Ontology-driven car pooling via semantic matchmaking: a context-aware approach

Michele Ruta, Floriano Scioscia, Saverio Ieva, Danilo De Filippis, Eugenio Di Sciascio,

Politecnico di Bari, BARI, Italy
Outline

• State of the art and main issues
• Proposal: car sharing via semantic matchmaking
  • Framework architecture
  • Semantic enrichment of OpenStreetMap
  • Resource annotation
  • Ontology model
  • Knowledge-based passenger/car matchmaking
• Case study
• Conclusion and Future Work
State of the art

Car sharing and pooling systems

- Provide real-time on-demand transport service

Features

- Distributed coordination and matchmaking among providers and clients
- Peer-to-peer architectures with simplified management

Main limits

- Shallow information content associated to location-based resources (e.g., just coordinates, name and category)
- Low recall problem in resource retrieval
  - Coarse “yes-no” outcomes only
- Retrieval systems cannot deal with articulate descriptions and dynamic resources
Goals

• Exploit standard Semantic Web technologies to annotate dynamic resources (vehicles)
• Enhance the data model of crowd-sourced OpenStreetMap cartography

Core ideas

• Allow embedding of semantic annotations into OSM maps
• Express both passenger and driver profiles in Web Ontology Language (OWL) based on Description Logics (DLs)
• Rank resources by semantic distance, measured formally in terms of conflicting and/or missing features
Proposed framework

Main components:

- OSM data files
  Encapsulate both geo data and semantic annotations of resources

- OSM data parser
  Extracts semantic annotations from OSM data for the user local area

- Lightweight reasoner
  Computes the semantic-based matchmaking and resource ranking
Semantic enrichment of OSM maps

- OSM XML Schema includes three basic elements:
  - `<node>`: single georeferenced points (e.g. POI)
  - `<way>`: ordered sequences of nodes
  - `<relation>`: group of ways and nodes modeling complex structures
- Each element can contain optional general-purpose informative tags

- Semantic tags introduced complying with the OSM tag structure

  `<tag k="semantic:n:key" v="value" />

- `<tag k="semantic:n:ontology" v="URI" ">: reference ontology
- `<tag k="semantic:n:encoding" v="format" ">: encoding compression format
- `<tag k="semantic:n:counter" v="data" ">: Base64 string representation of compressed semantic annotation
- n index identifies different annotations associated for the same map node
Resource annotation

- A vehicle is annotated as OSM node
- JOSM plugin allows editing semantic annotations through a fully visual user interface
- Monitoring and annotation of actual trip:
  - Semantic annotation enriched with contextual information
  - Auto-updated node coordinates
Ontology model

- **DLs basic elements:**
  - concepts a.k.a. *classes* → sets of objects
  - roles a.k.a. *object properties* → relationships linking pairs of objects
  - individuals a.k.a. *instances* → particular named objects

OWL 2 semantic annotations expressed w.r.t. an ontology modeled for the car pooling domain. Upper-level classes include:

- **Car Type** → different kinds of cars
- **Feature** → requested/provided vehicle equipment
- **Preference** → passengers' or drivers' personal requirements
- **Luggage** → classes related to passengers' load

- **Concept Abduction** and **Concept Contraction** non-standard inference services [Ruta et al., WIAS 2011] adapted to transportation service retrieval
  - Granular ranking of potential and partial matches
**Knowledge-based passenger/car matchmaking**

- **Problem**: relevance for the user depends not only on semantic match degree, but also on contextual information
- **Solution**: Overall resource score computed by a utility function

\[
u (R,C) = 100 \times \left[ 1 - \frac{s\_penalty (R,C)}{s\_penalty (R,\top)} \right] \times \frac{distance (R,C)}{max\_distance}\]

- **Passenger-Vehicle headings compared as a pre-filtering step**
- **Outcome explanation** is a unique advantage of approaches based on knowledge representation
Case study

unique identifier
of the reference
ontology

trip information

Car/driver semantic-based annotation

SUV: Car ∈ vehicle_Type ⊓ ∀ vehicle_Type.SUV ∈ accepts ⊓ ∀ accepts.NonSmoking
∈∃ has_Feature ⊓ ∀ has_Feature.(Car_Radio ∈ Air_Conditioning ⊓ Baby_Seat)
∈∃ comfort_Level ⊓ ∀ comfort_Level.High_Comfort ∈∃ driver_Experience
∈ ∨ driver_Experience.High_Xp

