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A Framework and a Tool for Semantic Annotation of POIs in OpenStreetMap

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Abstract

Current mobile systems for assisted navigation have limited effectiveness in satisfying user needs. The information content supporting location-based service discovery and path calculation is usually shallow. Semantic-based technologies can allow to overcome these limitations, by exploiting accurate and meaningful descriptions of locations, Points of Interest (POIs), road segments and environmental conditions. We present here a general framework leveraging an enriched cartography, which may be useful not only to enhance travel satisfaction and safety, but also to regulate vehicle efficiency, traffic and environmental impact.
The availability of annotated map data is a crucial requirement to make practically viable such a proposal. Unfortunately, the majority of available systems is developed upon closed and proprietary solutions for both maps and software applications, so third parties cannot extend their functionality. To go beyond this restriction, the framework presented here is based on open standards and tools: in particular, it leverages Semantic Web technologies and crowd-sourced maps available from OpenStreetMap (http://www.openstreetmap.org/), enriching nodes and POIs with semantic annotations to enable innovative Location Based Services (LBSs) for traveling users. Particularly, the paper proposes a general method for storing semantic annotations into OpenStreetMap road nodes and POIs. A user-friendly software tool is also presented for editing annotations through a fully visual user interface, based on simple drag-and-drop operations, implemented as a plugin for the popular open source JOSM OpenStreetMap editor (http://josm.openstreetmap.de/), that will make any OpenStreetMap contributor capable of enriching maps with semantic information. Finally, a semantic-enhanced navigation tool is proposed, capable of exploiting the enriched cartography. Early users' evaluation assesses the effectiveness of such a proposal.

Keywords: Location-based service discovery; semantic matchmaking; navigation systems; OpenStreetMap; map annotation.

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1. Introduction

Road congestion, environmental pollution and fuel consumption are increasingly urgent problems in many urban areas. In the last few years, the application of ICT to the transportation domain has opened promising possibilities to enable smarter traffic management solutions, while also promoting new services for drivers and passengers. This world-wide effort is usually referred to as ITS (Intelligent Transport System) initiative. ITS aims at improving travellers' safety and satisfaction, as well as reducing traffic and transportation times and costs. In the short to medium run, the best that could be reasonably achieved is a combination of (i) automated traffic surveillance and road charging in congested areas with (ii) a set of assistive measures exploiting information and communication technologies within vehicular equipments.

Particularly, assisted navigation systems support drivers in planning trips and during travels: they are up to now one of the most widespread parts of ITS technological effort. Navigation software allows to locate and track a user, to calculate a route toward a given destination and enrich the travelling experience through voice guidance. In latest years, the use of assisted navigation systems for vehicles and pedestrians has been growing significantly, through the adoption of either in-dash, mobile Personal Navigation Devices (PNDs) or smartphones equipped with GPS receiver and integrated sensors. Therefore, many businesses and organizations have emphasized efforts to enhance Location Based Services (LBS) for mobile users (Kansa & Wilde, 2008). Nevertheless, current solutions have a limited effectiveness in satisfying advanced user needs and interests. The information content supporting LBS discovery is usually low. The only search options for Points of Interest (POIs) are name-based or category-based, filtered according to proximity criteria. Such rigid approaches only support exact matches, thus being inherently affected by poor recall with consequent low user satisfaction. Moreover, the user cannot indicate characteristics and properties the destination should have, so that user's personal preferences and collateral requirements are not considered. Finally, often paths are calculated without taking into account factors influencing user travel, such as road congestions, accidents and dangerous routes due to either weather conditions or vehicle state.

Semantic-based technologies can allow to enhance the software-assisted navigation, by exploiting more accurate and meaningful descriptions of locations, POIs, road segments and environmental conditions. The use of annotations endowed with formal machine-understandable meaning can enable more advanced LBS discovery through proper inferences, as well as driver decision support capabilities during trips. The proposed framework exploits enriched cartographic information, but unfortunately the majority of available navigation systems is developed upon closed and proprietary solutions for both maps and pathfinding engines, so third parties cannot extend their functionality. Only open standards and tools can allow to overcome this restriction: in particular, Semantic Web technologies and crowd-sourced maps available from OpenStreetMap (http://www.openstreetmap.org/) have been used here, enriching nodes and POIs with semantic annotations in order to enable innovative LBSs. A prototypical software tool is also presented for editing semantic annotations through a fully visual user interface, based on simple drag-and-drop operations. It is implemented as a plugin for the popular open source JOSM OpenStreetMap editor (http://josm.openstreetmap.de/) that will make any OpenStreetMap contributor capable of enriching maps with semantic information, because no specific knowledge is required about Semantic Web languages and underlying logic-based formalisms.

