

The GeoKnow Handbook

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Abstract. Within the GeoKnow project, various tools are developed and integrated which aim to simplify managing geospatial Linked Data on the web. In this article, we summarise the state of the art and describe the status of open geospatial data on the web. We continue by presenting the Linked Data Stack as technical underpinning of GeoKnow and give a first presentation of the platform providing a light-weight integration of those tools.

1. Introduction

In recent years, Semantic Web methodologies and technologies have strengthened their position in the areas of data and knowledge management. Standards for organizing and querying semantic information, such as RDF(S) and SPARQL have been adopted by large academic communities, while corporate vendors adopt semantic technologies to organize, expose, exchange and retrieve their data as Linked Data. RDF stores have become robust enough to support volumes of billions of records (RDF triples), and also offer data management and querying functionalities very similar to those of traditional relational database systems.

Among the existing knowledge bases, those with geospatial data are among the largest in existence and have high importance in a variety of everyday applications. The data can be mapped and often manipulated with Geographic Information Systems (GIS), however the integration of external data sets into these systems is time-consuming and complex. The aim of the GeoKnow project is to provide the necessary tools and methods to easily integrate and process data across a wide range of data sources on the web of data. Producing and updating geospatial data is expensive and resource intensive. Hence, it becomes crucial to be able to integrate, repurpose and extract added value from geospatial data to support decision making and management of local, national and global resources. Spatial Data Infrastructures (SDIs) and the standardisation efforts from the

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Open Geospatial Consortium (OGC) serve this goal, enabling geospatial data sharing, integration and reuse among Geographic Information Systems (GIS). Geospatial data are now, more than ever, truly syntactically interoperable. However, they remain largely isolated in the GIS realm and thus absent from the Web of Data. Linked data technologies enabling semantic interoperability, interlinking, querying, reasoning, aggregation, fusion, and visualisation of geospatial data are only slowly emerging. The vision of GeoKnow is to leverage geospatial data as first-class citizens in the Web of Data, in proportion to their significance for the data economy.

The remainder of the article is structured as follows: In Section 2, we describe the status of open geospatial data on the web, followed by semantic web technologies for geospatial web data specifically in Section 3. After that, we give a general overview of the GeoKnow project in 4. A central vision behind the GeoKnow project is the Linked Data Life-Cycle described in Section 5. The technical realisation of this vision is done in the Linked Data Stack (Section 6), which consists of a variety of components (Section 7). Those components are integrated in an interface, which we call the GeoKnow Generator (Section 8). An application scenario using the GeoKnow Generator and Linked Data Stack is presented in Section 9. Related work is presented in Section 11 and we finally conclude in Section 12.

2. Open Geospatial Data on the Web

Currently, there are three major sources of open geospatial data in the Web: Spatial Data Infrastructures, open data catalogues, and crowdsourcing initiatives.

Spatial Data Infrastructures (SDIs) were created to promote the discovery, acquisition, exploitation and sharing of geographic information. They include technological and organisational structures, policies and standards that enable efficient discovery, transfer and use of geospatial data using the web [38]. Research and development in this field is closely tied to standardisation activities led by international bodies, namely the ISO/TC 211², OGC³ and W3C⁴. In Europe, the INSPIRE Directive⁵ follows the OGC open standards, and has defined common data models for a number of application domains, such as hydrography, protected sites and administrative units, to enhance interoperability of spatial data sets of the different European countries. It provides the legal and technical foundations to ensure member state SDIs are compatible and usable on a transboundary context. The major open standard Web services regarding discovery and querying of geospatial data in SDIs are OGCs Catalogue Service and Web Feature Service respectively. The first allows the discovery of geospatial data based on their metadata (e.g. scale, coverage) and the second enables querying of geospatial data. Additional standards provide access to maps and tiles (Web Map Service, Web Tile Service) and enable developers to programmatically invoke and compose complex geospatial analysis services (Web Processing Service). Currently practically all GIS and geospatial databases are fully compatible with these standards; GIS users can consume geospatial data from SDIs and publish geospatial data to SDIs with a few clicks. On a practical level, it is

²<http://www.isotc211.org/>

³<http://www.ogc.org>

⁴<http://www.w3.org/>

⁵<http://inspire.jrc.ec.europa.eu/>

clear that SDIs must be considered as diachronic and stable data infrastructures. They represent a significant investment from the public and private worldwide and are the basis for interoperability among significant scientific domains. Further, they constitute the most prominent source for high-quality open geospatial data. Thus, any contribution and advancement must either be directly involved in standardization efforts, or be based solely on existing standards, without directly affecting their applications.

Open data catalogues provide open geospatial data by a) encapsulating existing SDIs and/or b) ad hoc publishing available geospatial data. In the latter case, geospatial data are published as regular open data. The only difference regards the use of file formats of the geospatial domain (e.g. shapefile, GML) and availability of data for specific coordinate reference systems (typically national CRS). In the former case, an available national/regional SDI is exploited as a source for harvesting its geospatial data. The Catalogue Service is used to discover available data, and their metadata are added in the open data catalogue for homogenised data discovery. The actual data are available as exported file snapshots in common geospatial formats as before, or through the query services provided by the SDI. Consequently, open data catalogues typically offer geospatial data as files and at best expose any available SDI services for data access.

Crowdsourced geospatial data are emerging as a potentially valuable source of geospatial knowledge. Among various efforts we highlight OpenStreetMap, GeoNames, and Wikipedia as the most significant. GeoNames⁶ provides some basic geographical data such as latitude, longitude, elevation, population, administrative subdivision and postal codes. This data is available as text files and also accessible through a variety of web services such as free text search, find nearby or even elevation data services. OpenStreetMap⁷ (OSM), a community initiative for crowdsourced production of open global maps, has emerged as a significant platform for creating, sharing, mapping, browsing and visualising geospatial data on the Web. OSM includes geospatial data of various types (e.g. roads, public transit) daily increase in coverage, accuracy and quality. Data are integrated from public and private sector sources (e.g. transit authorities). Further, easy to use tools, straightforward publishing workflows, and support from the industry, have created a sustainable pathway for establishing OSM as the leading source of open geospatial data in the Web.

3. Semantic Web Technologies for Geospatial Data

The benefits of semantic technology for spatial data management are explored in a number of topics. For example, ontologies have been used in the form of taxonomies on thematic web portals (e.g. habitat or species taxonomies, categories of environmentally sensitive areas, or hierarchical land use classifications). The role of these ontologies is however limited. They provide background knowledge, but only in some experimental prototypes they are used for constructing search requests or for grouping of search results into meaningful categories. Further, in experimental settings, there are examples of using OWL for bridging differences in conceptual schemas, e.g. [12]. The role of ontologies and knowledge engineering in these prototypes is basically to provide methodologies for integration and querying [64,8]. Ontologies have played an important role in structuring data of geospatial domains [1,24]. However, semantic technology has not influenced

⁶<http://www.geonames.org/>

⁷<http://www.openstreetmap.org/>

spatial data management yet, and mainstream GIS tools are not yet extended with semantic integration functionality.

3.1. Standardization Efforts

Early work includes the Basic Geo Vocabulary⁸ by the W3C, which provides a namespace for representing lat(itude), long(itude) and other information about spatially-located entities, using the WGS84 CRS as its standard reference datum. This vocabulary explored the possibilities of representing mapping/location data in RDF, so it was not intended to address all issues covered by OGC. Instead, it was meant to provide just a few basic terms that can be used in RDF (e.g., RSS 1.0 or FOAF documents) so as to describe latitudes and longitudes. The motivation for using RDF as a carrier for lat/long information is RDF's capability for cross-domain data mixing.

GeoRSS⁹ has been designed as a lightweight, community-driven way to extend existing RSS feeds with geographic information, thus providing an interoperable manner to enable processing, aggregation, sharing and mapping of geographically tagged feeds. Two encodings of GeoRSS are available. GeoRSS-Simple is a very lightweight format that can be easily added to existing feeds. It supports basic geometries (point, line, box, polygon) and covers the typical use cases when encoding locations. GeoRSS GML is a formal GML Application Profile, and supports a greater range of features, notably coordinate reference systems other than WGS84 latitude/longitude.

