A Smart City Data Model based on Semantics Best Practice and Principles

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ABSTRACT

Data management is crucial in modern smart cities. A good data model for smart cities has to be able to describe and integrate data from multiple domains, such as geographic information, public transportation, road maintenance, waste collection, and urban faults management. We describe our approach for creating a semantic platform for the Municipality of Catania, one of the main cities in Southern Italy. The ultimate goal is to boost the metropolis towards the route of a modern smart city and improve urban life. Our platform exhibits a consistent, minimal and comprehensive semantic data model for the city based on the Linked Open Data paradigm. Both the model and the data are publically accessible thorough dedicated user-friendly services, which allow citizens to observe and interact with the work of the public administration. Our platform also enables interested businesses and programmers to develop front-end services on the top of it. We describe the methodology used to extract data from sources, enrich them, building an ontology that describes them and publish them under the Linked Open Data paradigm. We include in our description employed tools and technologies. Our methodology is based on the standards of the W3C, on good practices of ontology design, on the guidelines issued by the Agency for Digital Italy and the Italian Index of Public Administration, as well as on the in-depth experience of the researchers in this field.

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1. INTRODUCTION

The recent technological advancement and economic growth has brought increasing well-being in the larger urban centers, and, as a consequence, a progressive abandonment of rural areas towards cities and metropolis. According to the World Health Organization, population in cities will double by the middle of this century[1]. Therefore cities will have to deal with increasingly pressing issues such as environmental sustainability, economic growth and citizen mobility. Although this urbanization flow may offer an improvement of the economic conditions of people, thanks to numerous opportunities in terms of work, education, cultural level, and social life, it also generates some negative effects at a global level [10].

The concept of smart growth has begun to spread at the end of the last century, referring to a community-driven reaction to solve traffic congestion, school overcrowding, air pollution, loss of open space and skyrocketing public facilities cost [19]. More recently, the concept of smart cities emerged in the international context [19], with the purpose of achieving the objectives established by the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, and by the Kyoto Protocol in 1997. In these contexts, the term "smart" refers to cities able to solve urban issues and pay particular attention to topics such as health and environment.

Smart cities rely on collaboration networks among human communities, innovation ecosystems, digital infrastructure, applications and e-services, which enable urban challenges of competitiveness, sustainability and inclusion to be addressed more efficiently. This urban paradigm is characterized by a continuous transformation, fuelled by the evolution of innovation ecosystems, broadband networks and web technolo-

[1] http://www.who.int/gho/urban_health/situation_trends/urban_population_growth/en/

gies. However, the interaction among all city actors still remains a challenge.

In this context, Semantic Web technologies have an extremely high potential and practical impact by providing the ground for new e-services within the ecosystems of cities [7]. The use of ontologies, Linked Open Data (LOD), and other semantic technologies open up a new domain for smart city applications as they can combine information from multiple sources for purposes like statistics, analysis, maps and publications, inform users when information matches their interests, and describe products and services more accurately [6, 9]. By linking this knowledge, interrelations and correlations can be quickly understood, and new conclusions arisen. Semantic Web technologies offer a series of solutions that might work in parallel with the Internet-of-Things and embedded systems, providing new opportunities for social media collaboration, collective intelligence, and content management. In addition they allow to put into practice the Open Government's principles of transparency, participation and collaboration [18], which are central keys for the integration of citizens within the smart city paradigm.

Extracting meaningful information from data generated in a smart city is a complex task because of the heterogeneity of data, its rate of generation and its volume [29]. The heterogeneity problem has to be tackled at different levels. On the one hand, syntactic interoperability is needed to unify the format of knowledge sources, enabling e.g. distributed queries [20]. Syntactic interoperability can be achieved by conforming to universal knowledge representation languages and by adopting standards practices. Semantic interoperability is also required to provide a formal specification of shared conceptualisation. It can be achieved by adopting a uniform data representation and formalizing all concepts into a holistic data model (conceptual interoperability). RDF/OWL and LOD assist us in achieving syntactic and semantic interoperability. Aligning knowledge sources at a conceptual level, which are expected to be broken down by the use of Semantic Web technologies, allows to merge data from different sources and present them to citizens in a user-friendly way [29].