Finally, a semantic-enhanced navigation tool is proposed as an evolution of the one in (Ruta, Scioscia, Ieva, & Di Sciascio, 2010) and capable of exploiting the enriched OpenStreetMap cartography. It is based on Navit (www.navit-project.org) open source cross-platform software for smartphones and embeds a reasoning engine in order to perform a logic-based matchmaking of POI features against an articulate user profile or request. The proposed system can be considered as a general-purpose LBS discovery facilitator, because several resource domains (cultural heritage, shopping, accommodation, etc.) can be explored by simply selecting a proper reference ontology at startup.

The remaining of the paper is structured as follows: in Section 2, relevant related work about semantic-enhanced map annotation and navigation is briefly surveyed. Next, in Section 3 the proposed framework is described evidencing the three above-mentioned core contributions and in Section 4 a case study is used to clarify main benefits of the proposed approach. Finally, conclusion and future work close the paper.

2. Related work

Significant research and industry efforts are focusing on location- and context-aware service/resource discovery in mobile and ubiquitous computing. Advanced LBS discovery approaches based on classic (rigid) service categorization, such as (Koskela, Järvinen, Liu, & Ylianttila, 2010) for music venues and (Ng & Cheng, 2009) for traffic information and taxi availability, incur low generality of matching frameworks –based on overly specialized and complex ranking functions– and difficult manageability of information as systems evolve. Ontology-based annotations have been considered as an enabling technology for greater interoperability and flexibility (Arabshian, 2010). Nevertheless, the main challenge is to provide paradigms and techniques that are effective and flexible, yet intuitive enough to be of practical interest for a potentially wide user base.

In (Niaraki & Kim, 2009), a route planning framework was introduced, based on an ontology that describes road segments, modeling both user preferences and context. Though remarkable, the approach requires a single ontology to be adopted by everybody. Hence, manageability issues ensue and the solution cannot be extended easily to cover new application requirements.

In (Noppens, Luther, Liebig, Wagner, & Paolucci, 2006), a prototypical mobile client was presented for semantic-based mobile service discovery. An adaptive graph-based representation allowed OWL (Ontology Web Language, http://www.w3.org/TR/owl-ref/) ontology browsing. However, a large screen seems to be required to explore ontologies of moderate complexity with reasonable comfort. Also preference specification required a rather long interaction process, which could be impractical in mobile scenarios. Authors acknowledged these issues and introduced heuristic mechanisms to simplify interaction, *e.g.,*the adoption of default values.

A significant problem in designing advanced location-based services has been the limited availability of cartographic corpuses, since the largest and most detailed map data sources belong to enterprises, requiring expensive license fees. Internet-based collaborative projects have been created in latest years for worldwide map crowd-sourcing (Kansa & Wilde, 2008). The most mature one is OpenStreetMap (OSM). It provides map data in an open, well-documented format under the Creative Commons Attribution-ShareAlike 2.0 license, granting anyone the permission to use, copy, share and modify them.

An open framework is presented in (Auer, Lehmann, & Hellmann, 2009), allowing the transformation and publication of OpenStreetMap data into an Open Linked Data (Bizer, Heath, & Berners-Lee, 2009) repository in RDF (Resource Description Framework, www.w3.org/TR/rdf-primer/). A public endpoint on the Web allows users to submit queries in SPARQL RDF query language (www.w3.org/TR/rdf-sparql-query/), in order to retrieve geo-data of a given region, optionally filtered by property values. Authors also presented a mapping methodology to link geo-data to DBpedia (dbpedia.org), a large repository of information extracted from Wikipedia.

Nevertheless, developed facilities currently cannot support advanced LBSs such as semantic matchmaking for POI discovery. (Van Aart, Wielinga, & Van Hage, 2010) presented a mobile application for location-aware semantic search. An augmented reality client for iPhone sends GPS position and route to a server and receives an RDF dataset relevant to locations and objects in the direction of the user. The proposed framework integrates Linked Data sources with several cultural heritage collections. The applicability of the approach is limited by the availability of pre-existing RDF datasets, since the problem of creating and maintaining them was not considered. Our previous research efforts for Internet-based mobile semantic POI discovery (Ruta, Scioscia, Di Sciascio, & Piscitelli, 2010) were affected by similar issues. This prompted us to leverage open map data formats and crowd-sourcing.