GeoOWL¹⁰ provides an ontology which closely matches the GeoRSS feature model and utilizes the existing GeoRSS vocabulary for geographic properties and classes. Fragments of GeoRSS XML within RSS 1.0 or Atom which conform to the GeoRSS specification will also conform to the Geo OWL ontology. Thus, the ontology provides a compatible extension of GeoRSS for use in more general RDF contexts. Furthermore, topological modelling of geometric shapes in RDF is supported by the NeoGeo Geometry Ontology¹¹. NeoGeo is a still incomplete attempt to establish a vocabulary for describing geographical regions in RDF. It aims to support typical geometric objects as well as WKT serialization. However, both GeoOWL and NeoGeo ontologies only supported the WGS84 CRS (thus leading to gross errors in other CRSs), and offered limited support for geospatial operations required in real world GIS workloads. GeoJSON¹² is a geospatial data interchange format based on JavaScript Object Notation (JSON). A GeoJSON object may represent a geometry, a feature, or a collection of features. Features in GeoJSON contain a geometry object and additional properties, and a feature collection represents a list of features.

GeoRDF was intended as an RDF compatible profile¹³ for geographic information (points, lines and polygons). Vocabularies RDFGeom, and its 2d companion, RDFGeom2d, provide an RDF framework that is extensible via subclassing to all kinds of geometric data, although the class hierarchy is currently only sparsely populated. The class hierarchy is loosely based on the geometric part of SVG. Since lines, curves, and transformations

⁸<http://www.w3.org/2003/01/geo/>

⁹http://georss.org/Main_Page

¹⁰http://www.w3.org/2005/Incubator/geo/XGR-geo-20071023/W3C_XGR_Geo_files/geo_2007.owl

¹¹<http://geovocab.org/>

¹²<http://geojson.org/>

¹³<http://www.w3.org/wiki/GeoRDF>

are geometric, and not specifically geographical notions, RDFGeom and RDFGeom2d formulate geometry without reference to any particular application. Properties that connect geometry to intended interpretations are asserted by application-specific vocabularies

3.2. GeoSPARQL

GeoSPARQL [21] has emerged as a promising standard from W3C for geospatial RDF, with the aim of standardizing geospatial RDF data insertion and query. Standardization of GeoSPARQL is among the goals of OGC in order to ensure a consistent representation of geospatial semantic data across the Web, thus allowing to both vendors and users of data and applications to achieve uniform access to geospatial RDF data. GeoSPARQL provides various conformance classes concerning its implementation of advanced reasoning capabilities, as well as several sets of terminology for topological relationships between geometries. Therefore, different implementations of the GeoSPARQL specification are possible, depending on the respective domain/application. In addition, GeoSPARQL closely follows existing standards from OGC for geospatial data, to facilitate spatial indexing from relational databases. GeoSPARQL defines a small, but concrete ontology for representing features and geometries, as well as a set of SPARQL query predicates and functions, all according to spatial OGC standards. In order to cope with diverse and incompatible methods for representing and querying spatial data, GeoSPARQL follows the existing OGC standards concerning spatial indexing in relational databases. Hence, spatial ontologies can be combined, indexed and queried along with other proprietary ontologies from data providers. Equally important, interoperability among compliant triple stores is achieved, so spatial RDF data can be commonly accessed and exchanged. GeoSPARQL is designed to accommodate systems based on qualitative spatial reasoning and systems based on quantitative spatial computations. Systems based on qualitative spatial reasoning, (e.g. those based on the Region Connection Calculus [51]) do not usually model explicit geometries, so the geometries are either unknown or cannot be made concrete. Thus, queries in such systems will likely test for binary spatial relationships between features rather than between explicit geometries. A quantitative spatial reasoning system involves concrete geometries for features, so distances, areas and topological relations can be explicitly calculated. To allow queries for spatial relations between features in quantitative systems, GeoSPARQL defines a series of query transformation rules that expand a feature-only query into a geometry-based query. With these transformation rules, queries about spatial relations between features will have the same specification in both qualitative systems and quantitative systems. The qualitative system will likely evaluate the query with a backward-chaining spatial reasoner, and the quantitative system can transform the query into a geometry-based query that can be evaluated with computational geometry. With a common set of topological relations, GeoSPARQL allows conclusions from quantitative applications to be used by qualitative systems and a single query language for both types of reasoning. Future extensions are oriented towards definitions of new conformance classes for other standard serializations of geometry data (e.g. KML, GeoJSON). Developing vocabularies for spatial data, and expanding the GeoSPARQL vocabularies with OWL axioms to aid in logical spatial reasoning is also considered as a valuable contribution. Standard processes could also be developed for converting to RDF and exposing large amounts of existing feature data represented either in GML-like formats or in a data store supporting the general feature model [21].

3.3. Research Efforts

There has been a growing research interest towards representing and querying geospatial data in RDF. An extension to SPARQL, termed SPARQL-ST [50] proposed a modified SPARQL syntax for specifying spatial queries against data modelled in a GeoRSS-like ontology. This dialect supported data in different spatial reference systems, something missing from many vocabularies such as GeoOWL and the Basic Geo vocabularies. It also included support for temporal and thematic features. But the proposed query syntax deviates from the standard SPARQL, whereas exposed data cannot be accessed from third-party systems that do not use SPARQL-ST.

The issue of adding topological predicates to SPARQL was also examined in [63]. The proposed ontology takes advantage of OGC Simple Features [20] in order to provide a basic set of geometries and relations. However, relations have to be specifically encoded in RDF whereas there is no support for multiple CRS in the data. A hierarchical approach is proposed in [19], using a meta-level for abstract space-time knowledge, a schema-level for well-known models in spatial and temporal reasoning (e.g., RCC), and an instantiation-level for mappings and formal descriptions. This model refers to various spatiotemporal statements in the Linked Data clouds and nicely abstracts spatial knowledge from its underlying representation. However, mappings must be defined for each dataset at the instantiations level. A research prototype was presented in [7] that supports a native RDF triple store implementation with deeply integrated spatial query functionality. Spatial features in RDF are modelled as literals of a complex geometry type so spatial predicates can be expressed as SPARQL filter functions on this type. This makes it possible to use W3C's standardized SPARQL query language as-is, i.e., without any modifications or extensions for spatial queries. It is noteworthy that OGC Simple Features relations are used as the background for posing queries with spatial predicates. In parallel to research on geospatial support, Semantic Web technologies have also provided a great deal of schema flexibility useful in analyzing and integrating poorly structured data, e.g., web- or community-based data, such as map data from the OpenStreetMap project [3]. This LinkedGeoData set offers a spatial knowledge base, derived from Open Street Map¹⁴ and is interlinked with DBpedia¹⁵, GeoNames¹⁶ and other datasets as well as integrated with icons and multilingual class labels from various sources. It contains over many million triples describing the nodes and paths from OpenStreetMap. The LinkedGeoData set is accessible through SPARQL endpoints running on Virtuoso platform¹⁷, as well as via a REST interface in its most recent release [53].

4. The GeoKnow Project

GeoKnow is an EU research project running for three years from December 2012 to November 2015. It is motivated by previous work in the LinkedGeoData [53] project (LGD), which makes OpenStreetMap data available as an RDF knowledge base. As a result, OSM data were introduced in the LOD cloud and interlinked with GeoNames,

¹⁴<http://www.openstreetmap.org/>

¹⁵<http://dbpedia.org/About>

¹⁶<http://www.geonames.org/>

¹⁷<http://virtuoso.openlinksw.com/>

DBpedia [33,36], and multiple other data sources. LGD intended to simplify information creation and aggregation related to spatial features. During this exercise, several research challenges were found such as scalability with spatial data, query performance, spatial data modelling, flexible transformation of special data, as well data operations such routing data. It was realised that geospatial data, specially scientific data, available on the web can open new opportunities to improve management and decision making applications.

Consequently, the vision of the project is to make geospatial data more easily accessible on the web and improve its publishing, querying, interlinking and quality assessment based on the Linked Data principles and the Linked Data Life-Cycle vision [2]. This will facilitate the development of applications and backend functionality or enable answering questions that were not possible with isolated geospatial data. This change is also a step towards the discoverability of data that share geospatial features (i.e. supported by querying and reasoning), and a boosting for the geospatial data integration through geospatial data merging and fusing tools. The project applies the RDF model and the GeoSPARQL standard as the basis for representing and querying geospatial data. In particular, GeoKnow contributions are in the following areas:

Efficient geospatial RDF querying. Existing RDF stores lack performance and geospatial analysis capabilities compared to geospatially-enabled relational DBMS. We introduce query optimisation techniques for accelerating geospatial querying significantly.

