

A Hybrid and Semantic Location Management System for Mobile User Generated Geo Services

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Abstract The success of mobile location-based services depends considerably on the underlying location determination system. In fact, the localisation of mobile devices can be achieved through a multitude of location detection methods, from GPS to cell triangulation. We present a location management system, which integrates these heterogeneous location capture methods into one consistent, homogeneous, semantic location model. The notion of a *MUGGES Location* integrates physical, symbolic, and semantic features of locations. This ensures a consistent location model in which users can cooperate under sophisticated location-aware restrictions. We resemble the semantics of MUGGES Locations in different ontologies to account for different aspects of location relations. Such ontologies can be used to infer relations about MUGGES Locations and to support filtering and searching of relevant location-based services in a mobile environment. We will evaluate this location model in the MUGGES project, which aims at providing an infrastructure for peer-to-peer mobile user-created micro-services.

BIOGRAPHY

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1 INTRODUCTION

Social networking services such as Facebook, YouTube or MySpace have coined the term “Web 2.0”, where users are not only consumers of information but also producers. This trend is now moving to mobile social services, which offer a more natural way of social interaction – anywhere at any time from the user’s mobile device. Most current mobile devices incorporate Global Navigation Satellite Systems (*GNSS*) technology, such as GPS, making *location-based* mobile social services a very clear current trend of business innovation. This is due to the fact that location is a key context attribute for more optimal service filtering and recommendation in mobile domains [1],[2].

The MUGGES project (*Mobile User Generated Geo Services*) [3], funded by the European Commission’s 7th Framework Programme [4], goes one step further from current mobile location-based services (*LBS*) by providing such location-aware services and their contents *directly* from the user’s mobile device, i.e. the mobile device evolves to be a server. Thus, mobile users turn into location-aware service *super-prosumers*, i.e. *producers, providers, and consumers* of services and associated contents from their mobile devices.

One of the major challenges of MUGGES is the development of a sophisticated location management system – namely, a Hybrid and Semantic Location Management System (*HS-LMS*). It will mainly be based on *GNSS* technology, but complemented with further commonly available location technologies, especially suited for indoor environments. The *HS-LMS* will facilitate an easier provision and better remote discovery of content, and access to the most suitable services for the *prosumers*, directly accessed or provided from their own mobile devices. MUGGES will contribute to the GALILEO [5] objectives by demonstrating that there is a great mass-market potential for mobile social location-based services in Europe and that the technology is mature enough to deliver real benefits to the users.

2 RELATED WORK

A lot of research and a variety of actual products are focusing on the topic of mobile location-based social services. We will limit this section to similar projects.

2.1 MOBILE LOCATION BASED SERVICES

Whirrl [6] is a location-based social application, which lets users share their advices and feedback on pubs, restaurants, and the like, with a designated group of friends. Users can view these advices on a map in addition to their friends' current locations and real-time feeds about their status. This way, users can meet their friends and discover interesting places and activities around them, which they would have missed otherwise. Similar services to *Whirrl* include *Plazes* [7], *Google Latitude* [8], *Loopt* [9] and many more.

The mentioned LBSs are all "final" services in the sense that they do not allow users to create new kinds of services. Users create new content but they cannot create new functionality on top of this service, such as a location-based game built upon existing locations. In MUGGES this will be possible because we designed it as a service platform not as a content provider. Furthermore, the underlying location model in these services is restricted to points, by means of coordinates, or addresses on a map, e.g. via the Google Maps API [10], which, at this point, does not support semantic links between locations.

2.2 SERVICE PLATFORMS FOR MOBILE LBS

The *SPICE* (*Service Platform for Innovative Communication Environment*) project researches, prototypes, and evaluates the architecture and framework for rapid creation and deployment of intelligent and personalized mobile communications and information services, life-cycle management, context-awareness and multi-modality [11].

Similarly, the *m:Ciudad* project combines a service architecture, a set of mobile tools and a platform to allow users to create focused knowledge-based mobile micro-services. These micro-services are created, consumed and provided by users on the go, via their mobile devices.

