First of all we want to know, which device in the sphere is providing light. Below we can see the queries and their results for both versions of the activity sphere.

In the first case of Suki's bedroom edition of the activity sphere the device *Lamp:FloorLamp_1* provides the service *Light_1*. In the case of the hotel room edition of the activity sphere, the device is the *Device:wall_mounted_lamp* that provides *Service:Light*.

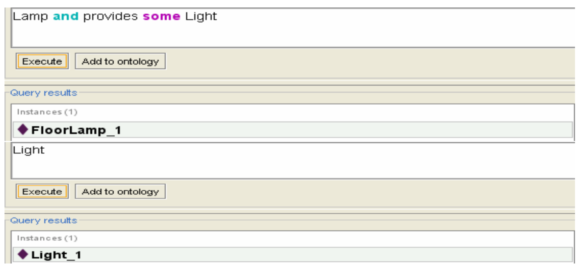


Fig. 9. Application and results with DL Query in Protégé

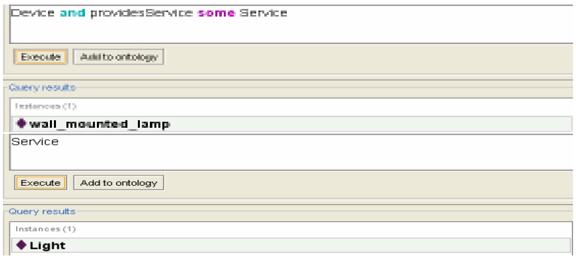


Fig. 10. Application and results with DL Query in Protégé

Next, to check if the above light providing devices are adapted to Suki's preferences, we should check if the brightness of the lighting they provide is set to "*Low"* (according to Suki's preferences).

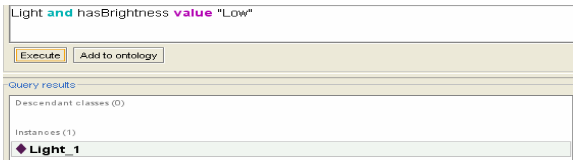


Fig. 11. Application and results with DL Query in Protégé

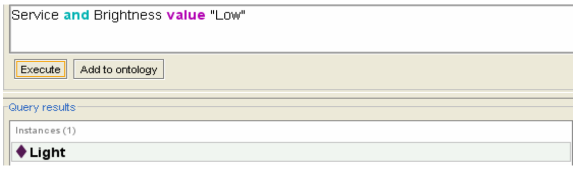


Fig. 12. Application and results with DL Query in Protégé

As expected, both devices have been adapted to Suki's preferences. Actually both properties *hasBrightness* and *Brightness* of the floor-lamp and wall-mounted lamp respectively, have been assigned with the value "*Low*".

However, it is possible that due to the different device specifications, the value "*Low*" for the brightness level to be slightly different in each sphere. In this case, the actual brightness range of values that corresponds to *"Low"* will be recorded in each of the resource ontologies. The SM will access these ontologies and then use the appropriate device service to set the brightness level to the correct value.

## VI. Conclusions and Future Work

In the context of project ATRACO, we have defined distributed implementations of user centered tasks as activity spheres. An activity sphere orchestrates the services of devices available in an ambient ecology. To deal with the heterogeneity of local resources, we claim that each device maintains its own ontology. To achieve user centered operation of activity spheres, we use user profile ontologies.

User profile information should contain not only static user information, such as user name, date of birth, address, etc., but also dynamic user information, such as activity-dependent preferences that depend on contextual information. The proposed user profile ontology comprises both a static and a dynamic part, allowing the specification of generic user traits and specific, activity related, preferences. However, in order for the user profile ontology to be useful in the context of an activity sphere, it is essential for the user profile ontology to be able to align with the other entities ontologies, so that the activity sphere can be adapted to the user's preferences.

Ontology alignment matches common terms and structures in the local ontologies and the use profile ontology. The alignments are themselves exported as ontologies. Then, the entire set of ontologies can be queried to retrieve user related information that can be used to adapt the resource operation according to user preferences for the specific service offered by this resource. Thus, an ontology-based model that allows specifying preferences for an activity in a sub-profile is a feasible solution for modeling a user profile within a dynamic and context-aware environment. We further plan to assess the quality of the proposed user profile ontology by using it in more demanding applications involving multiple activity spheres and users.

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