The Design and Implementation of Semantic Web-Based Architecture for Augmented Reality Browser

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Abstract. Due to the proliferation of smartphones, Augmented Reality applications have become more widespread nowadays. Augmented Reality browsers have especially enjoyed wide popularity within these applications. The physical environment could be extended by location-aware additional information using these browsers. At present, typically a specific data source is used by the current Augmented Reality browsers, even if there is an enormous amount of available data sources. The Semantic Web could help to bridge this problem. The goal of this work is to combine Augmented Reality and Semantic Web technologies in order to enhance the existing mobile Augmented Reality browsers using Semantic Web technologies. For this purpose, we utilize the advantages of the Semantic Web technologies such as data integration, unified data model as well as publicly available semantic data sources, among other things.

Keywords: Mobile semantic web · Augmented reality · Data integration · Ontology

1 Introduction

Smartphones have become an accepted part of our everyday life nowadays. With their help, many regular activities are much easier. The spread of mobile phones has facilitated the proliferation of Augmented Reality (AR) applications as well. Augmented Reality allows to extend the user's surrounding environment with computer generated virtual elements [3]. One type of Augmented Reality, called marker-based AR, uses images for this purpose. For example, when a user looks at a picture of a newspaper via mobile phone, then a three-dimensional model can be displayed on the top of the picture. Another type of Augmented Reality, namely location-based AR, is able to superimpose location-aware additional information about Points of Interests (POI-s) on the real-life view of the user. Points of Interest could be, for instance, monument, statue, museum. The position of the user can be determined easily by means of the built-in sensors of smartphones. A typical example is when the user looks around with the mobile phone and can see the icons which represent restaurants located nearby. Thus, the users can find interesting places and can get additional information about

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them, even if these are not in the field of view. Augmented Reality browsers can be used, among other things, for this purpose. These applications combine the traditional Augmented Reality application with Internet browsing.

Currently, the existing Augmented Reality browsers use only one data source while a huge amount of information has become publicly available on the Internet. We have realized that the combination of the Semantic Web offered possibilities with the Augmented Reality may result in more advanced AR browsers in terms of the richness of data provision. The benefits of Semantic Web technologies in the field of data integration can be used for merging data from heterogeneous sources. Currently, an enormous amount of publicly data source can be found on Linked Open Data cloud [4] in semantically represented format. Several data sources have spatial attributes. As a result, this information can also serve as a data source for an Augmented Reality browser. Due to the unified data model provided by Semantic Web technologies, the data from different sources will be stored in a common data format. Therefore, the browser does not have to deal with the data coming from different sources during the information processing.

The integration of geographic databases can play a particularly important role for location-based augmented reality browsers. The implementation of our proposed system is considered an improvement of the current Augmented Reality browsers. For this purpose, the examination and possible further extensions of the existing ontologies are needed. Several browsers have been developed in order to browse the publicly available semantic datasets. Nevertheless, relatively few of them are native mobile applications. Our proposed system is considered as a type of a visual interface to the Linked Open Data. In this way, it contributes to the development of Mobile Semantic Web.

The structure of the paper is as follows: after the introductory Sect. 1, we outline the State of the Art in Sect. 2. Section 3 deals with the problem statement and novel contributions. Thereafter, the research methodology and the proposed approach are described in Sect. 4. Then, the intermediate result and remaining work are presented in Sect. 5 while Sect. 6 describes our evaluation plan. Finally, the conclusions are described in Sect. 7.

2 Problem Statement and Contributions

This research relies on the hypothesis that the existing mobile Augmented Reality browsers can be enhanced using Semantic Web technologies in terms of the richness of data provisioning and additional practical functions. Our proposed approach allows us to use arbitrary geographic data sources, as opposed to the currently existing browsers. One possible scenario is the following. The user is in a foreign city and she does not know what interesting places are nearby. It would be great if she could somehow find out what kind of places are in the near, which she is interested in. Of course, she can ask somebody, but the asked person may not know every place in the city. It would be good if she could reach a database, from which she could get a lot of information about her environment and can visualize the data in a convenient way with her mobile phone. The problem raises a number of research questions.