Both *m:Ciudad* and *SPICE* act as service platforms, thus users can create their own services. However, none of them incorporates a sophisticated location model to enable users to easily create location-aware services and filter services based on location.

2.3 LOCATION MODELS

Becker and Dürr [12] propose the use of hybrid location models for ubiquitous environments. Such location models should incorporate several notions of locations, like geometric coordinates, e.g. WGS84 coordinates, and symbolic coordinates, e.g. a Wi-Fi base station SSID. Jiang and Steenkiste [13] introduce the idea of a virtual location as an abstract notion of different location types.

This facilitates easier querying within a homogeneous location model. Similarly, Li and Cao [14] present a location ontology to enable reasoning about containment relations between locations. The principles of these location models have influenced the *HS-LMS* proposed for the MUGGES project. Section 5 will describe the different location ontologies used within MUGGES to account for different types of location relations.

3 THE MUGGES PROJECT

Before going into detail about the MUGGES project, we would like to explain its application in a short real-world example about one specific MUGGES service, or *mugglet*, how we call these mobile location-aware user-created services. The "GeoTwitter" *mugglet* has been inspired by the Web 2.0 service Twitter [15], where users can publish short messages and follow other users' messages. GeoTwitter enhances these messages by a location attribute. Users of this *mugglet* can read GeoTwitter messages that other users in their vicinity have published.

Bob is visiting Lisbon's most traditional nightspot, Barrio Alto. After wandering around the streets for some time, he decides he may need advice on the best spots. He takes his mobile phone and searches for GeoTwitter on the MUGGES Mugglet Search Engine. Shortly thereafter, his phone is displaying a list of GeoTweets posted around his current location and Bob decides to check out "Maria Caxuxa" on the "Rua da Barroca", where people seem to be having a lot of fun! When he reaches the bar, he tweets a photo of himself showing how much fun he is having. This photo is now accessible by all the GeoTwitter users walking by and maybe attracts them to join Bob at the bar.

This example illustrates the benefits of attaching a location attribute to the messages. First of all, users who are already at the spot have posted messages, making them the up-to-date information about the respective bars. Secondly, the messages Bob sees are located close to his current location and thus are highly relevant for his present situation.

3.1 KEY CONCEPTS OF MUGGES

The MUGGES project will develop basic prosumer-enabling components, both at the mobile- and server-side, and market-ready MUGGES applications, called *mugglets*, to lower the users' barriers to entry and enable widespread adoption. *Mugglets* in the MUGGES platform have the following characteristics:

- **In the "Long Tail":** *Mugglets* are relevant mainly for micro-audiences, in a limited physical area or dealing with very specific types of contents.
- **Mobile:** *Mugglets* are provided and accessed from the mobile phone on the move.
- **User-provided:** Users create the content *and* can create new types of services (based on templates).
- **Social:** Users interact with each other using *mugglets*

- **Peer-to-peer:** Mugglets are shared directly from one mobile device to another, i.e. users have full control over their provided mugglets.
- **Instantaneous:** Mugglets are instantly available but only valid for a limited period of time and thus contain up-to-date information.
- **Personalised:** Users can get recommendations on mugglets that might be interesting to them according to their profiles.
- **Location-based:** Mugglets are always connected to a location, e.g. the provider's current location or a specified static location.

The MUGGES project's roots lie in the previously mentioned m:Ciudad project [16]. Both, m:Ciudad and MUGGES, share the idea to build a platform that allows users of mobile devices to create focused, knowledge-based, mobile micro-services on the go. There is no central service provider, only the service infrastructure, which facilitates connections between producers and consumers. However, a central server offers search capabilities and service templates to alleviate the creation, provision and discovery of user-created services (see the "prosumer triangle" in Figure 1).



Figure 1: The prosumer triangle

MUGGES enriches the idea of user-generated services by adding a semantic location attribute to these micro-services, which will allow for an easier access to the most suitable services for the users.