In this paper we extend our previous work [13, 12] on the production of Linked Data for the Municipality of Catania, a city in Southern Italy, in the context of the Italian R&D project PRISMA, "PlatfoRms Interoperable cloud for SMArt-Government" [27]. The work falls within the spirit of the Smart Cities initiatives of the European Commission, which aims at bringing together cities, industries and citizens to improve urban life through more sustainable integrated solutions. Our approach tackles the issue of reconciling large city data sources of different nature into a uniformed and integrated semantic data model. Our model enables semantic interoperability at the concept level and support application developers in the design of advanced city services and applications. The published data are accessible via queries and/or public facilities and can be integrated with higher-level services. We describe the collected city data, discuss some issues in collecting and organizing them and present our semantic model for the city data.

2. RELATED WORK

The smart city paradigm appeared at the beginning of this century as a fundamental component of the global knowledge economy [19]. Since then, the idea of smart cities has been adopted by many institutions (e.g. European Commission, Setis-EU, OECD, etc.) which launched several initiatives and projects relevant to cities sustainability [24], labeled with the term "smart". A major milestone has been the IBM initiative "Smarter Planet - Smarter Cities" launched in 2009 [21][2]. Proposed as a central strategy for sustainable future, this initiative was intended to stimulate economic growth and quality of life in cities and metropolitan areas with the activation of new technology systems and infrastructures. CISCO recently endorsed the concept of "Intelligent X" as a technology ecosystem which integrates smart devices involving machine-to-machine capabilities, high-speed ubiquitous communication networks, and intelligent software and services that can process, consolidate and analyze data in order to support industry-specific business processes [11]. Microsoft also launched in 2013 its global smart cities initiative, called "CityNext", intended to build smart cities around the world [22][3].

In smart cities, the deployment and integration of information and communication technologies is crucial to achieve significant improvements in efficiency and quality of life. This includes having the ability to quickly access and manage data. Such data must be properly integrated to add efficiency and interoperability. A big effort has been recently spent to employ Semantic Web technologies for extending and integrating smart city data systems[7]. City data provided by heterogeneous sources need to be appropriately interpreted, aggregated, filtered, annotated, and combined with other data sources in order to be queried or analyzed. [29] proposed a semantic data platform to provide an interoperable representation of data and achieve the mentioned goals. The model proposed in [5] describes some basic, common attributes on the characteristics of data for smart ICT systems. Their method delegates details about specific streams to linked-data models, which provide on demand and service-specific external domain knowledge. Linked Sensor Middleware [25] is a recent attempt to build a platform that bridges the real-world city data with the Semantic Web, thanks to wrappers for real-time data gathering and publishing, data annotation and visualization, and a SPARQL endpoint for LOD querying.

The Semantic Web paradigm of Linked Open Data [6, 9] is also an invaluable resource for increasing the interaction between citizens and the city administration in the view of assuring Open Government's principles [3]. The main thrust on the publication of LOD for Public Administration is coming from big initiatives in the United States (`data.gov`) [14, 15] and the United Kingdom (`data.gov.uk`) [28].

3. METHODOLOGY

This section describes methods and tools employed for extracting, modelling and publishing data for the Municipality of Catania, under the Linked Open Data paradigm and assuring syntactic and semantic interoperability. The adopted methods followed W3C standards[4], pattern-based ontology design techniques [17, 26], and guidelines for LOD production and publication, issued by the Agency for Digi-

[2]IBM, Smarter Cities - Overview, `http://www.ibm.com/smarterplanet/us/en/smarter_cities/overview`

[3]Microsoft CityNext, `http://www.microsoft.com/en-us/citynext`

[4]`http://www.w3.org/standards/semanticweb/`.

tal Italy [1, 2]. Our project also benefited from experience gained in previous projects, in particular the development of `data.cnr.it` [4], the Linked Open Data portal for the Italian National Research Council.