Fusion and aggregation of geospatial RDF data. Given a number of different RDF geospatial data for a given region containing similar knowledge (e.g. OSM, PSI and closed data¹⁸) we devise semi-automatic fusion and aggregation techniques in order to consolidate them and provide a data set of increased value and quantitative quality metrics of this new data resource

Visualisation and authoring. We develop reusable mapping components, enabling the integration of geospatial RDF data as an addition data resource in web map publishing. Further, we enable the light-weight creation of simple geospatial applications by shifting the complexity of development to data integration and modelling.

GeoKnow Generator. The GeoKnow Generator consists of a full suite of tools supporting the complete life-cycle of geospatial linked open data. The GeoKnow Generator enables publishers to triplify geospatial data, interlink them with other geospatial and non-geospatial Linked Data sources, fuse and aggregate linked geospatial data to provide new data of increased quality, visualise and author linked geospatial data in the Web.

5. The Linked Data Life-Cycle

The different stages of the Linked Data life-cycle (depicted in Figure 1) include:

Storage. RDF Data Management is still more challenging than relational Data Management. This is especially true for the large volume of geo-spatial data available on the Data Web. We aim to close this performance gap by employing column-store technology, dynamic query optimization, adaptive caching of joins, optimized graph

¹⁸http://ec.europa.eu/information_society/policy/psi/index_en.htm

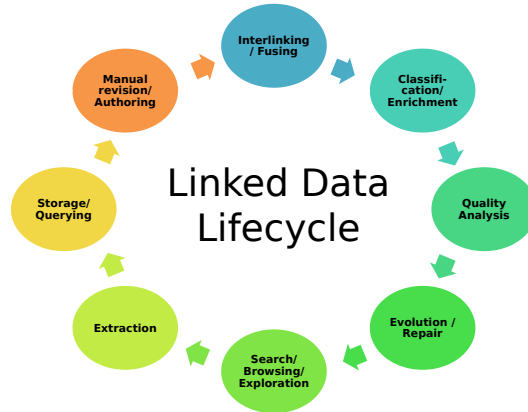


Figure 1. Stages of the Linked Data life-cycle supported by the Linked Data Stack.

processing and cluster/cloud scalability. Moreover, we aim to provide techniques that allow SPARQL to SQL mapping with the aim of making the results of decades of research on geo-information systems available to the Data Web community.

Authoring. In GeoKnow, we aim to facilitate the authoring of rich semantic knowledge bases by leveraging Semantic Wiki technology, the WYSIWYM paradigm (What You See Is What You Mean) and distributed social, semantic collaboration and networking techniques. Moreover, we aim to provide frameworks that allow for the time-efficient development of applications based on geo-spatial data.

Interlinking. Creating and maintaining links in a (semi-)automated fashion is still a major challenge and crucial for establishing coherence and facilitating data integration. We seek linking approaches yielding high precision and recall, which scale to large knowledge bases. These approaches need to support geo-spatial features such as vector geometry. In addition, we aim to devise approaches for efficient memory management through link discovery approaches which can configure themselves automatically or with end-user feedback.

Classification. Linked Data on the Web is mainly raw instance data. For data integration, fusion, search and many other applications, however, we need this raw instance data to be linked and integrated with upper level ontologies.

Quality. The quality of content on the Data Web varies, as the quality of content on the document web varies. We aim to develop techniques for assessing the quality of RDF data based on characteristics such as provenance, context, coverage or structure.

Evolution/Repair. Data on the Web is dynamic. We need to facilitate the evolution of data while keeping things stable. Changes and modifications to knowledge bases, vocabularies and ontologies should be transparent and observable. We also develop methods to spot problems in knowledge bases and to automatically suggest repair strategies.

Search/Browsing/Exploration. For many users, the Data Web is still invisible below the surface. We develop search, browsing, exploration and visualization techniques for different kinds of Linked Data (i.e. spatial, temporal, statistical), which make the Data Web sensible for real users.

These life-cycle stages, however, should not be tackled in isolation, but by investigating methods which facilitate a mutual fertilization of approaches developed to solve these challenges. Examples for such mutual fertilization between approaches include:

- Ontology matching and instance matching, as the detection of adequate class mappings facilitate the correct detection of links across knowledge bases and vice-versa.
- Ontology schema mismatches between knowledge bases can be compensated for by learning which concepts of one are equivalent to which concepts of another knowledge base.
- Feedback and input from end users (e.g. regarding instance or schema level mappings) can be taken as training input (i.e. as positive or negative examples) for machine learning techniques in order to perform inductive reasoning on larger knowledge bases, whose results can again be assessed by end users for iterative refinement.
- Semantically enriched knowledge bases improve the detection of inconsistencies and modelling problems, which in turn results in benefits for interlinking, fusion, and classification.
- The querying performance of RDF data management directly affects all other components, and the nature of queries issued by the components affects RDF data management.

As a result of such interdependence, we should pursue the establishment of an improvement cycle for knowledge bases on the Data Web. The improvement of a knowledge base with regard to one aspect (e.g. a new alignment with another interlinking hub) triggers a number of possible further improvements (e.g. additional instance matches).

The challenge is to develop techniques which allow exploitation of these mutual fertilizations in the distributed medium Web of Data. One possibility is that various algorithms make use of shared vocabularies for publishing results of mapping, merging, repair or enrichment steps. After one service published its new findings in one of these commonly understood vocabularies, notification mechanisms (such as *Semantic Pingback* [56]) can notify relevant other services (which subscribed to updates for this particular data domain), or the original data publisher, that new improvement suggestions are available. Given proper management of provenance information, improvement suggestions can later (after acceptance by the publisher) become part of the original dataset.

6. The Linked Data Stack

The Linked Data Stack serves two main purposes. Firstly, the aim is to ease the distribution and installation of tools and software components that support the Linked Data publication cycle. As a distribution platform, we have chosen the well established Debian packaging format. The second aim is to smoothen the information flow between the different components to enhance the end-user experience by a more harmonized look-and-feel.

6.1. Deployment Management Leveraging Debian Packaging

In the *Debian package management system* [37], software is distributed in architecture-specific binary packages and architecture-independent source code packages. A Debian software package comprises two types of content: **(1)** control information (incl. metadata) of that package, and **(2)** the software itself.

The control information of a Debian package will be indexed and merged together with all other control information from other packages available for the system. This information consists of descriptions and attributes for:

- (a) The software itself (e.g. licenses, repository links, name, tagline, ...),
- (b) Its relation to other packages (dependencies and recommendations),
- (c) The authors of the software (name, email, home pages), and
- (d) The deployment process (where to install, pre and post install instructions).

The most important part of this control information is its relations to other software. This allows the deployment of a complete stack of software with one action. The following dependency relations are commonly used in the control information:

Depends: This declares an absolute dependency. A package will not be configured unless all of the packages listed in its Depends field have been correctly configured. The Depends field should be used if the depended-on package is required for the depending package to provide a significant amount of functionality. The Depends field should also be used if the install instructions require the package to be present in order to run.

Recommends: This declares a strong, but not absolute, dependency. The Recommends field should list packages that would be found together with this one in all but unusual installations.

Suggests: This is used to declare that one package may be more useful with one or more others. Using this field tells the packaging system and the user that the listed packages are related to this one and can perhaps enhance its usefulness, but that installing this one without them is perfectly reasonable.

Enhances: This field is similar to Suggests but works in the opposite direction. It is used to declare that a package can enhance the functionality of another package.

Conflicts: When one binary package declares a conflict with another using a Conflicts field, dpkg will refuse to allow them to be installed on the system at the same time. If one package is to be installed, the other must be removed first.

All of these relations may restrict their applicability to particular versions of each named package (the relations allowed are $<<$, $<=$, $=$, $>=$ and $>>$). This is useful in forcing the upgrade of a complete software stack. In addition to this, dependency relations can be set to a list of alternative packages. In such a case, if any one of the alternative packages is installed, that part of the dependency is considered to be satisfied. This is useful if the software depends on a specific functionality on the system instead of a concrete package (e.g. a mail server or a web server). Another use case of alternative lists are meta-packages. A meta-package is a package which does not contain any files or data to be installed. Instead, it has dependencies on other (lists of) packages.