3.2 MUGGES ARCHITECTURE

Firstly, the MUGGES system consists of a server-side part, which in a real-world setting would be connected to the mobile operator's infrastructure. This MUGGES Server is composed of different software components, each of which has specific responsibilities according to the MUGGES system's functionality as we have envisioned it (see Figure 2):

- **Accounting Server:** It keeps an association between users and mugglets to enable billing scenarios (service fees). Moreover, it collects usage logs issued

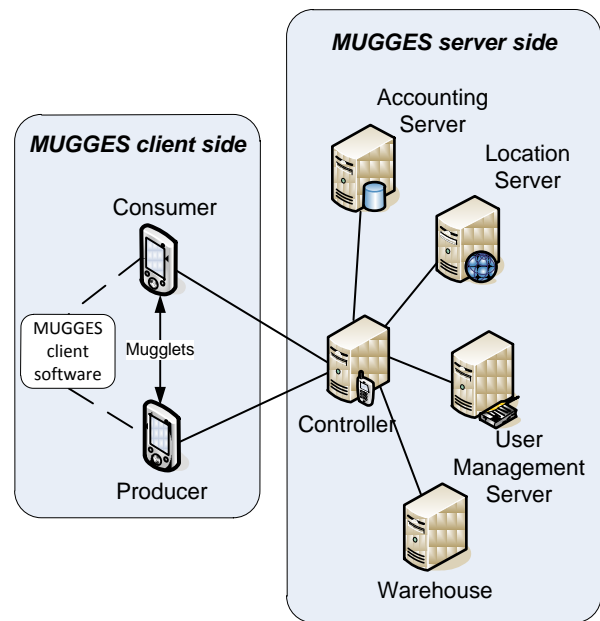


Figure 2: MUGGES architecture

by consumer and provider devices, so that statistics and data processing on usage may be carried out.

- **Location Server:** This is where the *HS-LMS* is located. It is designed to be able to cope with data provided from heterogeneous location sources such as GPS (and eventually Galileo), RFID, 2-D barcodes, Wi-Fi base station or Cell IDs, or even free location description text. Having alternative descriptions for a given location ensures that different users and mugglets can cooperate under sophisticated location-aware restrictions.
- **User Management Server:** It manages the users' profiles and their connections to the platform, e.g. the user's current location, a list of user specific keywords of interest, group management, and references to the mugglets consumed or provided by a given user's mobile device.
- **Warehouse:** This component manages information regarding mugglets, i.e. their types (template repository) and currently available instances. It allows providers to download and then instantiate mugglet templates. It tracks all the mugglet instances in the system, so they can be found by the users.
- **Controller:** A common gateway for the client side to access the server functionality.

For the prosumers' mobile devices we have developed a client-side software. It makes the mugglets accessible to the users via a graphical user interface and facilitates connections between different users via the server-side. Moreover, it is responsible for extracting location related information from the mobile device, e.g. access the GPS receiver or the cell-id information and send it to the server-side, which determines the user's location.

4 A HYBRID LOCATION MANAGEMENT SYSTEM

As mentioned before, to show users the mugglets that fit their current situation best, we need a versatile location model. Let us consider the following scenario:

Maria, a student at the University of Deusto in San Sebastian, is lining up at the cafeteria to get some food. Maria is still undecided what to eat, so she checks on her mobile phone if other students have already recommended any particular meal. She uses the GeoTwitter mugglet and immediately dozens of messages pop onto her display. The MUGGES automatic localisation system has determined her current location to be "University of Deusto, Campus of San Sebastian", which brings up all the GeoTwitter mugglets from the university. Maria could filter the messages by keywords like "cafeteria" or "food", but she finds it more convenient to simply use one of the 2D-barcodes attached to the cafeteria's walls. After taking a picture of one of the 2-D codes the MUGGES system knows that she is located in the cafeteria, and filters the mugglets accordingly. Now, there are seven GeoTwitter messages left, five of them recommending "Bacalao al Pil-Pil". This convinces Maria to take the recommended plate.