Data were collected from several organizations related to the Municipality of Catania. During the selection phase, a thorough analysis of the reference domain was carried out. The main data sources were identified in the following:

• GeoData from the Geographic Information System (GIS) [23] of the city, concerning the toponymy;

• Data on lines and stops of the public transport bus system (REST web service in JSON format[5];

• Maintenance of the public lighting system of the city (XML file);

• Maintenance of the state of roads, sidewalks, signs and markings (Microsoft SQL Server database);

• Historical data on municipal waste collection (Microsoft Excel file);

• Historical data on the urban fault reporting service (mySQL Server database).

Although the produced LOD model is lexicalized for the Italian context, as the handled data sources are provided in Italian[6], the whole generation procedure is completely generalisable and language-independent. Considering the heterogeneity to data sources, different engineering approaches were required to handle data, convert them into the LOD paradigm, and integrate them with a common ontology describing the city business processes, as shown below.

The *GIS* is a data warehouse (used for reporting and data analysis), consisting of several databases that integrate geo-located information about the province of Catania. Seven *territorial levels* – hydrography, topography, buildings, infrastructures, technological networks, administrative boundaries and land – form the geo-located part of the information flow in the Municipality of Catania [23]. The GIS is designed to contain the main data of the Municipality of Catania, with the purpose of maintaining in-depth knowledge of the local area. In order to convert the geo-referenced data provided by the GIS into RDF, we used Tabels[7]. Tabels relies on the GeoTools libraries[8] to store data records into a RDF representation and model the spatial geometry as a standard KML file. Tabels generates automatically a custom SPARQL-based script able to transform each row of the input data into a new instance of a corresponding RDF class. Each value in the column of the input table was converted into a new triple where the subject is the mentioned instance (SQL table), the predicate is a property based on the name of the column header, and the object is a *rdfs:Literal* whose value is the value of the column. The transformation procedure is completely customisable to suit specific requirements, i.e. to change and annotate classes, names and associated properties. We used Tabels for generating a first ontology and a set of shapes associated to geo-referenced objects in KML format following the standard Geodetic system WGS84 [16][9]. We also aligned the resulting RDF triples to existing vocabularies, in particular NeoGeo[10], an ontology for GeoData, and the Collections Ontology[11], an OWL 2 DL ontology for creating sets, bags and lists of resources, and for inferring collection properties, even in the presence of incomplete information.

Data on *lines and stops of the public transport bus system* were available in JSON format, and were parsed by a customized JAVA script into a set of RDF/OWL triples. We reused data and object properties already defined in our ontology to provide integration and uniformity. We also aligned the ontology to existing Semantic Web vocabularies when possible. Data are geo-referenced. In particular public transport lines are given as geometric lines while stops are geometric points. Coordinates are expressed in the standard Geodetic system WGS84, and organised by following the NeoGeo specification. For each geo-referenced data entity, the corresponding KML file is also created and made publicly accessible. We used the Collections Ontology for creating and handling collections in OWL 2, such as service areas, routes, and timetables.

Data related to the maintenance of the *public lighting system* of the city were provided in XML format. Although tools for transforming XML data into RDF are available (e.g. ReDeFer[12]), we found more flexible and useful to use a customised conversion script. This choice allowed us to provide alignments to existing Semantic Web vocabularies and to reuse data and object properties already defined. The datasets contain information related to management and maintenance of the public lighting system of the city, such as fault messages, the state of faults and the life-cycle of faults.

