T^2.O.M. T.O.M.: Techniques and Technologies for an Ontology-based Mobility Tool with Open Maps

Michele Ruta, Floriano Scioscia, Saverio Ieva, Eugenio Di Sciascio

Politecnico di Bari
via Re David 200, I-70125
Bari, ITALY
m.ruta@poliba.it, f.scioscia@poliba.it, ieva@deemail.poliba.it, disciascio@poliba.it

Abstract. Nowadays, vehicle navigation systems have a limited effectiveness in satisfying user interests and needs. They basically individuate the user's GPS position on a map and calculate a path toward a given destination. This paper presents an innovative semantic-based navigation system, acting as intelligent agent offering an advanced assistance during a road trip. It integrates a mobile matchmaker, which allows a knowledge-oriented path discovery, in order to fully accomplish requirements of a user during her travel. The framework we propose is based on open standards, and particularly it uses crowd-sourced maps available under the *OpenStreetMap* project, where Points Of Interest (POI) of the basic cartography are semantically featured in order to enable novel services supporting a traveling user.

1 Introduction

The continuous growth of vehicular traffic in urban centres causes several problems whose solution is very hard. Road congestions, environmental pollution and uncontrolled expenditure of energetic resources are only some aspects deriving from the actual volume of traffic which is growing faster than roads capacity. This is not a temporary problem: it will continue to be the case, lacking measures to reduce/reorganize car-based people and merchandise movements. Some of most common foreseen strategies envision: the creation of priority lanes, the switch to lower-impact modes including freight to rail and public transport, walking and cycling, "soft" policies to encourage reduced travel by car and land-use patterns for minimizing unnecessary travel. Anyway, in the last few years the use of ICT to transportation domain has open the most promising possibilities to enable an intelligent traffic management also promoting new services for drivers and passengers. Hence, the combined effects of road charging and a supportive set of complementary measures whose effectiveness is based on the use of information and communication technology, is the best that could be reasonably achieved in the short to medium run. The effort to exploit ICT in transportation infrastructures and vehicles equipment refers to the world-wide ITS (Intelligent Transport

System) initiative. ITS aims at improving people safety and at reducing traffic, transportation times and fuel consumption.

Particularly, assisted navigation systems support drivers in trips planning and during travels: they are up to now one of the most widespread part of ITS technological effort. Navigation softwares allow to locate and track a user, to calculate a route toward a given destination and voice guidance enrich the navigation experience. Nevertheless current GPS navigators present several limits. First of all they calculate a path by using minimum distance criteria without taking into account factors influencing user travel such as road congestions, accidents, dangerous routes due to either weather conditions and vehicle state. Furthermore, the informative content supporting map navigation is currently very low as the only advanced search option they enable is based on POI (Point Of Interest). Unfortunately a POI can be identified and selected by a user only after a category-based search filtered according to proximity criteria. It is practically unfeasible to indicate to the system characteristics and properties the destination should have to take into account user needs and collateral requirements conditioning path calculation.

The paper proposes an innovative framework to enhance functionalities of navigation systems for better assisting users in their trips and it envisions a generic approach to retrieve and provide information useful to regulate vehicular traffic and to enhance travel security. Borrowing from the Semantic Web initiative [3] we propose a knowledge-based system whose final goal is to provide a navigation based on semantics of both user's needs and profile and on context annotation. An open source mobile navigator has been equipped with deductive reasoning capabilities able to leverage semantically enriched crowd-sourced maps available under the *OpenStreetMap* project[1], where Points Of Interest will be semantically annotated in order to enable deductive inferences. We refer to knowledge representation and modeling theoretical studies, we adapt and apply them to ITS field. This open new interesting possibilities, including: formalization of vehicles, context and actors annotations that become machine understandable so enabling interoperability; reasoning on descriptions and inference of new knowledge; Open World Assumption (OWA) by-passing structured data models. By means of formal ontologies, expressed using Description Logics (DLs) formalisms [1] and particularly OWL[2], knowledge about transportation and travel domain can be modeled and exploited in order to derive new information from the one stated within metadata associated to POIs and user profiles. Once the request has been formalized w.r.t. the reference ontology, its formal relations are exploited in order to arrange the navigation for satisfying user requirements and to take into account roads conditions, weather and traffic. Based on the formal semantics of such descriptions, an explanation of the matchmaking outcome is then provided to the user to foster further interaction. This is accomplished by

[1] OpenStreetMap: http://www.openstreetmap.org/
[2] OWL Web Ontology Language, W3C Recommendation 10 February 2004, http://www.w3.org/TR/owl-features/

using a lightweight version of non-standard inference algorithms, *i.e.*, *Concept Abduction*, *Concept Contraction* and *Bonuses Calculation* [5, 4].