This scenario shows some important features, but also challenges that the MUGGES system has to face. First of all, indoor location, so far, does not work perfectly. Without GNSS information, the MUGGES localisation system determined Maria's position using alternative techniques, like Wi-Fi base station IDs or the operator's Cell-ID information, resulting in the very coarse location "University of Deusto, San Sebastian campus". The mapping of such information to actual locations will be very coarse, unless the wireless infrastructure has been analysed beforehand, e.g. through "wardriving" of interesting zones. This is usually a tedious task and cannot be done for every location. A fallback solution can always be narrowing down the results using filtering by tags, keywords, mugglet-types, etc. Another approach showcased in the example is the use of 2D barcodes or image tags. Of course, locations have to be prepared beforehand as with the wireless infrastructure by placing these codes into the relevant locations. Yet, they offer two advantages: They are cheap and easily generated (e.g. [17]) and such codes link unambiguously to a specific location.

4.1 TYPES OF LOCATION

To design a sophisticated, versatile location model it is necessary to incorporate different aspects of location [12]. We will distinguish the following three different types of locations:

- **Physical:** A point in a reference system (might be accompanied by a geometric bounding shape). In geographic systems this is typically expressed through coordinates in latitude, longitude and altitude, e.g. in the World Geodetic System [18] used by GPS receivers. The city of Bilbao is located at

latitude: 43°15'25", longitude: -2°55'24", altitude: 19.

- **Symbolic:** A human-readable and understandable textual description of a location, e.g. "University of Deusto, Bilbao" or "United Kingdom".
- **Semantic:** A machine-understandable location expression upon which location-related inferences can be undertaken, e.g. University of Deusto, Bilbao lies in the city of Bilbao, which is located in the province of Biscay, which is located in the Basque Country and so on.

All of these different location types play an important role in the MUGGES platform. To the user the most comprehensible location type would certainly be the symbolic one, whereas to show the location on a map, we usually need the location's coordinates. To enable sophisticated location search capabilities, we need semantic links between the locations to reason about their relationships [14],[13].

Conventionally, only one of those facets will be specified while searching locations or reasoning about locations relationships. It is the *HS-LMS*'s duty to translate, among the different manifestations of location specifications to enable the requested location-related tasks.

4.2 MUGGES LOCATION

Taking into account the "hybrid" nature of locations in MUGGES we have introduced (similar to [13],[19]) the concept of a virtual location, namely *MUGGES Location (ML)*, which is an aggregate of the three previously mentioned location facets (physical, symbolic, semantic) into one notion. Thus, the *MUGGES Location* relative to Bilbao would contain information about its physical location (latitude, longitude, altitude), its symbolic description ("Bilbao, Spain") and links to other *MUGGES Locations* (the city of Bilbao is child of the province of Biscay). This information will not always be complete, e.g. a *ML* might lack semantic links to other *MLs* or its coordinates may be unknown. One of the main tasks of the *HS-LMS* is to create, maintain and constantly update a coherent location model. For this, it will seek help from external location mapping or modelling services such as GeoNames [20], Google Maps [21] and the like. Besides, it will identify the equivalence of close locations specified by different users by means of different location facets.

Moreover, the *HS-LMS* hides the underlying technology used to determine the user's location. This may be anything from a GNSS receiver's coordinates, the phone's Cell-ID, the surrounding Wi-Fi base stations, RFID readers, 2D barcodes to plain text. It is the *HS-LMS*'s responsibility to identify the correct *ML* based on one or a combination of these location information pieces. If the Location Management System does not find such a *ML* in its database, it registers a new *ML*.