1. What are the challenges of integrating geographic POI datasets? In detail: how can static databases used by AR applications be connected and extended by semantic datasets?
   The proposed approach should be able to integrate data on the fly from arbitrary geographic data sources in a unified manner. In addition, the appearing difficulties during the integration (see details in Sect. 4) should be handled by the system. The proposed solution has to ensure the use of semantic datasets located in the Linked Open Data cloud. As a result, it becomes possible to combine the currently used data with semantic datasets.
2. (a) What kind of architecture is suitable for a semantically enriched Augmented Reality browser?
   (b) How can we model the POI data sources in order to ensure the appropriate generality?
   Here, generality means that the proposed approach should be able to use arbitrary data sources which contain Points of Interests. To ensure this, an appropriate architecture is needed that enables an efficient and scalable implementation. The effectiveness means in our case that the system is able to add datasets on the fly to an augmented reality browser. In addition, the development of an appropriate information model is required. Since the data come from different sources, therefore, the same properties may appear under different names in distinct datasets. For example, the name of a POI is identified by *rdfs:label* property while the name of the same POI is stored by a *name* attribute in a second database. These mappings can be well described by an ontology. Thus, the examination and extension of ontologies created for this purpose are needed.
3. How can we extend the recent Augmented Reality browsers with new functionalities?
   Data enrichment can serve as a possible step in the further development of Augmented Reality browsers. However, in addition to the existing functions, with the implementation of quite different features can be enhanced the popularity of Augmented Reality browsers.
4. Can our system be used in new application fields?
   It is important to know what are the possible application areas of the newly implemented approach. The implementation of the above-mentioned unique functions may result in new application fields beyond the recent ones.

3 State of the Art

In the past few years, some commercial and open source Augmented Reality browsers have been published (for instance, Layar[1], Mixare[2], Wikitude[3]).

[1] https://www.layar.com/.
[2] http://www.mixare.org/.
[3] http://www.wikitude.com/.

These applications use only one data source and the openly available datasets are not used. Wikitude is built on Augmented Reality Markup Language (ARML)[4], Mixare and Layar use hidden and proprietary data structures [28].

Recently, some papers have been published aiming to utilize the advantages of the combination of the Semantic Web and Augmented Reality in the field of AR browsing. Martín-Serrano, Hervás, and Bravo present a tourism Android application that is using Web 3.0 technology tools in order to extract data from various data sources with the help of publicly available services on the Internet [15]. This approach can be seen as a possible answer to the research question 4. FOAF ontology [8] was used for determining the user's context. Furthermore, Semantic Web Rule Language (SWRL) [13] served as a basis of a recommendation system that provides new places to the users using rule-based inferences. Braun, Scherp, and Staab describe a mobile application called csxPOI (collaborative, semantic, and context-aware points-of-interest) in [7]. The users are able to collaboratively create, share and modify Points of Interests using this application. As usual, the Points of Interests represent real physical places. The properties of such places are stored in a collaboratively created ontology. This solution is related to the research question 2(b). However, whereas our approach is proposed to use multiple data sources, their solution is based on POI-s created by the users. Van Aart et al. in [27] explore the characteristics of location-aware smartphones for browsing and searching cultural heritage information. Their application determines the location of the user based on GPS coordinates and creates a user context from the combination of nearby locations, local historic events, etc. The authors combine two types of knowledge. The first one is general knowledge (for example, about geolocations and point of interests stored in Geonames and DBpedia). The second one is specialized knowledge about cultural heritage. The issue raised by the research question 2(a) is solved in the following way. The authors proposed a three-tier architecture: LOD resources as a data layer, a reasoning layer, and an AR-based user interaction layer.

The management of data from different sources is the task of data integration, which is an intensively researched area [9,20,21]. The Semantic Web technologies can be used for this purpose as well. Currently, one of the most preferred data integration methods is the ontology-based data integration. This method is responsible for defining the scheme and it helps to avoid the semantic problems [23]. In our case, geographic data sources (including POI-s) are used, therefore, these specific properties should be also considered. Harth and Gil describe their geospatial dataset integration method in [12]. The data come from Linked Open Data, similarly to the our proposed approach. The authors presented the NeoGeo [22] integration vocabulary to model two datasets. This vocabulary can be seen as a partial solution to the research question 1. The authors describe the integration of data only from the LOD while, in our case, the integration of other data sources are also needed.