= 6 available_Seats ⊓ = 650 available_Capacity ⊓ ≥ 1 carries_Luggage

Dynamic, context-aware features

Static features
(Vehicle feature/driver’s profile)
Case study: matchmaking process

UserA: \( \exists \text{vehicle}_\text{Type} \sqcap \forall \text{vehicle}_\text{Type}.\text{SUV} \sqcap \exists \text{accepts} \sqcap \forall \text{accepts}.(\text{NonSmoking} \sqcap \text{Quiet}) \sqcap \exists \text{comfort}_\text{Level} \sqcap \forall \text{comfort}_\text{Level}.\text{High_Comfort} \sqcap \exists \text{driver}_\text{Experience} \sqcap \forall \text{driver}_\text{Experience}.\text{High_Xp} \sqcap \exists \text{has}_\text{Feature} \sqcap \forall \text{has}_\text{Feature}.(\text{Baby_Seat} \sqcap \text{Air}_\text{Conditioning}) \sqcap \geq 2 \text{ available}_\text{Seats} \)

Matchmaking finds which vehicles of the fleet best meet user’s requirements.

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Available space</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>320 L</td>
<td><img src="image1" alt="Icon" /> <img src="image2" alt="Icon" /> <img src="image3" alt="Icon" /> High XP <img src="image4" alt="Icon" /> <img src="image5" alt="Icon" /> <img src="image6" alt="Icon" /> <img src="image7" alt="Icon" /></td>
</tr>
<tr>
<td></td>
<td>200 L</td>
<td><img src="image8" alt="Icon" /> <img src="image9" alt="Icon" /> <img src="image10" alt="Icon" /> <img src="image11" alt="Icon" /> <img src="image12" alt="Icon" /> <img src="image13" alt="Icon" /> <img src="image14" alt="Icon" /> High XP</td>
</tr>
<tr>
<td></td>
<td>490 L</td>
<td><img src="image15" alt="Icon" /> <img src="image16" alt="Icon" /> <img src="image17" alt="Icon" /> <img src="image18" alt="Icon" /> <img src="image19" alt="Icon" /> <img src="image20" alt="Icon" /> <img src="image21" alt="Icon" /> Low XP</td>
</tr>
<tr>
<td></td>
<td>650 L</td>
<td><img src="image22" alt="Icon" /> <img src="image23" alt="Icon" /> <img src="image24" alt="Icon" /> <img src="image25" alt="Icon" /> <img src="image26" alt="Icon" /> <img src="image27" alt="Icon" /> <img src="image28" alt="Icon" /> <img src="image29" alt="Icon" /> High XP</td>
</tr>
</tbody>
</table>
Concept Contraction output:

Give up: $\forall$ vehicle FEATURE.Baby Seat $\cap \geq 2$ available seats

- When the passenger/car association is confirmed, the new passenger's information is appended in conjunction with the car annotation
- Next user is matched with the updated fleet
At the end of the matchmaking process passengers arranged on the cars as follows:

Relevant examples include:

- UserC $\rightarrow$ Large Citycar preferred over Small Citycar: they both provided most of the specified features, but the luggage carried by UserC best fitted in Large Citycar trunk available/residual capacity.
- UserF/Large Citycar match $\rightarrow$ poor score due to insufficient available seats after accommodating both UserC and UserE.
Conclusion: contribution

- A framework for semantic-enhanced discovery of transport resources in car sharing and pooling scenarios
- A general technique for semantic annotation of crowd-sourced OpenStreetMap cartographic data
- An embedded lightweight reasoner exploiting semantic matchmaking between user and vehicle profiles is integrated
- A case study demonstrating management of multiple dynamic constraints about drivers and passengers
Conclusion: future work

- Improvements to the framework with further discovery features and contextual parameters
- Development of a full prototype of mobile travel assistant
- Field trials validating the overall acceptability of the proposed solutions