Data concerning the maintenance of the *state of roads, sidewalks, signs and markings* and those related to *municipal waste collection* were provided as distinct Microsoft SQL Server databases. However the re-engineering process was analogous. The structured input data were managed by the D2RQ platform[13], an open-source framework for accessing relational databases and producing "RDF dumps" according to certain specifications. Initially the tool creates a D2RQ mapping file [8] by analyzing the schema of the existing database. This mapping file, called the default mapping, maps each table to a new RDFS class (named after the table's name), and each column to a property (named after the column's name). We customize the mapping to align the resulting ontology to existing Semantic Web vocabularies and reuse data and object properties already defined. In this way semantic interoperability at the concept level among heterogeneous data was enabled within the uniformed city ontology.

Historical data on the *urban fault reporting service* are related to signalling, reporting and managing services of urban faults. Data were provided as a mySQL Server database instance. We again used D2RQ to map the relational database, customise the mapping appropriately, and produce an RDF/-OWL dump of the database. The dataset contains information related to fault reports, actions required, status, workflows, localisation addresses and WGS84 coordinates, arranged by using NeoGeo and the Collections Ontology.

[5] `http://www.amt.ct.it/iamt/iamtj.php`)

[6] Raw data are available upon request.

[7] `http://idi.fundacionctic.org/tabels/`

[8] `http://geotools.org`

[9] WGS84 Geo Positioning RDF vocabulary: `http://www.w3.org/2003/01/geo/wgs84_pos`

[10] `http://geovocab.org/doc/neogeo.html`

[11] Collections Ontology (CO), version 2.0: `http://purl.org/co`

[12] `http://rhizomik.net/html/redefer/`

[13] D2RQ - Accessing Relational Databases as Virtual RDF Graphs, Version 0.8.1, `http://d2rq.org/d2r-server`

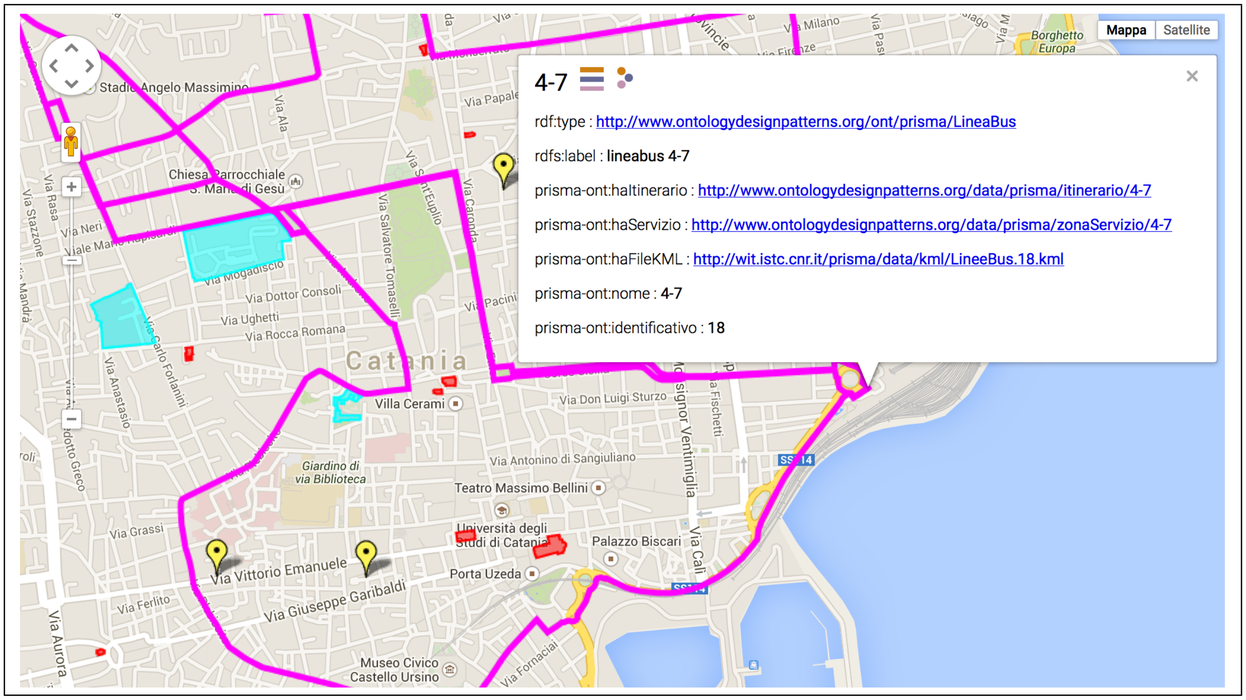

Figure 1: A screenshot of our geo-RDF visualizer map.