Installing the Linked Data Stack The Linked Data Stack is available at <http://stack.linkeddata.org/>. Our reference OS is *Ubuntu 12.04 LTS*. Most of the components run on old or more recent releases without a problem. In general, deploying the Linked Data Stack software or parts of it is simple. There are only two steps to execute in order to install Linked Data Stack software: **(1)** Add the Linked Data Stack package repository to the system's repository list and update the repository index. **(2)** Install desired software packages by using a graphical or text-based package management application. The procedure can be executed using graphical front-ends like Synaptic¹⁹. Using the command line the Linked Data Stack installation is performed as follows²⁰:

```
# download the repository package
wget http://stack.linkeddata.org/download/lds-repo.deb
# install the repository package
sudo dpkg -i lds-repo.deb
# update the repository database
sudo apt-get update
```

This action will download, install and update the repository package. The actual list of components available to install can be found in the LDStack website²¹.

GeoKnow has also contributed to the Stack by providing a web-based application: the GeoKnow Generator, that integrates some of the components of the stack. The Generator can be installed with the command line as follows:

```
# install GeoKnow Generator
# with dependent components from Linked Data Stack
sudo apt-get install geoknow-generator-ui
```

6.2. Data integration based on SPARQL, Authentication and Provenance

The basic architecture of a local installation of Linked Data Stack including GeoKnow Generator is depicted in Figure 2. All components in the Linked Data Stack act upon RDF data and are able to communicate via SPARQL with the central system-wide RDF quad store (i.e. SPARQL backend). This quad store (Openlink Virtuoso) manages user graphs (knowledge bases) as well as a set of specific system graphs where the behaviour and status of the overall system is described. The following system graphs are currently used:

Package Graph: In addition to the standard Debian package content, each Linked Data Stack package consists of a RDF package info which contains:

- The basic package description, e.g. labels, dates, maintainer info (this is basically DOAP data and redundant to the classic Debian control file);
- Pointers to the place where the application is available;
- A list of capabilities of the packed software (e.g. resource linking, RDB extraction). These capabilities are part of a controlled vocabulary. The terms are used as pointers for provenance logging and access control definition.

¹⁹<http://www.nongnu.org/synaptic/>

²⁰More information, tutorials and FAQs can be found at <http://stack.linkeddata.org/documentation/>.

²¹<http://stack.linkeddata.org/download/repo.php>

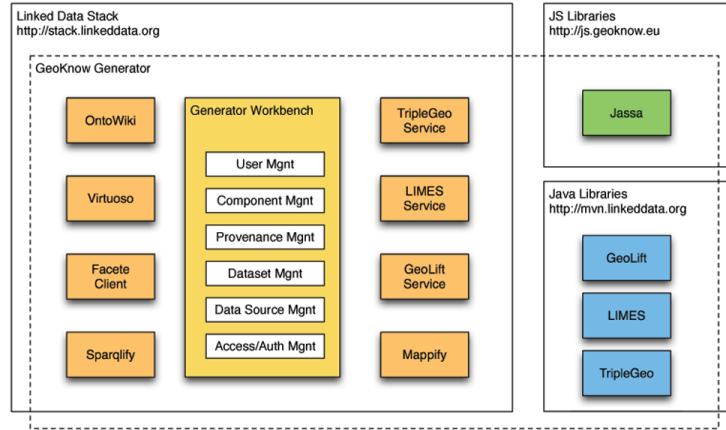


Figure 2. Basic architecture of GeoKnow Generator within Linked Data Stack.

Upon installation, the package info is automatically added to the package graph to allow to query which applications are available and what is the user able to do with them.

Access Control Graph: This system graph implements a simple authentication and a graph level authorisation. It describes which users are able to use which capabilities and have access to which graphs. The default state of this graph contains no restrictions, but could be used to restrict certain authorisation control to specific capabilities.

Provenance Graph: Each software package is able to log system wide provenance information to reflect the evolution of a certain knowledge base. Different ontologies are developed for that use-case. To keep the context of the Linked Data Stack, we use the controlled capability vocabulary as reference points.

In addition to the SPARQL protocol endpoint, application packages can use a set of APIs which allow queries and manipulation currently not available with SPARQL alone (e.g. fetching graph information and manipulating namespaces). The Debian system installer application automatically adds and removes package descriptions during install / upgrade and remove operations. All other packages are able to use the APIs as well as to create, update and delete knowledge bases.

7. GeoKnow Linked Data Stack Components

Table 1 shows the current Linked Data Stack components in alphabetic order. In the following, we give a brief summary on some of the most important packages.

Tool	Category	Supported Stages
DL-Learner [29,30,32]	Machine Learning in OWL	Enrichment
Facete [54]	Faceted browser for spatial data	Browsing, Exploration
GeoLift	Enrichment with with geo-spatial information	Enrichment
LIMES [44,40,41,42,43]	Linking Workbench	Interlinking
Mappify	Map view generator	Browsing, Exploration
OntoWiki [15]	Generic Data Wiki	Authoring, Exploration
ORE [31]	Knowledge Base Debugging	Repair
R2RLint	RDB2RDF quality assessment	Quality Analysis
RDFauthor [57]	RDFa authoring	Authoring
RDFUnit [26]	Quality assessment tool	Quality Analysis
Sparqlify	RDB2RDF Mapping	Extraction
TripleGeo	Geo-spatial feature extraction	Extraction
Virtuoso	Hybrid RDBMS/Graph Column Store	Storage / Querying

Table 1. Overview on GeoKnow Linked Data Stack components.**DL-Learner**

Life-cycle phase	Enrichment (and Analysis)
Website	http://dl-learner.org
Licence	GPL 3.0
Source	https://github.com/AKSW/DL-Learner

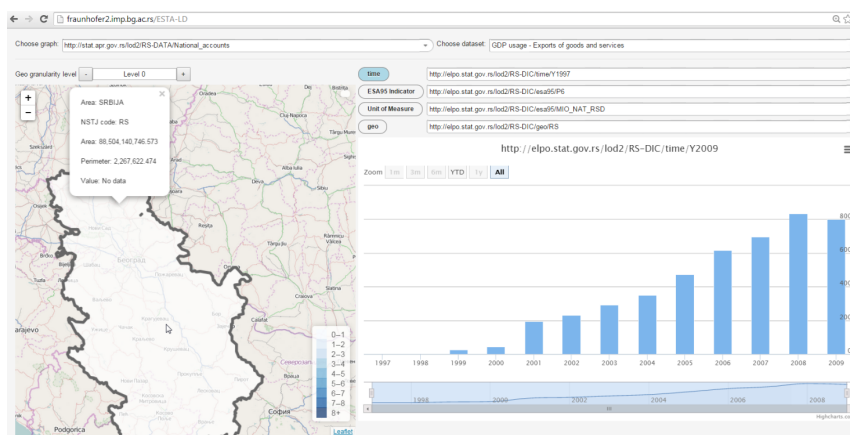


The DL-Learner framework provides a set of supervised machine learning algorithms (see e.g. [32]) for knowledge bases, specifically for OWL ontologies and SPARQL endpoints. The goal of DL-Learner is to support knowledge engineers in constructing knowledge and learning about the data they created, by generating axioms and concept descriptions which fit the underlying data. DL-Learner is used in the backend of the ORE and RDFUnit tools.

DL-Learner includes several learning algorithms, including refinement operator based algorithms, a genetic programming algorithm, a hybrid algorithm using refinement and genetic programming and an algorithm based on least general generalisation. The framework supports different kinds of learning problems, including various types of OWL axioms as well as standard supervised learning from positive and negative examples or only positive examples. Various input formats such as OWL file formats, RDF file formats and SPARQL endpoints are supported. Most major reasoners can be used via the OWL API interface and efficient light-weight reasoners optimised for machine learning are also integrated.