The remaining of the paper is structured as follows: in the next section, current state of the art in ITS and navigation systems is briefly recalled, Section 3 outlines system features and architecture evidencing its peculiarities and in Section 4 a toy case study will explain the proposed approach and the rationale motivating it. Finally conclusion and future work terminate the paper.

2 State of the Art

Current personal navigation systems share the common basic architecture depicted in Figure 1 [7]. The navigation software is responsible for location tracking, route calculation and update toward the current destination, and output to the user through both map visualization and voice guidance. Input comes from the following main sources.

- A *map database* contains geographic and cartographic data, as well as a catalog of *points of interest* (POIs). The database can be either pre-loaded and stored locally in the navigation device (such an approach is currently followed in the majority of solutions), or retrieved in real-time during system usage. Hybrid approaches are also possible. POIs include notable touristic venues and several utility categories.
- The *user* inserts information about destination, either as a street address or by selecting a POI from the catalog.
- *Location and heading sensors* are a key element of real-time navigation devices. In all current commercial solutions, location is determined through satellite-based technologies, such as *GPS* (Global Positioning System). Stand-alone navigation devices and most recent smartphones are equipped with an integrated GPS antenna, while other solutions include connecting an external GPS receiver through wired or wireless (*e.g.*, Bluetooth) technology. Magnetometers are used as heading sensors.
- A *data transceiver*, usually based on cellular network connectivity, is currently exploited by many systems to acquire additional information during navigation. This is mainly the case of smartphone applications, but also several stand-alone device vendors integrate a data module in their high-end products. Downloaded data may include temporary map modifications –due to *e.g.*, road maintenance–, as well as information about traffic, accidents and weather. That allows the navigation software to determine the best route based not only on static road information, but also on dynamic conditions. Vendors generally gather traffic status information from partner entities managing vehicle fleets and/or roadside sensor networks, and also collectively from their own users' devices, via the uplink channel of transceivers.

Recent navigation systems aim to provide value-added features for POIs such as phone numbers –directly usable by smartphones and other telephony-enabled

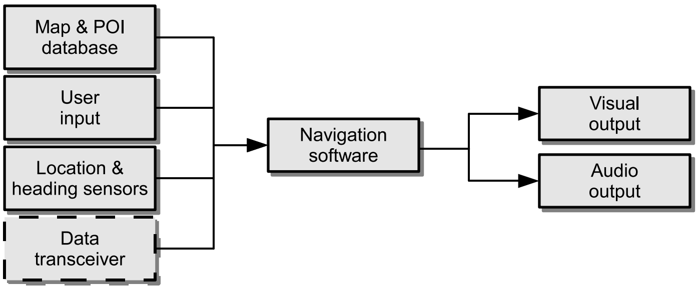

Fig. 1. General architecture of personal navigation systems

navigation devices– and reviews. Nevertheless, significant limitations affect POI management in currently available solutions: they are organized in a rigid and often oversimplified classification and, as such, they allow category-based or keyword-based queries only. This prevents users from performing semantically richer searches, limits the quality of resource retrieval and hinders more advanced use cases, such as personalized suggestions based on user profiles. Studies about the behavior of users of navigation systems highlighted the importance of increasing user familiarity with the surrounding environment through more sophisticated POI tagging, including social and contextual information [8].

Solutions are thus required for a more expressive annotation of POI characteristics. The proposal in the present work supports the above-mentioned features through a robust framework –based on Semantic Web technologies– for resource annotation and discovery, while also tackling practical issues related to the creation, maintenance and storage of world-scale richly annotated POI catalogs.