(Becker & Bizer, 2009) developed a mobile application, which allows user to search for resources located nearby, by means of information extraction from DBpedia and other datasets. The system also enables users to publish pictures and reviews that further enrich POIs. The user may filter the map for resources that match specific constraints or a SPARQL query. However, in the first case approximated matches are not allowed; a resource is found if and only if all constraints are satisfied. In the second case, SPARQL query builder requires the user to know language fundamentals. The approach presented here aims at avoiding both restrictions.

3. Framework

The proposed open framework aims to by-pass closed source LBS constraints through the following strategies:

- Standard Semantic Web languages are exploited to create and share geographic resource annotations, expressed w.r.t. ontologies providing the conceptual vocabulary and enabling automated inferences.
- OpenStreetMap is selected as cartography provider.
- Two well-known cross-platform open source software tools: (i) JOSM, a desktop OSM map editor; Navit, a mobile navigation tool, are selected and extended with novel semantic-based features.

The overall architecture is depicted in Figure 1; a general method and a tool are presented here for a collaborative crowd-sourced enrichment of OSM basic cartography. Enhanced maps can be so downloaded into the navigation system described hereafter, which enables a discovery of POIs via a logic-based matchmaking. It is supported by an exploratory search GUI for request composition, results examination and query refinement. Each component is discussed in greater detail in what follows.

3.1. Map Enhancement

OpenStreetMap data are exported and edited in XML format adhering to a quite simple schema. It includes three basic elements: (i) *nodes*, representing single geospatial points; (ii) *ways*, intended as ordered sequences of nodes; (iii) *relations*, grouping multiple nodes and/or ways. In addition to a unique identification code, coordinates and versioning information, each element can include general-purpose informative tags. A tag is a key-value pair of Unicode strings of up to 255 characters. Users can create new tag types without restriction (albeit following OSM community guidelines is highly recommended) to accommodate previously unforeseen map usages. The proposed enhancement of the OSM cartography introduces semantic annotations in a POI description in a way that best fits OSM storage infrastructure. Similarly, mobile computing limitations must be taken into account, and particularly the size of map data to be transferred from OSM server to PDAs should be minimized.

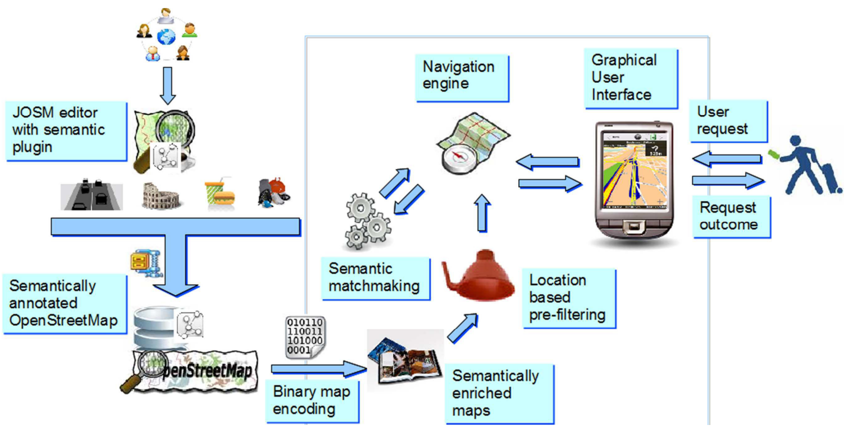

Fig. 1. Framework architecture

In order to store semantic annotations within map elements, some novel tags have been introduced complying the structure: *<tag k="semantic:n:key" v="value" />*

The *semantic* prefix is used to distinguish semantic annotations from other tags. The index *n* identifies different annotations –possibly referring to different ontologies– associated to the same map node. *Key* name suffix and *value* format differ for each proposed tag type, as in what follows:

- *<tag k="semantic:n:ontology" v="URI" />* denotes the ontology the node annotation refers to. All the ontology languages supported by W3C (World Wide Web Consortium) for the Semantic Web are supported, *e.g.,* standard RDFS (RDF Schema, www.w3.org/TR/rdf-schema/) or OWL. Accordingly, annotations can be expressed in RDF and OWL. The tag value is the unique ontology URI (Uniform Resource Identifier), as recommended by W3C specifications, which usually consists of a URL (Uniform Resource Locator) where the ontology can be retrieved.
- *<tag k="semantic:n:encoding" v="format" />* specifies the compression format used to encode the semantic annotation. Compression techniques are needed in order to cope with the well-known verbosity of XML-based ontological languages such as RDF and OWL. The tag value denotes one of possible sets of encoding formats, including *e.g.,* the *EXI* W3C standard (Efficient XML Interchange, http://www.w3.org/XML/EXI/) or experimental algorithms such as *DIGcompressor* and *COX* (Scioscia & Ruta, 2009).
- *<tag k="semantic:n:counter" v="data" />* tags contain the *Base64* string representation of the compressed semantic annotation. If its length is $L \leq 255$ characters, a single tag is used, else it is split in 255-character segments and each one is stored in a tag. The *counter* suffix is assigned as a segment index, starting from 1.

Though this paper focuses on enriching POIs with semantic-based annotations, the proposed method is open and general-purpose. Leveraging the OSM collaborative approach, annotations can be defined for any map element type (road segments, urban areas, archaeological sites, land features, and so on). Users can refer to already published ontologies in the (Semantic) Web, but also new ontologies could be defined to meet specific requirements of applications or interest groups/communities, using given editors as Protégé (Noy, et al., 2005).

3.2. Semantic-based map editor

A prototypical software tool has been designed and implemented for editing semantic annotations, through a fully visual user interface based on simple drag-and-drop operations. The choice to extend the open source JOSM (Java OpenStreetMap editor) application derives from several reasons: (i) it is the most widely used and supported OSM editor; (ii) it is cross-platform, being written in Java; (iii) it offers a plugin mechanism to extend core functionalities. Thanks to an easily understandable GUI, the proposed tool can make any OpenStreetMap contributor capable of enriching maps, because no specific knowledge of Semantic Web languages and underlying logic-based formalisms is required. A screenshot of the actual prototype GUI is shown in Figure 2.

The tool exploitation experience consists of an extension of the typical map annotation workflow with JOSM:

1. The user selects a geographic area of interest to be downloaded from OSM server, then selects the element she wants to annotate (POI, street, urban area, etc.) on the map.
2. The plugin loads the semantic annotation(s) of the selected map element, if present. The annotation content is shown in the lower portion of the plugin area. An intuitive tree-like graphical representation is provided, typical of ontology editors (Noy, et al., 2005). Meanwhile, the ontology referenced by the annotation is loaded and its elements are displayed in the upper part of the GUI: (i) *classes* a.k.a. *concepts*, denoting kinds of objects in the application domain (*e.g., Museum, Painting* for a cultural heritage ontology); (ii) *object properties* a.k.a. *roles*, denoting relationships between pairs of objects (*e.g., hasStyle* could link a work of art to its reference artistic style); (iii) *data type properties* a.k.a. *features on concrete domains*, associating objects to data-oriented attributes (numbers, strings, dates and so on, *e.g.,* the creation year of a work of art or the opening hours of a venue). User can edit the annotation through drag-and-drop of classes and properties of the associated ontology: context menus appear whenever additional information should be specified.

3. If the selected map point lacks annotations, or none satisfies the user's needs, then she can add a new one. She selects the ontology that suits the domain better (*e.g.,* cultural heritage, shopping, road safety). Like in the previous case, the user can compose the annotation by simply selecting properties and classes from UI panels.