In conclusion, it can be seen that there are existing solutions for some subproblems. However, in the best of our knowledge, there is no complex solution which

[4] http://openarml.org.

can integrate arbitrary geographic data sources (including POI-s) in order to provide richer data than the existing solutions to an Augmented Reality browser.

4 Research Methodology and Approach

The main aim of this work is to design and implement a semantically enhanced Augmented Reality browser framework by answering the issues raised in Sect. 2. To achieve our goal, we may not necessarily invent a new approach but rather combine existing methods and adapt as well as extend them to our own purposes.

The first step of the research is the design and implementation of the module which enables the data integration. The task can be divided into subproblems. The selection of a specific set of data sources that are used by the prototype is needed. Thereafter, the schema matching [25] should be performed that gets two schemas as input and generates semantically correct schema mappings between them. This requires the examination of the literature and the preparation of possible enhancements. Another similarly important problem is the entity resolution (also known as deduplication) [6,26]. This method is responsible for the identification and merging of the same real-world entities. After reviewing the existing solutions, our aim is to adopt them in case of such datasets that contain Points of Interests, if necessary, to develop new solutions. We propose to use for this purpose density-based clustering on POI-s as well as performing string similarity metrics on POI names.

In order to have efficient and scalable operation of the system, it is essential to construct a well-designed architecture. Our proposal offers a three-tier architecture. The first layer is the data layer, which includes a variety of data sources, such as relational databases, NoSQL databases or semantic datasets located in Linked Open Data cloud. The second layer is the middleware, which is responsible for the integration of data, the schema matching as well as performing the entity resolution. It is also responsible for providing the data to the client in a unified manner. This can be achieved by web services. The last layer is the lightweight client, in our case it is a smartphone with Android operating system. This part of the architecture communicates with the middleware. It is also important to create a unified data model for the reasons mentioned in Sect. 2. After we reviewed several spatial ontologies, we propose to use and extend the ontology of LinkedGeoNames [1] as the information model. Our proposed approach produces the integrated data in RDF format [14]. Due to this solution, the integrated data can easily be queried by SPARQL [24] queries, regardless of the POI-s origin. They come from different sources and the data sources use different data storage methods.

The next step is the investigation of the functionality of current Augmented Reality browsers. Then, we try to identify possible potential new functions. The current AR browsers display only a static content corresponding to a specific POI during the browsing. This method could be more dynamic when the POI is used as a search term and the Linked Open Data cloud is served as a data source. The resulting semantic content can be further browsed through on the links. Therefore, our proposed approach can be seen as a combination of an Augmented Reality browser and a semantic browser. The system described so far is considered to be static in the sense that users cannot add new POI-s to the data sources. The proposed approach should provide this method as well. For this purpose, the investigation of performance of spatial databases in terms of insertion time and query time is needed. The system can recommend POI-s based on their corresponding information and the user's context using rule-based inferences. For example, the user wants to go to a cinema. In that case, the system would recommend cinemas based on the starting time and the current time. For this purpose, Semantic Web Rule Language (SWRL) or SPARQL can be used.

5 Intermediate Results

We give a solution to the research question 1 and research question 2(a) in [16]. As we mentioned in Sect. 4, it should be selected a subset of data sources that are used by the prototype during the data integration. We have chosen five datasets, including social networks (Facebook, Foursquare), semantic datasets (DBpedia [5], LinkedGeoData [1]) as well as Google. In the case of Facebook, Foursquare, and Google, the public API-s were used while SPARQL queries were sent to the public endpoints of semantic datasets. Due to the general implementation, the system can be extended by arbitrary data source that contains Point of Interests. For this purpose, only the implementation of the parser of the new data source is needed, no other modifications are required during the integration process. We have determined the common schema pairwise using COMA++ [2]. The problem of entity resolution was solved by a two-step solution. The first step is a density-based clustering algorithm (we have chosen the DBSCAN algorithm [11]), which determines the POI-s belonging to the common cluster based on their coordinates. In this way, the possible same entities are determined. However, this solution is not yet sufficient for the unique identification. Hence, the name of the POI-s belonging to the common cluster were compared with two string similarity metrics. If the value of the comparison exceeds an empirically determined threshold, then the probability that the two POI-s are same entities is quite large. The integrated data will be available in RDF format and it can be accessed via web services. We have implemented our integration system as a middleware, which provides web services that are accessible via REST API.