ESTA-LD

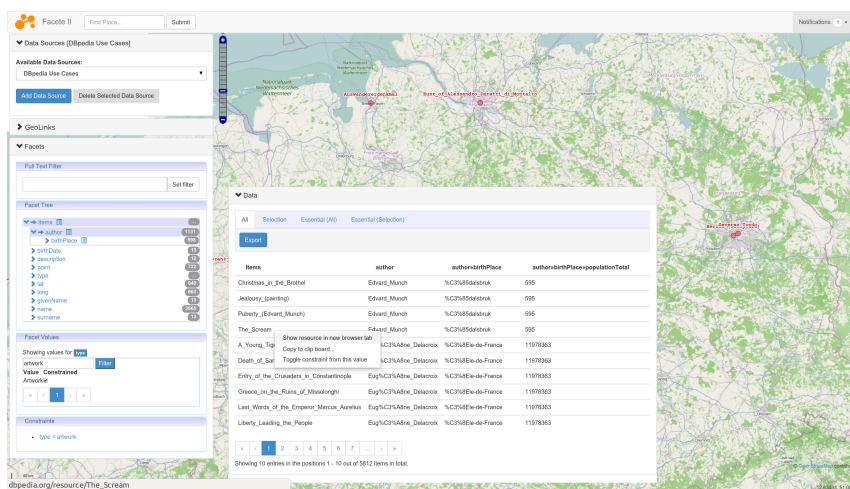
Life-cycle phase	Browsing and Exploration
Website	https://github.com/GeoKnow/ESTA-LD
Licence	GPLv3
Source	https://github.com/GeoKnow/ESTA-LD



In the last few years, the global Open Government Data (OGD) initiatives, such as the Open Government Partnership, have helped to open up governmental data to the public, thus creating a potential to integrate and analyze governmental data coming from different sources. ESTA-LD (Exploratory Spatio-Temporal Analysis for Linked Data) is a software tool for interactive analysis, visualization and drill-down style online access to highly granular spatio-temporal data. It is aimed for business users interested in spatial analysis of different socio-economic indicators modelled using W3C standard vocabularies (RDF Data Cube, eGovernment) and LinkedData principles. The data retrieved from a specified SPARQL endpoint is visualized on the choropleth map thus allowing the user to study the indicators (stored in a single or multiple datasets) across a geographic area. The geographic data (such as region borders), originally created from shape files, is stored in GeoJSON format. Different user interaction and filtering options are foreseen. Currently supported filtering options are selection of indicator under study, selection of the area of interest on the geographical map, selecting geo granularity level, selecting values from the hierarchical dimensions modelled with the SKOS vocabulary, and selecting the chart type. The results of the spatio-temporal analysis are visualized using Highcharts library, while choropleth map is used to visualize how measurements vary across a geographic area.

Facete2

Life-cycle phase	Browsing and Exploration
Website	https://github.com/GeoKnow/Facete2
Licence	Apache License, Version 2.0
Source	https://github.com/GeoKnow/Facete2



Facete2 is a powerful Web application for faceted browsing of (spatial) RDF data that is accessible via SPARQL. When a user selects a SPARQL endpoint, the application automatically shows all spatial resources on a map and presents the user with a facet tree for navigation and filtering of the data. A constraint list displays the currently active filters, and a customizable table view shows information about the resources. This information can be exported in different formats. The map and table view update themselves as the filters change. Facete2 also performs relationship finding between resources that match the constraints and those resources that can be shown on the map, and enables the user to choose which one to use as a data source for map display.

Many features of Facete2 are available through separate libraries, such as the *Javascript Suite for Sparql Access* (Jassa)^a and the *Jena SPARQL API*^b.

^a<https://github.com/GeoKnow/Jassa-Core>

^b<https://github.com/AKSW/jena-sparql-api>

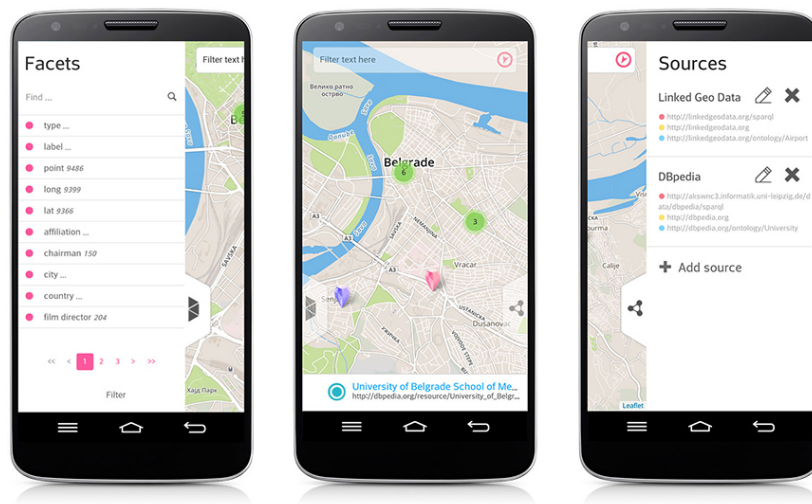
DEER

Life-cycle phase	Enrichment
Website	http://aksw.org/Projects/DEER
Licence	CC BY-SA 2.5
Source	https://github.com/GeoKnow/DEER

Over the last years, the Linked Data principles have been used across academia and industry to publish and consume structured data. Thanks to the fourth Linked Data principle, many of the RDF datasets used within these applications contain implicit and explicit references to more data. For example, music datasets such as Jamendo include references to locations of record labels, places where artists were born or have been, etc. Datasets such as Drugbank contain references to drugs from DBpedia, where verbal description of the drugs and their usage is explicitly available. The goal of mapping component, dubbed DEER, is to retrieve this information, make it explicit and integrate it into data sources according to the specifications of the user. To this end, DEER relies on a simple yet powerful pipeline system that consists of two main components: modules and operators. Modules implement functionality for processing the content of a dataset (e.g., applying named entity recognition to a particular property). Thus, they take a dataset as input and return a dataset as output. Operators work at a higher level of granularity and combine datasets. Thus, they take sets of datasets as input and return sets of datasets.

GEM

Life-cycle phase	Enrichment
Website	https://github.com/GeoKnow/GEM
Licence	GPLv3
Source	https://github.com/GeoKnow/GEM

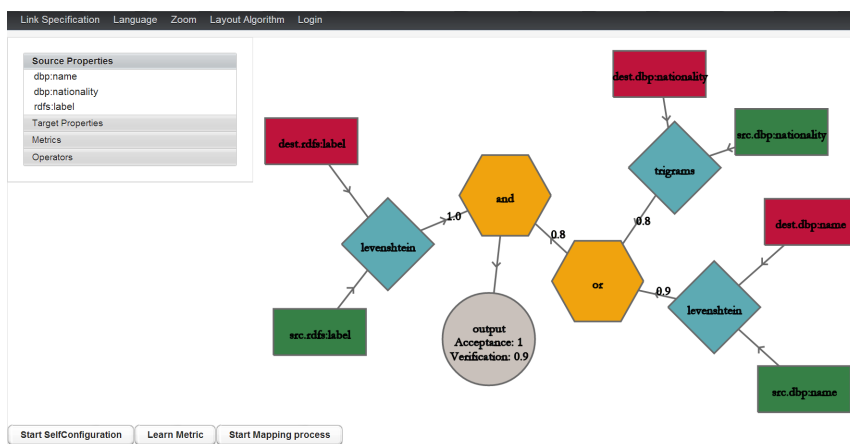


The explosion of location aware technology has made the move of geographical information to their, perhaps, more natural setting, i.e. mobile devices, inevitable for any geospatial software striving to survive the demands of the ever-growing market. However, the functionality of the majority of available navigation systems is developed upon closed and proprietary solutions for both maps and software applications. Furthermore, such applications are unable to offer information specifically tailored to data consumer's needs, and cannot be extended by third parties. Although recent attempts propose ways of overcoming some of these barriers, none leverage the full power of the Linked Data paradigm. The design and usability choices of desktop applications make them often hard or impossible to interact with on mobile devices due to both hardware (smaller screens, lower screen resolutions, lack of buttons, less processing power etc.) and software constraints. Therefore, the work on the GeoKnow spatial-semantic visualization and exploration component (Facete) might prove impractical for a user on the go (e.g. in a car, on a bike, on foot etc.).