During the whole conversion process, ontology parts have been aligned among them and with standard existing ontologies to achieve conceptual interoperability. Moreover several refinement steps have been performed to conform to international standards. The design process followed the good practices of formal representation and naming in use in the domain of the Semantic Web and Linked Open Data [1, 2]. In particular the guidelines of the W3C Organization Ontology[14] for generating, publishing and consuming LOD for organizational structures have been ensued. In a first phase, each entity type described by the supplied data has been represented by a class and each entity field has been converted into a data property. Then, entities and properties referring to the same concepts have been unified. This phase is important since often the same concept from different data sources is described by different names. Specifically, to assure semantic interoperability and compliance to W3C standards, the following transformations have been performed by means of a final XSLT conversion:

• The names of classes were lemmatised (e.g., from "Hospitals" to "Hospital");

• The names of datatype properties were aligned when they were clearly showing the same semantics. For example, the properties "Name-of-CATANIA.SDO_Churches" and "Name-of-CATANIA.SDO_Hospitals" were converted into the same property "Name", assigned to the entity classes "Church" and "Hospital";

• Relations between entities and values (e.g. strings) that correspond to other entities were represented by object properties and connected to the corresponding entity. For example, the relation "MUNI-of-CATANIA.SDO_NursingHomes", generated by Tabels, became a property "Municipality" and was used to connect individuals of the class "Nursing Home" with individuals of the class "Municipality";

• The data properties having values clearly assigned to resources from external ontologies were transformed into object properties and their values were *reified* as individuals of specially created classes.

The alignment was a manual process done by experts.

Once the data were represented in RDF and the triples for each data object were produced, we performed a knowledge discovery step in order to enrich the resulting knowledge base by linking to knowledge from DBpedia. In particular, all addresses and names of extracted data objects were sent to TAGME[15], a popular entity linking tool freely available. TAGME performs named entity resolution: given a short sentence, it recognises named entities in the text, and link the identified text fragment to its corresponding Wikipedia page. The name of the extracted entities were compared by string similarity with the original object name (or address). We introduced new DBpedia RDF relations `owl:sameAs` and `dul:associatedWith` based on such a string similarity. Specifically, we inserted the `owl:sameAs` relation when TAGME produced an object with the same name as the entire data object; we inserted a `dul:associatedWith` relation when TAGME extracted entities whose names are different from the input.

3.1 Data access and consumption

We developed user-friendly access services to allow citizens, developers, and companies to access the produced data and ontology. For programmers, the data and the ontology are accessible by SPARQL queries through a dedicated Virtuoso triplestore[16]. Data are stored in the RDF graphs

[14] `http://www.w3.org/TR/2014/REC-vocab-org-20140116/`

[15] `http://tagme.di.unipi.it/`

[16] `http://wit.istc.cnr.it:8894/sparql`

<prisma>, while the ontology is stored in the RDF graph *<prisma-ont>*[17]. The SPARQL endpoint is also accessible as a REST web service. It requires as input a user-defined SPARQL query and produces as output the query result in one of the following formats: *text/html*, *text/rdf +n3*, *application/xml*, *application/json*, or *application/rdf+xml*.

The ontology[18] is also browsable by means of *Live OWL Documentation Environment (LODE)*[19] as human-readable HTML pages[20]. It is also visualizable by *WebVOWL*[21] as a force-directed graph layout[22]. Both tools enable user-oriented visualizations and provide the description of elements of the ontology. Interaction techniques allow the user to explore the ontology and to customize the visualization.