A fundamental issue is that cartography databases are proprietary, owned and maintained by companies that license them to navigation system manufacturers. File formats and data structures are not open, hence augmenting data is not possible. On the other hand, creating a detailed map database from scratch would require huge resource investments, even for a single municipality; maintenance is also very expensive. Recently, a different approach to map database development was conceived, based on *crowdsourcing*: anyone can contribute to a common worldwide cartography by uploading collected data about road segments and POIs to a website. The most famous and mature project is *OpenStreetMap*: map data are published in an open format under the Creative Commons Attribution-ShareAlike 2.0 license[3], granting anyone the permission to use, copy, share and modify. Contributing a road segment to a map region typically involves the following steps.

[3] Summary and link to full license text are available at http://creativecommons.org/licenses/by-sa/2.0/

1. Record a *GPS trace* while traveling on the road, using *GPS logging* software which periodically records current geographical coordinates. A collection of data points is obtained.
2. Optionally, annotate relevant information about nearby POIs during the trip. This could be done with paper and pencil, but specialized *map collection* software has been recently developed for several mobile platforms, integrating a GPS logger and a user interface dedicated to terrain and landmark annotation.
3. Import collected data into an OpenStreetMap-compatible *map editor*, which transforms sets of raw geographic data points into road segments and allows the user to add road information (such as name, type and speed limit), mark different terrain areas and insert POIs. Finally, collected data are uploaded to OpenStreetMap web servers. After integration into the database, they become visible on the OpenStreetMap website and usable with all compatible software.

A wide range of freely available software tools exists on practically all smartphone and computer platforms, as listed in the OpenStreetMap Wiki[4]. In this work OpenStreetMap is adopted because it proved itself a viable solution for global-scale collaborative cartographic data collection and enrichment, from both legal (licensing) and technical (scalability, interoperability, openness to new features) standpoints.

3 Framework and approach

Main features of the proposed framework are: (i) to follow multi-platform code development rules; (ii) to adopt open source policies in both map data and software components creation; (iii) to enable a semantic-based discovery of POIs enhancing the current trivial category-based search of them filtered by nearness criteria. In the following subsections the overall architecture and the map annotation procedure are reported, respectively.

3.1 System Architecture

The proposed system adopts a so-called *thick client* paradigm: differently from classical client-server model, most of the processing is done on the client side. Rationale motivating this approach is to grant full operation also in case of slow or congested data links. Anyway external interaction is also enabled, via wireless communication protocols, in order to set up further (either client-server or peer-to-peer) services. The overall system architecture is depicted in Figure 2.

The mobile client (a standard PDA or a smartphone), is equipped with the navigation tool proposed here. Its main components are summarized in what follows.

[4] http://wiki.openstreetmap.org/

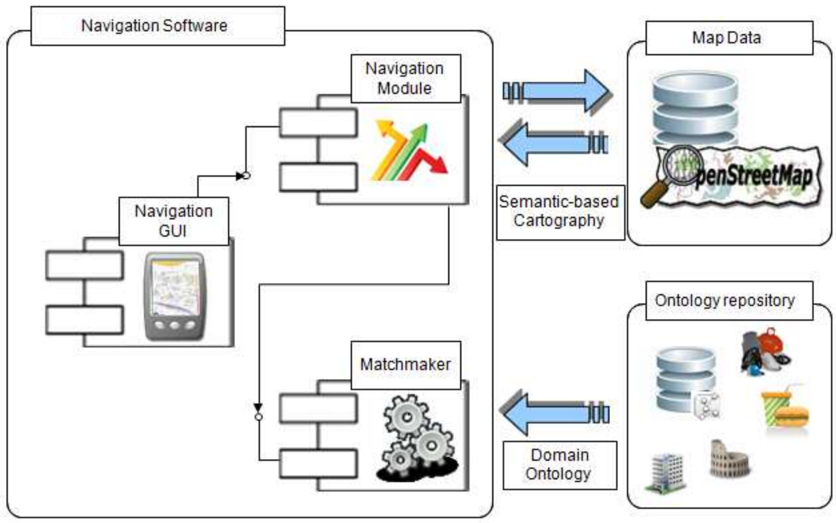

Fig. 2. System Architecture

1. *Graphical User Interface (GUI)*. User can access all functionalities in a quick and straightforward way. Particularly, ontology-based requests addressed to the system can be composed exploiting a graphical toolbar adopting some UI elements familiar to PC users.
2. *Navigation engine module*. User requests are processed by the navigation module, which is the core of the system. It extracts information from installed map files and a map graphical view is rendered through the GUI, using the embedded Scalar Vector Graphics engine. We will give a more detailed description of this component later on.
3. *Map data files*. All map data are locally stored within one or more related files, which encapsulate both geographical data and a semantic annotations of resources. The file structure is described in detail in the next subsection.
4. *Matchmaker*. This component is aimed at processing semantic-based user requests exploiting lightweight *Concept Abduction*, *Concept Contraction* and *Bonuses Calculation* algorithms. They are used by the navigation module to perform an advanced discovery of the best path for a user also providing a detailed explanation of matchmaking results in order to allow user to refine requests in an iterative way.