GEM (Geospatial-semantic Exploration on the Move) complements the desktop GeoKnow Generator component through a rich mobile experience that exploits all strengths of Linked Data and further rises above the common mobile geospatial visualization limitations by relying on open, crowd-sourced and semantically linked information found in publicly available sources, such as the LOD Cloud. This information is loaded, clustered and filtered according to user's needs, on demand, in order to prevent maps from overpopulating. Moreover, in order to reach a larger target population and ignite community engagement and contribution (through a live authoring component), the tool is deployed through Apache Cordova / Adobe Phonegap, making it easier to target multiple major mobile platforms (Android, iOS, Windows Phone) and increase the impact on the society as a whole.

LIMES

Life-cycle phase	Interlinking
Website	http://limes.sf.net
Licence	GPLv3
Source	http://github.com/AKSW/LIMES



LIMES implements time-efficient approaches for link discovery. The main emphasis of the tool is on providing *correct*, *complete* and *efficient* approaches for the discovery of links between knowledge bases. By these means, LIMES tackles the two main challenges of link discovery: scalability and accuracy.

The *scalability* problem is addressed by providing approximation techniques to compute estimates of the similarity between instances. These estimates are then used to filter out a large amount of those instance pairs that do not suffice the mapping conditions. By these means, LIMES can reduce the number of comparisons needed during the mapping process by several orders of magnitude. The approaches implemented in LIMES include the original LIMES algorithm for edit distances, REEDED for weighted edit distances, HR3, HYPPO, and ORCHID, the first link discovery approach for orthodromic spaces. In its current version, RC 0.6.4, LIMES supports 13 similarity measures of which six are geo-spatial distance measures. Moreover, LIMES provides the first planning algorithm for link discovery, dubbed HELIOS. This algorithm relies on linear regression to detect time-efficient plans to run specifications efficiently.

In addition to being scalable, LIMES tackles the *accuracy* problem by implementing several machine learning paradigms for finding accurate link specifications. For example, LIMES provides supervised and active machine-learning approaches to detect correct links in a user-driven manner. When faced with 1 to 1 relations (especially owl:sameAs), LIMES can even run unsupervised machine learning to detect link. Moreover, LIMES is the first link discovery framework that can make use of the distributed topology of the Data Web to improve not only links but even detect errors in the data underlying the link discovery process. These insights are implemented with several machine-learning approaches, in particular genetic programming and hierarchical search in similarity spaces. The algorithms implemented here include the supervised, active and unsupervised versions of EAGLE, COALA and EUCLID.

Mappify

Life-cycle phase	Browsing and Exploration
Website	http://mappify.aksw.org/
Licence	Apache License, Version 2.0
Source	https://github.com/GeoKnow/Mappify



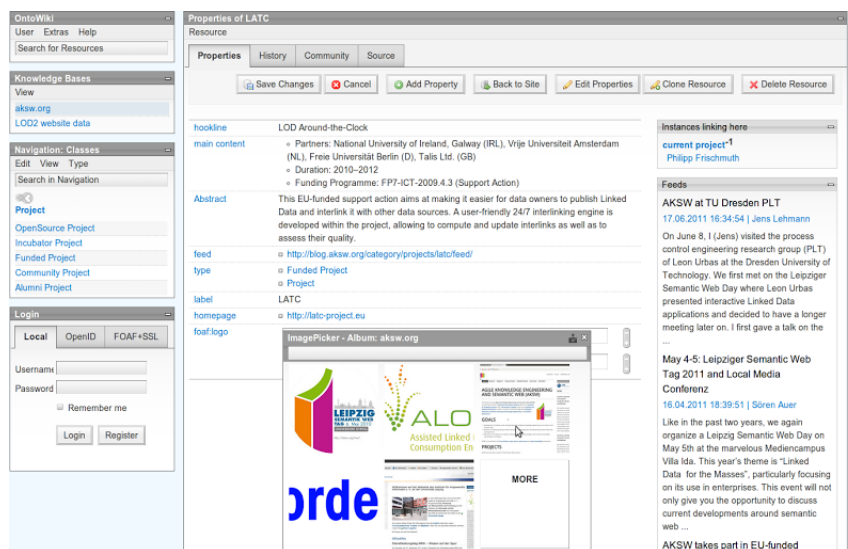
Mappify is a web application to easily create map views displaying concept based points of interest. Mappify provides faceted exploration capabilities for arbitrary SPARQL endpoints, utilizing the reusable Jassa faceted browsing components. This allows to define custom, complex concepts based on per-facet constraints to describe certain points of interest. These might be for example restaurants that serve fish and are accessible by wheelchair. Such *concepts* serve as complex class descriptions to capture all RDF instances that should be shown on a map.

For the actual display Mappify provides controls to define *how* the instances should be rendered and *which properties* should be presented. The instances' properties to present are specified via a SPARQL query. The query variables are then bound to JSON attributes utilizing a SPONATE^a mapping. The JSON attributes can be referenced in a custom HTML template that is filled with the instance's properties data and shown whenever a user clicks on an instance marker on the map. A screenshot of the input controls is shown on the left. Mappify comes with a comprehensive library of free map markers allowing to customize the marker icons for defined concepts as shown on the right screenshot above. All the map settings configured with Mappify can be exported, embedded in an HTML snippet, which contains all the information to render the configured map. This snippet can then be re-used and integrated in arbitrary web sites. This enables users to easily create own individual map views combining the presentation of different custom points of interest on one map.

^a<https://github.com/GeoKnow/Jassa-Core/tree/master/lib/sponate>

OntoWiki

Life-cycle phase	Extraction, Storage/Querying, Revision/Authoring, Search/Browsing/Exploration
Website	http://aksw.org/Projects/OntoWiki
Licence	GPLv2
Source	https://github.com/AKSW/OntoWiki



OntoWiki facilitates the visual presentation of a knowledge base as an information map, with different views on instance data. It enables intuitive authoring of semantic content. It fosters social collaboration aspects by keeping track of changes, allowing to comment and discuss every single part of a knowledge base. Additional features are:

- OntoWiki is a Linked Data Server for you data as well as a Linked Data client to fetch additional data from the web
- OntoWiki is a Semantic Pingback Client in order to receive and send back-linking request as known from the blogosphere.
- OntoWiki is backend independent, which means it can save data on a MySQL database as well as on a Virtuoso Triple Store.
- OntoWiki is easily extendible, since it features a sophisticated Extension System.

ORE

Life-cycle phase	Enrichment/Repair
Website	http://aksw.org/Projects/ORE
Licence	Apache License, Version 2.0
Source	https://github.com/AKSW/ORE

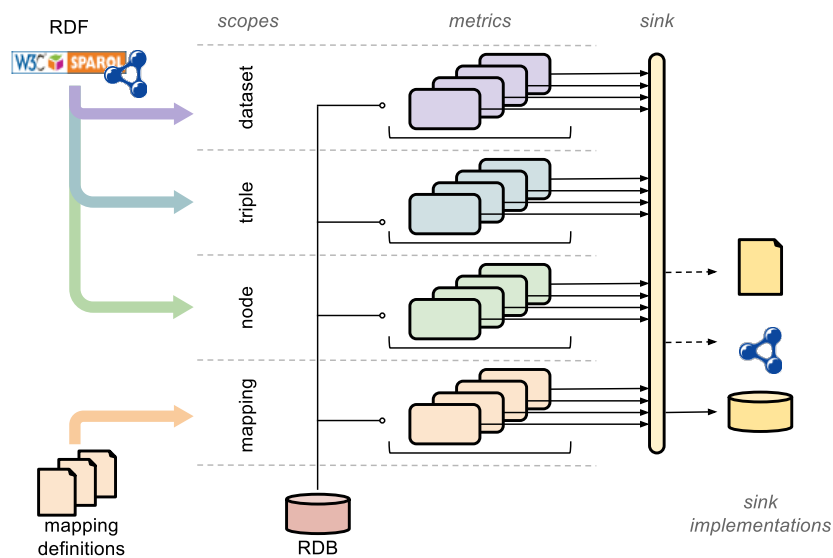
The ORE tool supports knowledge engineers in enriching the schema of OWL-based knowledge bases, either accessible as file or via SPARQL. Additionally, it allows for the detection and repair of logical errors and naming issues as well as the validation of instance data by defining constraints in forms of OWL axioms. First of all, ORE supports a user in the detection and repair of unsatisfiable classes and inconsistencies by computing so-called justifications, i.e. minimal sets of axioms of the ontology that cause the issues. Metrics for the ranking of these axioms allow the user to change or remove the most appropriate ones.