Figure 3 shows the Location Management System in the MUGGES system, integrated into the prosumer triangle already shown in Figure 1. In the example, the provider's

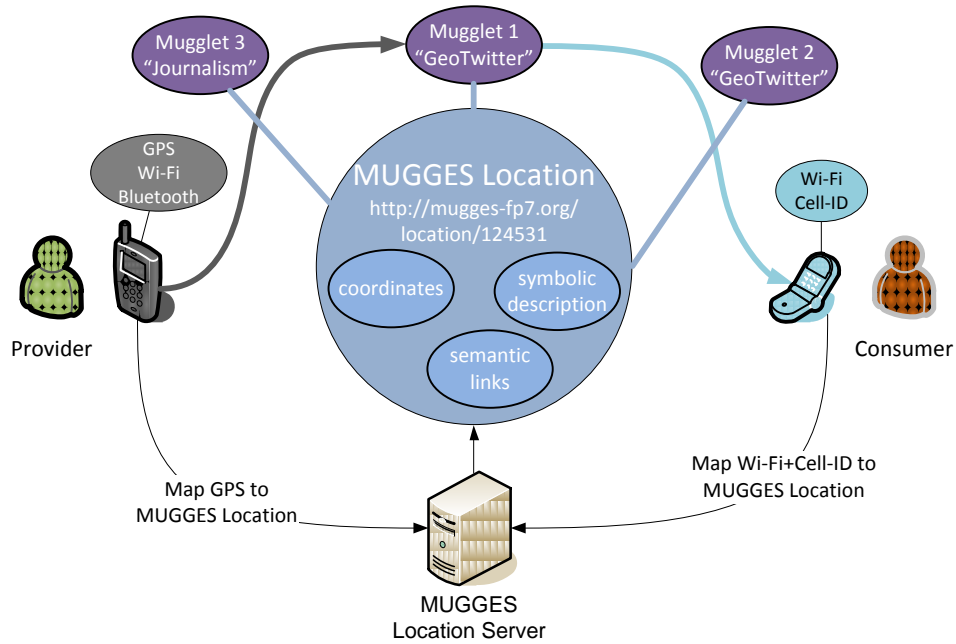


Figure 3: Location Management System in MUGGES

mobile device has access to GPS, Wi-Fi and Bluetooth, whereas the consumer’s mobile device only features Wi-Fi capabilities (like Maria, when she is in the cafeteria). To determine the current *ML*, the MUGGES client software on the mobile reads the available information and sends it to the MUGGES Location Server. The location server will try to determine the appropriate *ML*. The provider can then publish a mugglet connected to this *ML*, e.g. the *ML* with the symbolic description “Guggenheim Museum, Bilbao”. The consumer in Figure 3 does not have GPS capabilities. Due to the lower accuracy of determining the location via Wi-Fi or cell-tower triangulation, the Location Server might return the *ML* with symbolic description “Central Bilbao”. Because the *ML* “Guggenheim Museum, Bilbao” is semantically connected as child to the *ML* “Central Bilbao”, the provider’s mugglet would also show up on the consumer’s mobile device. The coarser *ML* “Central Bilbao” might be associated to many connected mugglets making it more difficult to spot relevant mugglets. As we have already mentioned, further mugglet filtering can be achieved in several ways, by using keyword filters, manually selecting a different location, or using 2D barcodes (if present).

5 LOCATION ONTOLOGY

We will make use of ontologies to resemble the mentioned real-world semantic connections between locations. Let us continue with Maria’s scenario:

While Maria is having her delicious meal, she is interested in news about the university. She chooses the “On-the-spot Journalism” mugglet only to find out that there is no news available in the cafeteria. Therefore, she changes her location manually by selecting a location one level higher, to “University of Deusto, Campus of San Sebastian”. As she is also interested in news about

the campus of Bilbao, she chooses the location “University of Deusto”, which includes both campuses. After filtering the mugglets by the keyword “talk”, she finds out, that the talk she wanted to attend the next day in Bilbao was cancelled. Maria is glad that she found out about it before buying the bus ticket.

To undertake reasoning about location relations like the connection between the two University of Deusto campus sites, locations need to be semantically interlinked. The web service “GeoNames” [20] provides a geographic ontology about millions of places in the world, and contains location relations such as parent-child, sibling or neighbour. We have taken such an ontology as an example to design our own *ML*-ontology.