As far as map navigation module is concerned, we decided to extend the *Navit*[5] software navigation tool which is released as open source project under the GPL General Public License. It provides routes calculation and POI finding (but only via a category-based search and selection). Another noticeable feature is multi-platform portability over several mobile Operating Systems through

[5] http://www.navit-project.org/

available cross compilers. Furthermore, in order to enable semantic-based POI discovery functionalities, the original Navit code has been enriched with novel software components whose features will be explained hereafter when describing operation steps involving the proposed system:

1. User starts navigation tool, selecting the proper application icon on the screen. The navigation module is loaded; it reads a configuration file containing startup information. Among other things, the configuration file also contains an annotated user profile expressed in DIG 2.0 [2] a more compact OWL-DL variant. It specifies personal information like interests and hobbies either user has input in the setup phase or the tool has imported from other installed application such as Facebook (http://www.facebook.com/) or LinkedIn (http://www.linkedin.com/).
2. The navigation tool checks the matchmaker which runs in background and acts as a server listening for requests submitted from navigation module (which acts as client).
3. The system starts keeping track of user position, by means of available location services, *e.g.*, internal/external GPS antennas or location APIs.
4. POI discovery can happen in two different ways. (i) User explicitly submits her request selecting related features from main menu. Basically she indicates a general category search (*e.g.*, Cultural Heritage, Accommodation, Entertainment, Dining), each of them corresponding to a given ontology. Furthermore, she browses all concepts and roles within the ontology so detailing the request. (ii) Alternatively, the navigation tool is able to retrieve POIs best matching user interests in a transparent fashion simply referring to her profiles and preferences.

In order to take geographical distance into account to grade semantic matchmaking results, we introduce a Score Combination Function (SCF), also known as *utility function*:

$$SCF(r, POI) = 100[1 - \frac{rankPotential\ (r, POI)}{rankPotential\ (POI, \top)}][1 - \frac{distance(User\_GPS, POI\_GPS)}{max\_distance}]$$

where *rankPotential* (r, s) [5] is the semantic distance measuring the degree of correspondence between request r and point of interest annotation *POI*, computed solving the Concept Abduction Problem (CAP) [5]; *rankPotential* $(s, \top)$ is the maximum possible semantic distance w.r.t. axioms in the selected ontology. The second local score factor weights the influence of geographical distance: a ratio is used between POI-user distance and maximum distance the user can tolerate for discovery.

3.2 Map Enhancement

As said, the proposed tool is based on OpenStreetMap (OSM) collaborative project aiming at creating a free editable map of the world. Map data are exported and edited in an XML format adhering to a quite simple schema.

It includes three basic elements: (i) **nodes**, which represent single geospatial points; (ii) **ways**, which are intended as ordered sequences of nodes; (iii) **relations**, which group multiple nodes and/or ways. Each element can include a given number of general tags reflecting a key/value pair structure. There are no restrictions about attributes, *i.e.*, user can create new needed tags accommodating previously unforeseen uses of maps. With reference to POI description, OSM default representation is made by unconnected nodes, adding one or more additional key-value pairs tag. For instance the `amenity=place_of_worship, religion=catholic` annotation refers to a catholic church.