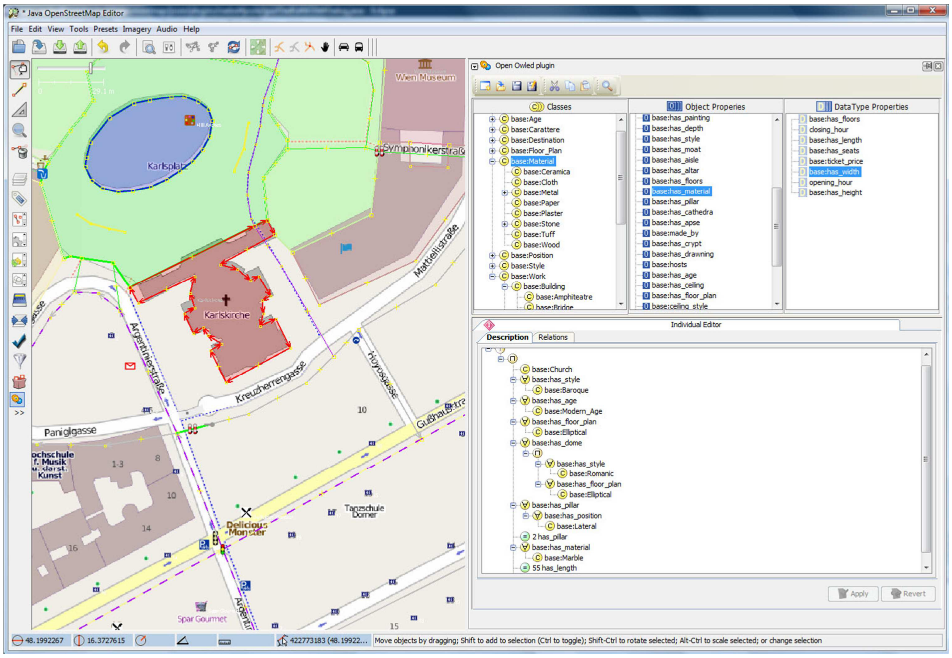

Fig. 2. JOSM ontology-based plugin

4. After user saves changes, the application embeds the annotation into OSM data, by storing the tags described in Section 3.1. Finally, the enriched map can be submitted to the OSM server through usual JOSM functions.

3.3. Semantic-enhanced mobile navigation

In order to allow users to exploit enriched maps, a mobile navigation tool has been developed, which introduces novel advanced functionalities for semantic-based resource discovery. It is an extension of *Navit* cross-platform navigation software for smartphones, released under the GPL General Public License. In (Ruta, Scioscia, Ieva, & Di Sciascio, 2010) there was a first basic implementation. Here a newer version is presented, with more user-friendly interface and better performance.

User can access all functionalities in a quick and straightforward way. Particularly, requests can be composed using list-based GUI forms, which are familiar to most mobile phone users. Navit navigation engine already supports OSM maps; in particular, it uses a compact binary encoding of XML map data, defined by the OSM project. The engine has been extended to exploit semantic-enhanced maps. A mobile matchmaker using non-standard reasoning services was integrated in the system. It has been adapted to mobile LBS discovery by using a utility function to combine the partial scores obtained from semantic matchmaking and geographic distance calculation.

The *Semantic matchmaking* can be defined as the process of finding the best matches among several resources (points of interest, in our reference scenario) with respect to a given request, where both request and resources are annotated w.r.t. a common reference ontology (Colucci, et al., 2007). Standard reasoning services for matchmaking include *Subsumption* and *Satisfiability*. Given a request *R* and an available resource *S*, *Subsumption* checks whether all features in *R* are included in *S*: its outcome is either "full match" or not. *Satisfiability* verifies whether any constraint in *R* contradicts some specification in *S*, hence it divides resources in "compatible" and "incompatible" ones w.r.t. a request. This approach usually gives poor results, because full matches seldom occur and incompatibility is frequent when matching articulate descriptions. Using standard inferences it is impossible to detect *what* constraints caused incompatibility (or missed full match), nor *how much* they are truly important for the user.

In order to give more implicit information to the user, the non-standard inference services *Concept Abduction* and *Concept Contraction*, originally formalized and applied in e-commerce scenarios (Colucci, et al., 2007), can be adapted and exploited. In case *R* and *S* are not compatible, Contraction detects what part *G* of *R* contradicts *S* (and should be given up, *i.e.,* retracted from *R*, in order to achieve compatibility) and what part can be kept. Therefore Contraction provides an extension and an explanation of (un)satisfiability. If *R* and *S* are compatible, but *S* does not fully satisfy *R*, Abduction identifies what is missing in *S* in order to reach a full match. In other words, Abduction provides an explanation for (missed) subsumption, returning what additional feature set *H* should be hypothesized in *S*.

Furthermore, *penalty functions* can be associated to *G* and *H*, in order to compute a semantic distance score of each available resource w.r.t. a given request (Colucci, et al., 2007). In Abduction, penalty grows accordingly to the number (and type) of elements in *H*; in Contraction, penalty grows accordingly to the "size" of *G*. Finally, the *Bonus* service returns features that are present in *S* but were not requested in *R* (Colucci, et al., 2007). In the system presented here, this knowledge is proposed to the user in order to refine her initial query, since it may provide features she was unaware of but is interested in. In the next section, it will be explained in depth how the system works in a practical case study.