5.1 ONTOLOGY DESIGN

In the example, Maria is interested in news from the University of Deusto at both campuses, which are located approximately 100km apart from each other. Hence, within the MUGGES *HS-LMS* we will not only make use of one single location ontology (as e.g. in [14]) but of several ontologies, which account for different kinds of location relations, e.g. geographic, political or administrative, as showed in Figure 4. For the time being, we restrict MUGGES to these three ontologies but plan to incorporate other semantic vocabularies. For example, a tourist ontology could connect a city’s interesting places into one *ML* “Places to visit” and dangerous places into the *ML* “Dangerous suburbs”, etc. The meanings of the ontologies we use in MUGGES are:

- **Geographic:** Geographic relations, e.g. “Campus of Bilbao” is contained in “Deusto” (a suburb of Bilbao).

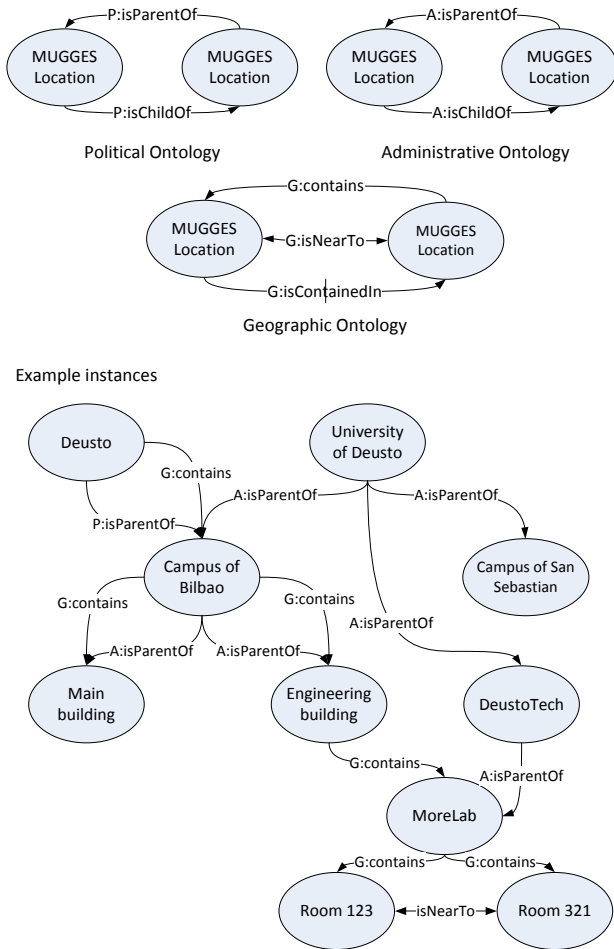


Figure 4: Ontologies used in MUGGES

- **Political:** Political entities, such as Spain, France, Germany, and the EU (which is the parent of all of the former countries).
- **Administrative:** Relations between administrative, not necessarily physical, entities, e.g. the Spanish Science and Technology Foundation FECYT, which consists of different departments distributed all over Spain.

The example ontology instances in Figure 4 illustrate advantages of incorporating several types of ontologies into the semantic location model. We can directly see from the graph that “Engineering building” is both geographically located on the “Campus of Bilbao” and administered by the latter. Furthermore, through ontology reasoning we can infer that the “Campus of Bilbao”

- is located in “Deusto” (a district of Bilbao), using the Geographic ontology (G)
- belongs to the administrative entity “University of Deusto”, using the Administrative ontology (A)
- contains the “Engineering building” (G and A)
- contains the “MoreLab” department (G), as inferred from c) (the G :contains property is transitive)
- is *not* administering the MoreLab department, because it is connected (A) to the “DeustoTech” branch of the “University of Deusto”

The difference between P and G might not be obvious. To make it clear, let us consider the political entity “European Union” and the geographical entity “Europe”. While Switzerland is definitely located within “Europe” it does not belong to the “European Union”.