Secondly, the integration of the DL-Learner framework enables a user to enrich the ontology schema by applying ILP-based machine learning algorithms, which generate axioms that fit the instances data as good as possible.

Moreover, in ORE it is possible to detect and repair naming issues by making use of the capabilities provided by the PatOMat framework. Given some naming patterns as input, pattern instances like e.g. [Superclass=Person;Subclass=Religious] are computed, and renaming instructions like [Religious → ReligiousPerson] will be provided which can then be used to transform the ontology and solve the detected naming issues.

R2RLint

Life-cycle phase	Quality Analysis
Website	https://github.com/AKSW/R2RLint
Licence	Apache License, Version 2.0
Source	https://github.com/AKSW/R2RLint



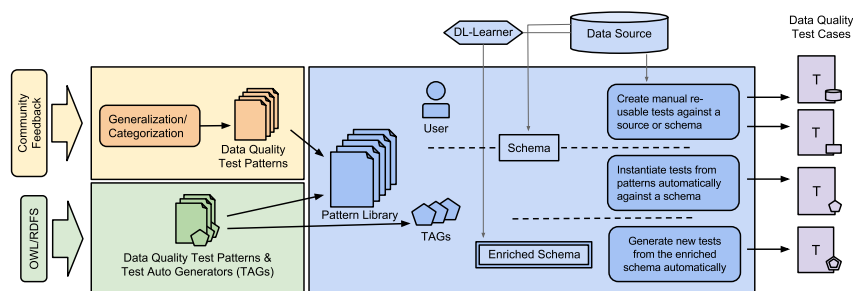
R2RLint is a quality assessment tool for RDB2RDF mapping projects that not only considers the generated RDF output but also takes the relational input and mapping definitions into account. The core of R2RLint is a command line tool to run quality assessments on arbitrary RDB2RDF mapping projects. It comes with 43 implemented quality assessment metrics covering different quality aspects.

Moreover R2RLint provides a framework that can be easily expanded by own metrics without expensive wiring and deeper insights into the software. Metrics in R2RLint can be defined for different *scopes* which determine the amount of information given as input to compute a quality score (see the conceptual overview above). They are divided into the *dataset scope* for dataset wide quality evaluations (e.g. ontological consistency), the *triple scope* to assess the quality of generated triples (e.g. to detect certain RDF features that are considered as deprecated or prolux[18]), the *node scope* to assess single nodes, i.e. URIs, blank nodes or literals (e.g. to detect the generation of invalid URIs or language tags), and finally the *mapping definition scope* to find mapping errors (e.g. the introduction of many duplicate triples due to copy-and-paste errors).

Furthermore each metric has access to the underlying relational database to obtain input values of the RDB2RDF conversion or relational schema information. Apart from this R2RLint is also extensible with regards to the component that receives and holds the actual assessment results, the *assessment sinks*. Different custom sink implementations can be added without further knowledge of the internals of R2RLint to write the assessments results to relational databases, RDF files etc.

RDFUnit

Life-cycle phase	Quality Analysis
Website	http://rdfunit.aksw.org
Licence	Apache License, Version 2.0
Source	https://github.com/AKSW/RDFUnit



RDFUnit [26] is a quality assessment tool following the *Test-Driven Data Quality Methodology* [27]. It can be used as command line tool, via the RDFUnit web interface^a or as library component in other applications. The main building blocks of the underlying methodology are

- *test cases* that define certain constraints that must hold for high quality data
- a *test suite* comprising a set of test cases to check against an RDF dataset
- *Data Quality Test Patterns* being abstract templates that define general relations between data that might be desirable in a dataset under assessment
- *pattern bindings* which bind Data Quality Test Patterns to a dataset or ontology, forming instantiated test cases that can be evaluated
- *Test Auto Generators (TAGs)* which can automatically derive pattern bindings for Data Quality Test Patterns based on ontology or schema information

Besides the automatic pattern instantiation based on the ontological or schema restrictions defined directly in the dataset or in the used ontologies, patterns can also be instantiated based on inherent schema information derived from the actual data. This is especially useful for datasets or vocabularies without rich ontological structures. These ‘artificial’ schema axioms are computed by the DL-Learner tool [29]. Since test cases derived from common vocabularies are highly reusable they can also be directly chosen from the RDFUnit test case library. One last means for the test case creation is to instantiate Data Quality Test Patterns manually which can be performed e.g. by domain experts to express certain dataset specific constraints that must hold.

In an automatic quality assessment run RDFUnit evaluates all instantiated test cases and highlights all test case violations, i.e. all cases where tests fail together with the triples that caused the failure. Hence, RDFUnit can directly point to the data that cause data quality issues and also allows the storage of the results to document the dataset’s temporal data quality evolution.

^aFind a demo at <http://rdfunit.aksw.org/demo/>

RDF Data Cube Validation

Life-cycle phase	Quality Analysis
Website	https://github.com/GeoKnow/DataCubeValidation
Licence	Apache License, Version 2.0
Source	https://github.com/GeoKnow/DataCubeValidation

Data Cube Validation
Refresh
RDFUnit Validation
Evaluate All
Settings

Summary
Provenance

IC-1 Observations have links

- IC-2 Unique DSD
- IC-3 DSD includes measure
- IC-4 Dimensions have range
- IC-5 Concept dimensions have code lists
- IC-6 Only attributes may be optional
- IC-7 Slice Keys must be declared
- IC-8 Slice Keys consistent with DSD
- IC-9 Unique slice structure
- IC-10 Slice dimensions complete
- IC-11 All dimensions required
- IC-12 No duplicate observations
- IC-13 Required attributes
- IC-14 All measures present
- IC-15 Measure dimension consistent
- IC-16 Single measure
- IC-17 All measures present in meas. dim. cube
- IC-18 Consistent data set links
- IC-19 Codes from code list
- IC-20 Codes from hierarchy
- IC-21 Codes from hierarchy (inverse)

Below is the list of observations that are not linked to exactly one data set. Click on any of them to get more information and either edit the resource in OntoWiki or choose a quick solution

Observations

http://elipo.stat.gov.rs/iod2/RS-DATA/National_accounts/Gross_value_added_by_activities_at_current_prices/data_2011_12_28/obs1

Details

Property	Object
http://elipo.stat.gov.rs/iod2/RS-DIC/rs/geo	http://elipo.stat.gov.rs/iod2/RS-DIC/geo/RS
http://elipo.stat.gov.rs/iod2/RS-DIC/rs/time	http://elipo.stat.gov.rs/iod2/RS-DIC/time/Y2000
http://purl.org/linked-data/sdmx/2009/attribute#unitMeasure	http://elipo.stat.gov.rs/iod2/RS-DIC/esa95-unit/MIO_NAT
http://purl.org/linked-data/sdmx/2009/measure#obsValue	357785.5
http://www.w3.org/1999/02/22-rdf-syntax-ns#type	http://purl.org/linked-data/cube#Observation

Problem description: The selected observation belongs to 0 data sets. It should belong to exactly one.

Quick Fix
After the fix the selected observation will belong only to the data set selected below or you can choose to edit the selected observation manually in OntoWiki

http://elipo.stat.gov.rs/iod2/RS-DATA/National_accounts/Gross_value_added_by_activities_at_current_prices/data_2011_12_28

Quick Fix Edit in OntoWiki

RDF Data Cube Validation tool aims to ensure the quality of statistical datasets. It is based on the integrity constraints defined by the RDF Data Cube vocabulary, meaning that the tool detects violations of these constraints, and helps in resolving the issues. Namely, it identifies violating resources, provides a description of the problem, and offers an automatic fix (this feature is not available for every integrity constraint). It can be configured to work with any SPARQL endpoint, however in order to repair the dataset it needs to be writeable, i.e. the tool uses SPARQL Update queries for this purpose. Considering the need for write access, basic authentication can be used to connect to the endpoint. However, if any of the Update queries cannot be executed (e.g. the endpoint is not writeable for everyone and doesn't support basic authentication), the user is notified and provided with the query so that it can be executed manually. Main purpose of the tool within the GeoKnow project is to ensure the quality of input data that is to be processed and visualized with ESTA-LD.