In order to enable novel semantic-based discovery of POIs, we have integrated an ontology-based annotation within current descriptions of interest locations in OSM. Knowledge Representation formalisms have been used, and particularly DIG which is grounded on the Attributive Language with Unqualified Number Restrictions ($\mathcal{ALN}$), a subset of OWL-DL. Compression techniques [12, 10] have been also employed for making more compact semantic metadata. Furthermore two new tags have been introduced:

- `<tag k="semantic:ouuid_counter" v="DIG description" />`
  whose *key* is the OUUID, *i.e.*, an Ontology Universally Unique IDentifier [9] marking the domain ontology the description refers to. The *value* field contains a semantically annotated DIG description. The counter suffix has been added to allow splitting DIG compressed description in two or more tags. All of them will have the same key value, but a progressively increased counter.
- `<tag k="ontology:ouuid" v="Ontology URI" />`
  whose value attribute contains the URI from where the ontology can be downloaded. This tag can also be omitted, and in that case the ontology will be searched and retrieved locally from the device storage.

A toy example of a DIG description referred to the *S. Maria Maggiore* cathedral point of interest is shown in Figure3.

In addition, Figure4 reports on an OSM excerpt of the same semantically annotated POI whose semantic annotation has been compressed.

The following three cases are possible in the annotation: (i) the POI is described using only one ontology and the compressed DIG is less than 255 characters; (ii) the POI refers to a single ontology, but compressed DIG description is longer than 255 characters; (iii) the POI is expressed w.r.t. more ontologies and DIG annotation are longer than 255 characters. Compression procedure accepts in input a DIG annotation and generates a *Base64* string output. If it is too much long, it is split in 255 characters segments and corresponding tags are inserted within node elements. If it is less that 255 characters, it can be inserted within a single semantic tag.

The OSM file including semantic annotations can be finally submitted to the OpenStreetMap server. Navigation systems directly use binary map files generated by the encoding tool which are smaller than original textual ones. They extract POI annotations directly from binary sources, decode DIG compressed description and join all segments (in case they overcome 255 characters limit).

```
<defindividual name="Cattedrale_Santa_Maria_Maggiore"/>
  <instanceof>
    <individual name="Cattedrale_Santa_Maria_Maggiore"/>
    <and>
      <catom name="Church"/>
      <all>
        <ratom name="located_in"/>
        <and>
          <catom name="Barletta"/>
        </and>
      </all>
      <all>
        <ratom name="has_destination"/>
        <and>
          <catom name="Religious"/>
        </and>
      </all>
      <all>
        <ratom name="has_age"/>
        <and>
          <catom name="Middle_Age"/>
        </and>
      </all>
      <atleast num="3">
        <ratom name="has_aisle"/>
        <top/>
      </atleast>
      <atmost num="3">
        <ratom name="has_aisle"/>
        <top/>
      </atmost>
      <atleast num="3">
        <ratom name="has_apse"/>
        <top/>
      </atleast>
      <atmost num="3">
        <ratom name="has_apse"/>
        <top/>
      </atmost>
      <all>
        <ratom name="has_style"/>
        <and>
          <catom name="Romanic"/>
        </and>
      </all>
      <atleast num="3">
        <ratom name="has_altar"/>
        <top/>
      </atleast>
      <atmost num="3">
        <ratom name="has_altar"/>
        <top/>
      </atmost>
          <atleast num="1">
        <ratom name="has_portal"/>
        <top/>
      </atleast>
      <atmost num="1">
        <ratom name="has_portal"/>
        <top/>
      </atmost>
    </and>
  </instanceof>
```

Fig. 3. POI DIG description

```
<node id='413962293' lat='41.3205606' lon='16.2862326' version='4'
    timestamp='2009-12-28T10:28:46Z' uid='191809' visible='true'>
    <tag k='amenity' v='place_of_worship' />
    <tag k='denomination' v='catholic' />
    <tag k='name' v='cattedrale S.Maria Maggiore' />
    <tag k='religion' v='christian' />
    <tag k='semantic:44211a01_1' v='eNqFjU0KgzAQhc9UeoLWtZv2AGEwQ
        xxIE0nGRS/kz64bXRYqIpR6ptKoSO2qm4H3vvfevJ8RMKN0oFGcwTCIGBxNV
        ymyDu+vP4FmiNLcJWk7aptASAoyzXAEp5EZirIdU/BComcywGQDPKGm0M39S
        kGFmZikDD8OCovysV988hr7qtuqemWZ36BJ1MuY56sOcyd7AUNJ2NrNdmYdg
        +6rta4Z3Lc/q7r7idbF7QO844cq' />
    <tag k='ontology:44211a01' v='http://sisinflab.poliba.it/cultural.dig' />
</node>
```


Fig. 4. OSM XML excerpt of a semantically annotated POI

Furthermore, they check if the reference ontology is locally available, and if not it is downloaded from a given URI. Finally, a request for matchmaking is addressed to the reasoner running in background.