In [16], we have created an information model as well, which is related to the research question 2(b). We have extended the ontology of LinkedGeoData by the appropriate classes and properties. The goal of LinkedGeoData is to add a spatial dimension to the Semantic Web. The spatial data is collected by the OpenStreetMap[5] project and it is available in RDF format. Furthermore, the extended ontology includes the mappings resulted by the schema matching. In addition, we wanted to provide the filtering of the POI-s by categories, thus these categories were also selected from this ontology. In order to map the different

[5] http://www.openstreetmap.org.

names of the categories to the ones stored in our ontology, it was necessary to create some data properties (for example, *inFoursquare*). For provenance reasons, we have created a *Datasource* class and derived the classes of the corresponding data sources from this class. The origin of a POI can be determined by means of these classes. The Protege editor was used for editing the above- mentioned OWL ontology.

In [17], we present a Linked Data-driven mobile Augmented Reality browser. The users can navigate and collect local-aware information by means of this solution. A sensor-based tracking approach was combined with RDF processing of related geographical data. The used data come from semantically represented data source from the Linked Open Data. Henceforth, we improved our prototype, it communicates with the above-mentioned data integration middleware and acquires the underlying data from there. In addition, we do not want to restrict the users only to the use of existing Points of Interests, but we may want to allow them to create new ones as well. For this purpose, we want to know, which spatial database is the most effective in terms of insertion and query time of POI-s. In [18], we implemented a benchmarking application which can be used for this purpose. In addition, we measured the performance of several relational and semantic databases. As we mentioned in Sect. 4, it could be more dynamic when the POI is used as a search term and the Linked Open Data cloud is served as a data source. In [19], we describe a Linked Data-driven mobile semantic web browser. Federated datasets can be browsed by means of this Android application. The client finds the list of resources for the desired keyword. Thereafter, the associated data can be displayed and filtered. Furthermore, due to the interconnectivity, the total federated dataset will become browsable.

In the remainder of this Ph.D. project, our focus lies on the following components. The integration of our semantic browser into the prototype of our Augmented Reality browser is needed. In addition, we want to find additional functionalities and application areas as well as we will implement and evaluate the rule-based recommendation system. In order to validate the work, we have to carry out a more in-depth evaluation of the proposed approach.

6 Evaluation Plan

In the evaluation method of the entity resolution part of data integration system we aim to use well-known evaluation metrics to count the number of correctly identified same entities. We will use the following standard concepts: true positive, true negative, false positive, false negative, precision, recall and accuracy. Furthermore, we want to measure the number of the resulted POI-s of several queries separately and collectively (i.e. the result of our proposed integration system). The fundamental assumption was that the given result after data integration will be much wider than separately.

We will perform usability test and user evaluations of our Augmented Reality browser based on the evaluation methods described in [10]. Different measures will be observed regarding, for example, the performance of spatial databases, the running time of the semantic browser part of our proposal.

7 Conclusion

In this work an approach which combines Semantic Web technologies and Augmented Reality is proposed. It is designed to enhance the existing mobile Augmented Reality browsers in terms of richness of data provisioning and additional practical functions. For this purpose, the existing data integration methods and Augmented Reality browser approaches were reviewed. The utilization of Semantic Web technologies, such as OWL, RDF, SPARQL was proposed to achieve the goal of this research. Preliminary results were described, namely the details of the proposed data integration system, a prototype implementation of a client and a mobile semantic browser as well as a plan for the future was established. The proposed approach is regarded as an improvement of the current Augmented Reality browsers as well as a type of a visual interface to the Linked Open Data. In this way, it could contribute to the development of Mobile Semantic Web as well.

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