4. Case study

A toy example in the cultural heritage tourism sector is reported with the aim to show the benefits of the proposed framework. For the sake of readability, ontology constraints and concept expressions (for both request and POIs) are summarized in textual form.

Semantic-enhanced POI search. *James is a tourist visiting Vienna for the first time. He knows little about the city, but he loves art and he would like to discover interesting cultural attractions.* So he runs the prototype tool and builds his profile via the setup wizard, selecting cultural heritage among his interests. Then a customized subset of OSM city map is downloaded on the smartphone local memory. The system starts keeping track of user position, by means of available location services, *e.g.,* internal/external GPS antennas or cell-based positioning.

The POI discovery can happen in two different ways. (i) The user explicitly submits his request selecting needed features. Basically he indicates a search category (*e.g.,* Cultural Heritage, Accommodation, Entertainment, Dining), corresponding to a specialized ontology. Then he can browse the ontology to compose the request. (ii) Alternatively, the navigation tool is able to retrieve POIs best matching user interests in a transparent fashion simply referring to the loaded profile.

Request composition. *James decides to search a modern-age church, built in Baroque style. While browsing ontology features, he notices that the kind of floor plan can be specified too, so he tries choosing an elliptical one.* As said, the user can set the request constraints by means of the ontology browser. As shown in Figure 3-a, he can select desired characteristics by navigating through the class hierarchy and property lists, without seeing the underlying Semantic Web language or logic-based formalism. The tool adopts familiar UI patterns, in order to make the interface comfortable. Finally, each built request can be repeatedly reviewed and when it is defined, the user can set a maximum acceptable distance from his current location, as in Figure 3-b.

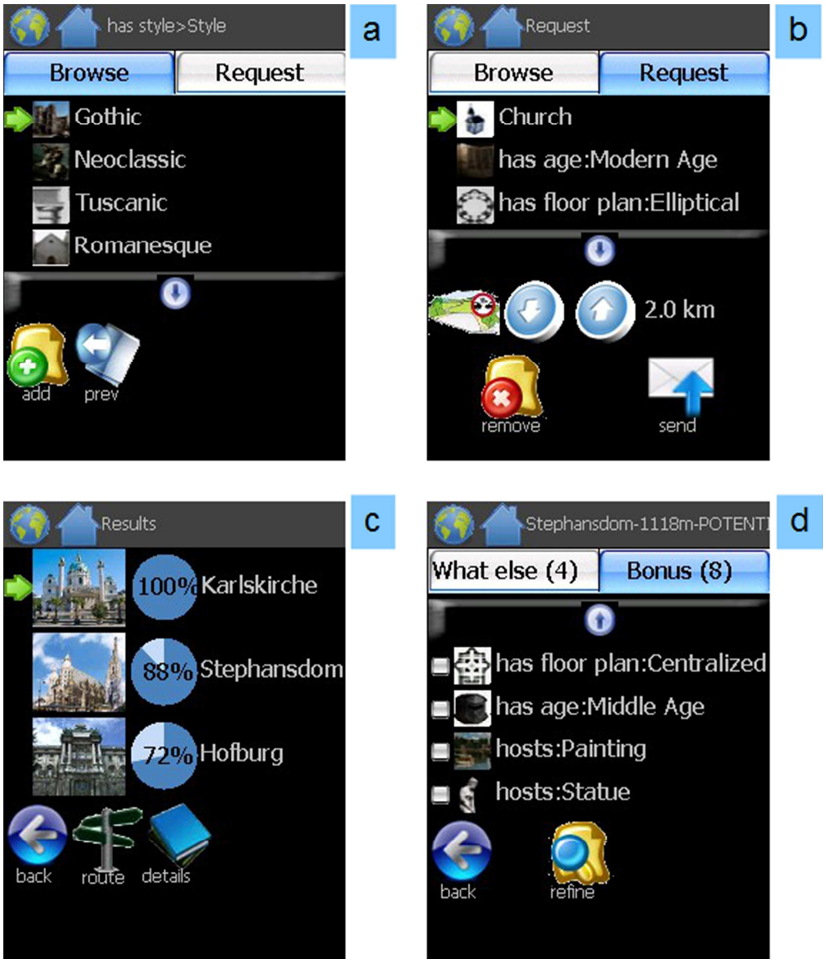

Fig. 3. Semantic-enabled navigation system

Results review. In a pre-processing step, the distance is exploited as a filter to exclude POIs outside the user-specified range.