Furthermore, there may be MLs without physical location information, i.e. coordinates, because they are unknown. Using an ontology, we can still infer information about their spatial location through reasoning or by explicitly adding spatial relations manually. For example, “Room 123” and “Room 321” are both located in the MoreLab research group’s area (G). As they both share the same parent, we might infer that they are located rather “close” to each other. Nevertheless, the meaning of “closeness” depends on the dimensions of the parent, what “close” means to the individual user, and the user’s current context (e.g. walking, going by car, etc.). For controlled environments where we know the locations of interest, we could insert this relation manually, via the “isNearTo” relation (G), without the need of the physical location attribute, as is shown in Figure 4. The two rooms “123” and “321” are both located in More Lab’s area, which consists only of one floor; hence, the vast majority of people would consider them close to each other, which is reflected by the connection “isNearTo”.

5.2 IMPLEMENTATION

On a large-scale project, it is not feasible to create instances for our ontology one by one, so we will make use of third party location information systems. For now, we have limited our external sources to GeoNames and Google Maps, but we plan to incorporate other sources as well, e.g. Yahoo Maps and OpenStreetMap [22],[23], to generate the best possible location model. As mentioned before, GeoNames offers a geographic location ontology with instance data covering the countries of interest for the MUGGES project (mostly Europe), which we will use to feed our own geographic ontology. We plan to extract semantic location instance data from other sources mapped through RDF scrapping. We will create instance data for areas of focus or special interest for a MUGGES deployment manually, e.g. the University of Deusto. Google Maps on the other hand, does not keep semantic relations between locations, so that in this system, e.g. “University of Deusto” and “Universidad de Deusto” are two different locations. The *HS-LMS*’s focus is to merge the locations of both providers, so that it identifies equivalent locations and inserts them correctly into the ontology. Our simple, yet effective, merging algorithm is based on the idea of different hierarchy levels of locations. These are in detail from lowest to highest: *room*, *spot* (e.g. a building), *street address*, *street name*, *street intersection*, *postcode*, *suburb*, *city* (city of Bilbao), *administration level 1* (e.g. district of Bilbao), *administration level 2* (e.g. Biscay), *administration level 3* (e.g. Basque Country), *country* (e.g. Spain), *continent* (e.g. Europe). We chose this classification scheme to create a common denominator between similar schemes of GeoNames, Google Maps, and Yahoo Maps. This classification is sufficient for the applications envisioned for MUGGES, and more importantly, we can build on

instance data from external services by mapping them to our hierarchy level. Apart from geographic information, the classification also contains political information, like the administration level or the postcode. We can use these locations in both, the geographical and political ontology. The following steps detail the merging algorithm:

1. Get location information from Google and GeoNames; extract physical and symbolic location attributes.
2. Compare list of alternative names returned by GeoNames (which contains names in different languages, such as “Paris”, “Paris“, “Parigi”) with the name returned by Google
3. Search in MUGGES database if a MUGGES Location with this name already exists
4. **IF** there is already a *ML*, **THEN** check if we can extract some piece of information from either of the two location objects which is not yet set in the *ML* e.g. the list of alternative names, but also the unique GeoNames identifier for this location and the Google Name, which is unique
5. **ELSE IF** names are equal **AND** hierarchy level is the same (after mapping to MUGGES hierarchy level) **THEN** store information of GeoNames combined with Google location information into new MUGGES Location
6. **ELSE** store GeoNames and Google location as separate *ML* **IF** Google hierarchy level < GeoNames hierarchy level **THEN** add parent-child link to geographic ontology between *ML* from Google and *ML* from GeoNames
7. Get parent location of GeoNames (via the GeoNames ontology) and check if this already exists as a *ML* (via GeoNames unique identifier)
8. **IF** *ML* exists **THEN** create parent-child link in the geographic ontology between the two *MLs* obtained from GeoNames **ELSE** create new *ML* and link to this newly created *ML*

This way we can benefit from the already existing GeoNames ontology, while at the same time refining the locations with information from the abundant location database of Google Maps. As new *MLs* are created the first time they are needed, the location model grows according to its usage and finally will contain more locations than the GeoNames ontology alone. The algorithm might not link every location correctly, e.g. if the names in step 2 are different, although in reality the locations are equivalent. In this case, there would be two *MLs* of the same real-world location. We intend to involve the users of the system to help and improve the location model collaboratively by selecting two *MLs* as identical, when they encounter them. We may also allow users to introduce missing locations that they would like to use for mugglets through a location specification wizard.