4 Case study: where are you going?

The *Navit* navigation system was extended with support to semantic-enhanced POI annotations. It was tested in a case study concerning discovery of cultural heritage resources in the Apulia region. Hereafter implementation details are briefly reported and a simple system usage example is described, in order to highlight main features of the proposed approach.

Resource annotation. Map data were collected and added to OpenStreetMap for an uncovered portion of the city of Barletta. An OWL ontology for description of cultural heritage resources –not reported here due to space constraints– was developed. Several POIs in the Apulia region were annotated w.r.t. it, with highest concentration in Barletta.

Navit evolution. Support for semantically annotated POIs (see Section 3.2) and semantic-based discovery was added to Navit. A very basic cross-platform GUI was developed for ontology browsing and semantic request composition: its purpose was only to allow testing of the solution, while a more sophisticated and user-friendly interface is planned for subsequent system versions. Microsoft Windows Mobile was selected as the first reference platform for system evaluation. *MaMaS-tng* [6] semantic matchmaker was ported to Windows Mobile and run as a server process. The Navit process acts as a client, interfacing to the inference engine via a local socket using the DIG protocol interface which provides an XML-based concept language and a simple request/response mechanism for Knowledge Base instantiation, population and querying.

Semantic-enhanced POI search. *Isabel is in Barletta for the first time, and she would like to visit interesting places. She is particularly fond of mod-*

Fig. 5. Using the semantic-enhanced navigation system.

ern artistic palaces and she knows that Apulia has a rich cultural heritage. She launches Navit on her smartphone and starts a new semantic-based POI search, selecting cultural heritage as resource domain. The system uses the related reference ontology to dynamically generate a nested menu of POI types, sub-types and relevant characteristics. The user can browse ontology classes and properties in a hierarchical structure [11]. She is not only able to choose from a taxonomy of landmark types (see Figure 5(a), 5(b) and 5(c)) like in traditional navigation systems, but also to express the desired resource properties (Figure 5(d)) in order to make her search more meaningful and precise. In our example, after selecting the *Palace* POI class, she sets her constraint on monument age by navigating the appropriate portion of the ontology model (Figure 5(e)). In our very short and simple example, the user ignores further available properties, such as style, materials and size. The final semantic request is summarized in Figure 5(f). The user can review it and she eventually confirms it. In addition to the semantically annotated expression, the user can insert a maximum acceptable resource distance from her location, as reported in Figure 5(g).

Results review and selection. Navit instantiates a Knowledge Base on the local instance of the semantic matchmaker. It consists of the reference domain ontology, the user request and the annotations of the POIs in the search range that refer to the same ontology. Now inference services for semantic matchmaking are requested. After receiving the reply of the matchmaker, the navigation system computes the utility function, as explained in Section 3.1. In our example, Figure 5(g) reports the final outcome. Only one POI in Barletta, *Palazzo della Marra*, is a full match for the user request. The next best matching options are *Castello Svevo* and *Paraticchio*, which are a medieval castle and a medieval tower, respectively. Their good score is due to the fact that palaces and forts are sibling concepts in the reference ontology. Churches and museums, on the other hand, have higher semantic distance, because of their public nature and different purpose. *Isabel selects* Palazzo della Marra *from the result list and navigation begins as in traditional personal navigation systems.* Figure 5(i) shows the planned route to the destination; the other POIs in the result list are also marked on the map for further reference.

5 Conclusion

We have presented a novel semantic-based navigation approach enabling knowledge-oriented path calculation, which takes into account needs and profile of a user planning a travel. The system we proposed is fully based on open source maps referred to the *OpenStreetMap* project, which have been semantically enriched to make possible advanced matchmaking services.

Future work will aim at extending the proposed system with further vehicle and road condition retrieval techniques including traffic and weather conditions detected by means of Wireless Sensor Networks and OBDII On-Board Diagnostic system interfaces. Semantic-based map annotation will be speed-up with the integration of an ontology-based editor within the OpenStreetMap one. Finally a throughout experimentation will be carried out in order to improve GUIs and navigation experience recalling user's feedbacks.

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