Let us suppose that there are three POIs in the user's range: *Karlskirche*, *i.e.,* a modern-age Baroque church with an elliptical floor plan and a dome in Romanesque style; *Stephansdom*, described as a middle-age Romanesque and Gothic church, with centralized floor plan and two towers, hosting paintings and sculptures; *Hofburg*, that is as a medieval and modern palace in Renaissance style with Baroque elements.

The embedded reasoning engine applies semantic matchmaking between the request and each POI annotation. The overall resource score is then computed using the utility function:

$$f(R, POI) = 100\left[1 - \frac{s\_match(R,POI)}{s\_match(R,\top)}\left[1 + \frac{distance(User\_GPS,POI\_GPS)}{max\_distance}\right]\right] \quad (1)$$

where *s_match(R,POI)* is the semantic distance between the request *R* and each *POI*; this value is normalized dividing by *s_match(R,⊤), i.e.*, the distance between *R* and the universal concept (a.k.a. *Top* or *Thing*) and depends only on axioms in the ontology. The geographical distance (normalized by user-specified maximum range) is combined as weighting factor.

Results are displayed in Figure 3-c. *Karlskirche* completely satisfies the user request, in fact it matches all required features. Moreover, *Stephansdom* has a quite good score because it has no conflicts w.r.t. the request, since artistic style and floor plan type are not modeled as mutually exclusive in the reference ontology. *Hofburg* has a lower score because it is a palace, hence it is in contrast with the request of a church (according to concept definitions in the ontology); nevertheless, some requested features are satisfied, *e.g.,* age and style.

Query refinement. *James wants to review the search outcomes.* When selecting a resource, the user can see its features, grouped into different panels (Figure 3-d). Particularly, the *What else* panel lists all missing features computed through the Concept Abduction. In the proposed example, if the user selects *Stephansdom*, he can see that unlike the request, it is not a modern age Baroque church. In case of incompatibility, the *Keep* panel lists request properties that are satisfied by the POI, whereas *Give Up* panel lists not compatible elements, *e.g.,* there the user can verify that *Hofburg* is incompatible due to the request of a *church*. Finally, the *Bonus* panel lists the additional features of the selected POI that were present but not asked for, *e.g.,* the presence of paintings and statues in *Stephansdom*.

James can refine his request until he is satisfied. The user can easily add or remove features, by selecting them from *Bonus* or *Give Up* panels respectively, and submit new requests to the embedded matchmaker again.

Finally, James finds something he would like to visit. When the user selects a POI in the results list, the tool computes the path to the destination and displays the route on map, using the Navit engine.

5. Conclusion and Future Work

We presented a framework for semantic and location-based services exploiting enriched maps. In particular, we proposed: a general technique for semantic annotation of crowd-sourced OpenStreetMap cartographic data; an innovative ontology-based map editor; an advanced navigation system, equipped with an embedded mobile matchmaker for semantic-based discovery of points of interest, having significantly greater expressiveness and flexibility w.r.t. search capabilities in current navigation systems. A case study, focused on cultural heritage, provided a small example of benefits of our approach. Due to the possibility of addressing different application domains by simply switching reference ontology, our framework can be useful not only for LBS discovery, but also for the detection of critical road/traffic conditions and for scientific study, *e.g.,* in Earth sciences or economics.

Both feasibility and usefulness are under investigation via user testing and performance analysis. Particularly, the developed tool will be shared with the OpenStreetMap community in order to obtain an authoritative feedback about their usability. In addition, performance measurement, focusing on memory usage and latency time, will help to identify potential bottlenecks.

Further work will aim at extending the framework with a semantic-based driver assistance tool, which detects vehicle condition by means of *OBD-II* On-Board Diagnostics car interface. This will grant more advanced functions, *e.g.,* the driver will be alerted when occurring critical situations during a planned trip. The embedded reasoner will automatically infer risk or inefficiency situations from the semantic characterization of vehicle performance, traffic, road surface and environment. Such an information will be shared among driving users, possibly through OSM service and/or VANETs (Vehicle Ad-hoc Networks).

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