We have implemented a two-fold *ML* database storage. Firstly, the ontologies reside in an ontology model implemented with the Jena Framework [24] and stored in a Postgres database [25]. Additionally, we keep a Postgres database with the physical location part of the

MUGGES Locations, i.e. their coordinates. Apart from the coordinates, these entries contain a link to the respective *ML* instance in the different ontologies, by means of URIs. We keep this separate “copy” outside of the ontologies to take advantage of the Postgres GIS extension, namely PostGIS [26], which enables us to carry out spatial calculation on the data directly in the database. PostGIS allows querying distances between two coordinates, but can also manage geographic shapes and reason about inclusion and overlapping relationships among these shapes. This way, we can speed up distance calculations, which are often needed to show mugglets in the surroundings of the user.

6 EVALUATION AND USER TESTS

Once all the components of the MUGGES architecture are completed, we will carry out a full field trial evaluation of the system and business models brought forward by MUGGES. The field trial comprises two different phases, a pilot phase and a main phase. The pilot trial will focus on technological issues, especially focusing on the location model. We will use results obtained in this trial to refine the *HS-LMS*, the MUGGES infrastructure as a whole, and the mugglets. This will prepare the system for the larger scale main phase. The investigation of the main trial will focus on the identification of social benefits that MUGGES technology can provide for future users.

We will execute the trials in Bilbao (Spain) and Espoo (Finland) from July to November 2010 and we will test a fixed set of mugglets to evaluate the MUGGES infrastructure itself, as well as the benefits of our *HS-LMS* for the users. For the pilot trial, we will choose users that are interested and experienced in technology. These are usually more tolerant to potential MUGGES problems and are more qualified to give feedback for improvement. In contrast, in the second trial phase, where we will evaluate the social potential of the MUGGES system, the primary goal is to emulate realistic user scenarios. Therefore, it is important to achieve sample groups with a broad variety of users regarding their experience with technology.

During the trials, mugglet usage data will be recorded and analysed to identify important usage preferences, behaviour patterns, and community-related aspects. More importantly, this will allow us to identify problems with the location management model on a large-scale test environment. After the trials, we will ask each test user to participate in focus interviews or online surveys to give us their personal feedback about the MUGGES system. These surveys will reveal the real benefits and potential problems of the underlying location model behind the MUGGES infrastructure.

7 CONCLUSION

We have presented the MUGGES project, whose main objective is to design and develop the necessary basic components in order to deploy a set of new innovative social location-aware mobile user-generated services

benefiting from GNSS technology. Accordingly, one of the project's key concepts is "location" posing the need to develop a sophisticated semantic location management system. The focus of this paper has been to show how a sophisticated Hybrid-Semantic Location Management System supports improved personalised search and filtering of services and thus will encourage the use of MUGGES. The proposed hybrid and semantic location management system (*HS-LMS*) autonomously, and transparently to the user, selects the most appropriate location-detection technology to find the best location match to the user's current context, whether indoors or outdoors.

An intelligent handling of location types and aspects is carried out by the MUGGES *HS-LMS* by introducing the MUGGES Location concept, an aggregation of physical, symbolic and semantic location aspects. Notably, we interlink MUGGES Locations semantically through different semantic vocabularies (ontologies), addressing distinct types of location relations, namely, geographically, politically or administrative. This supports the non-trivial reasoning about location relationships and eventually about relationships between MUGGES services, the *mugglets*, which are always connected to MUGGES Locations.

Several tests at the University of Deusto, Bilbao, Spain and the VTT Technical Research Centre of Finland in Espoo will verify how the *HS-LMS* supports users in their quest for personalised location-aware mobile services.

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