Data and ontology nodes are also accessible through content negotiation. The negotiation can be done either via a web browser (in this case the output type is always *text/html*), or by making HTTP REST requests to the corresponding namespaces, specifying as input the object identifier. The request produces as output the object triples in one of the following formats: *text/html*; *text/rdf+n3*; *text/turtle*; *text-/owl-functional*; *text/owl-manchester*; *application/owl+xml*; *application/rdf+xml*; *application/rdf+json*. We provide a visualization tool that shows geo-referenced objects in a map[23]. A screenshot of our tool is shown in Figure 1. A user can select a set of object classes and then a set of objects through two listbox (not shown in the figure but included within the tool). The selected objects are visualized on a map as displayed in the figure. Yellow points correspond to schools, red objects to churches, blue regions to hospitals and pink lines to bus lines. The user can click on an object on the map for obtaining related information. In figure, information about a bus line (namely line "4-7") is shown.

We also integrate two other visualization tools: LodView[24] and LodLive[25]. LodView is a Java web application able to offer a W3C standard compliant IRI dereferentiation. LodView improves the end user's experience by providing HTML based representations of our RDF resources. Besides its intuitive interface, LodView adds interesting features to the content negotiation, such as the possibility to download the selected resource in different formats (*xml, ntriples, turtle, ld+json*). The second visualization tool, LodLive, is a navigator of RDF resources based on a graph layout. It is used for connecting RDF browser capabilities with the effectiveness of data graph representation. For instance it allows the user to expand automatically the relations of a selected resource, calculate inverse and `owl:sameAs` relations, store images during the navigation, and geo-localize the browsed data as points in a map. We integrated LodView and LodLive with both content negotiation and our visualization tool of geo-referenced objects.

Last but not least, we fed our data to Exhibit[26], an open source publishing framework for data-rich interactive web pages. Exhibit allows the creation of dynamic exhibits of data collections without resorting of complex database and server-side technologies. The data collections can be searched and browsed (through advanced text search and filtering functionalities) using faceted browsing. To proper use Exhibit we had to decide which kind of data within our collection to show using Exhibit widgets and prepare a JSON format according to Exhibit requirements. The application we have created using Exhibit on top of our data is publicly accessible here[27] where the reader may see the data and filter them using the views that Exhibit offers.

All the described tools, ontologies and data we have mentioned and designed in this paper have been plugged into a project website[28] publicly accessible.

4. CONCLUSIONS

This paper describes our work in collecting, enriching, and publishing LOD for the Municipality of Catania in the context of the Italian Smart Cities project PRISMA. Based on our experience we outline a general methodology for developing consumable semantic data models for smart cities. Our approach includes leveraging well-known open standards, using extensive metadata and pursuing semantic interoperability at domain level. It produces a clean city-specific ontology that describes data from distributed, heterogeneous sources. Our methodology is based on the Linked Open Data paradigm, and adheres to the W3C standards, and to the guidelines issued by the Agency for Digital Italy and the Italian Index of Public Administration. Data are publicly accessible to users through a dedicated SPARQL endpoint, REST web services, content negotiation, and by means of several user-friendly visualization tools and widgets.

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[18] http://ontologydesignpatterns.org/ont/prisma/ontology.owl

[19] Live OWL Documentation Environment (LODE), Version 1.2, http://www.essepuntato.it/lode

[20] http://www.essepuntato.it/lode/http://www.ontologydesignpatterns.org/ont/prisma/ontology.owl\#d4e2763

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[22] http://vowl.visualdataweb.org/webvowl/#iri=http://www.ontologydesignpatterns.org/ont/prisma/ontology.owl

[23] Publicly accessible at: http://wit.istc.cnr.it/prisma/geovisual/selectvisualize.php

[24] http://lodview.it/

[25] http://lodlive.it/

[26] http://www.simile-widgets.org/exhibit/

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