Sparqlify

Life-cycle phase	Extraction and Loading
Website	http://sparqlify.org
Licence	Apache License, Version 2.0
Source	https://github.com/AKSW/Sparqlify

Sparqlify Service Management

Add New Service

Existing Services

View	Service	Config	Path	Status	Jdbc Uri	Username
			lgd	RUNNING	<jdbc:postgresql://localhost/lgd>	postgres
			lgdseq	RUNNING	<jdbc:postgresql://localhost/lgd>	postgres
			demo	RUNNING	<jdbc:postgresql://localhost/lgd>	postgres

Details for lgd Hide

Log	Mapping
<pre> /** * Sparqlify configuration file for LinkedGeoData * * Triplify flavour */ // Prefixes (these will also be used in the query responses) Prefix spy:<http://aksw.org/sparqlify/> Prefix ogc:<http://www.opengis.net/ont/geosparql#> </pre>	

Sparqlify is a scalable SPARQL-to-SQL rewriter engine with the purpose of exposing relational data as RDF on-the-fly. The system ships with command line and Web interfaces of which both support the configuration of virtual SPARQL endpoints based on provided database connection settings and one or more mapping files. The web admin is capable of running multiple endpoints simultaneously and it has the handy SNORQL SPARQL browser^a integrated.

The primary supported database and mapping language are Postgres and the *Sparqlification Mapping Language* (SML)^b. SML is a human friendly language inspired by SQL's CREATE VIEW statement and combines it with syntactic elements known from SPARQL. It offers nearly the same features as R2RML^c for which current support is only experimental. Furthermore, the mapping of SPARQL functions to backing SQL functions is customizable via an XML configuration, and several spatial functions of Postgres are preconfigured to be accessible via GeoSPARQL function IRIs^d. Sparqlify is used in the LinkedGeoData project^e, where it provides access to more than 25 billion virtual triples.

^a<https://github.com/kurtjx/SNORQL>

^b<http://sml.aksw.org/>

^c<http://www.w3.org/TR/r2rml/>

^d<http://www.opengeospatial.org/standards/geosparql>

^e<http://linkedgeodata.org>

TripleGeo

Life-cycle phase	Extraction and Loading
Website	https://web.imis.athena-innovation.gr/redmine/projects/geoknow_public/wiki/TripleGeo
Licence	GPLv3
Source	https://github.com/GeoKnow/TripleGeo

The screenshot shows the TripleGeo web interface. On the left is a sidebar with navigation links: Extraction and Loading (selected), Import RDF data, Sparqlify Extraction, TripleGeo Extraction, Querying and Exploration, Authoring, Linking, and Enriching and Data Cleaning. The main content area is titled 'TripleGeo' and 'Utility for Converting Geospatial Data into Triples'. It includes a 'TripleGeo Configuration' section with the following fields:

- Data Source:** Shape File
- File Examples:** Points shape file extraction
- Input and Output Parameters:**
 - Data Source:** points.shp
 - Output Format:** RDF/XML
 - Target Store Type:** GeoSPARQL
- Data Parameters:**
 - Feature String:** points
 - Attribute:** osm_id

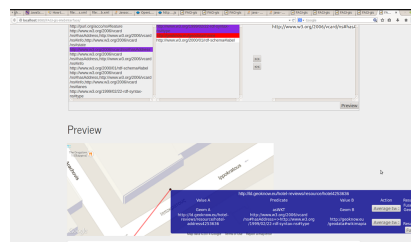
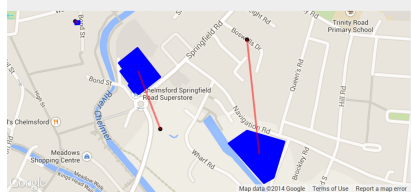
TripleGeo is an open-source ETL utility that can extract geospatial features from various sources and transform them into triples for subsequent loading into RDF stores. TripleGeo can directly access both geometric representations and thematic attributes, either from standard geographic formats or widely used DBMSs. It can also reproject input geometries on-the-fly into a different Coordinate Reference System, before exporting the resulting triples into a variety of notations. Most importantly, TripleGeo is compliant with the recent GeoSPARQL standard endorsed by the Open GeoSpatial Consortium, although it can extract geometries into other vocabularies as well.

The execution of the utility is parameterized with a configuration file that declares user preferences for the conversion. Configuration can be performed either online by filling the required fields in the tool's web interface or by loading the completed configuration file. TripleGeo provides the following functionality: (i) It can take as input ESRI shapefiles, as well as spatial tables hosted in major DBMSs (*Oracle Spatial*, *PostGIS*, *MySQL*, *IBM DB2*). (ii) It handles most common spatial data types, including points, (multi)linestrings and (multi)polygons. (iii) It can perform on-the-fly transformation of a given dataset into another spatial reference system. (iv) It can export geometries in several triple (*RDF/XML*, *RDF/XML-ABBREV*, *N-TRIPLES*, *N3*, *TURTLE*) and serialization (*Basic Geo*, *GeoSPARQL*, *VirtRDF*) formats. When initiated, this process iterates through all features in the original dataset and emits a series of triples per record. Every geometric feature is turned into properly formatted triple(s), according to the specified vocabulary. Additional descriptive attributes can be extracted, including identifiers, names, or feature types. Such attributes are exported as literals, without taking into account any underlying ontology. TripleGeo has been successfully tested against OSM datasets, thus offering concrete evidence of its robustness and suitability for importing large geospatial datasets into RDF stores.

FAGI-gis

Life-cycle phase	Fusion
Website	https://github.com/GeoKnow/FAGI-gis
Licence	GPLv3
Source	https://github.com/GeoKnow/FAGI-gis

Preview

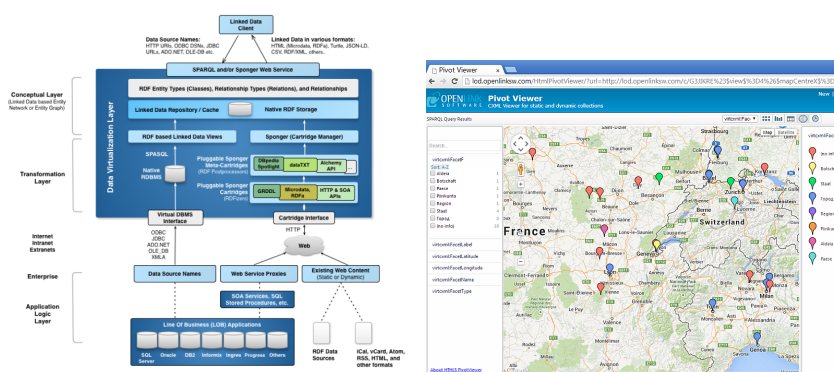


FAGI-gis is a software for fusing geospatial RDF data. It receives as input two datasets and a set of links that interlink entities between the datasets and produces a new dataset where each pair of linked entities is fused into a single entity. The fusion is performed for each pair of matched properties between the linked entities and considers both spatial and non-spatial properties. FAGI-gis's implementation focuses on efficiency, allowing the fusion of millions of triples in a few minutes. Also, it offers a set of 15 fusion actions that is constantly extended, as well as functionality for fusing property chains and for fusing m-to-n properties. The software can be used in two modes of operation: (a) a batch processing mode, which takes as input a configuration file, containing the required parameters, and fuses large numbers of linked entities according to these specified parameters; (b) a user-interactive mode, via a Web user interface, where the linked entities are visualized on a map and the user can filter them and perform separate fusion actions on the level of their properties.

In the user-interactive mode of the tool, the user is able to filter pairs of linked entities, based on the types of the entities they regard. Then, the linked entities are visualized on the map of the interface through points or polygons. Further, a straight line segment connects each pair of linked entities representing the link between them. With respect to property matching, FAGI-gis first selects some sample linked entities pairs and tries to automatically match the properties of the entities. Eventually, all the matched properties are presented, divided into two lists, one for each of the two input datasets. The final selection of the matching is performed by the user, who is able to match a property from one list with one or more properties from the other list. Eventually, after the final set of links to be considered for fusion is selected, and matchings of their properties are identified by the system and verified by the user, the actual fusion task takes place. The user can select one or more pairs of linked entities, either from the list of links or through the map (by clicking on the line segments that represent links). Then, the fusion panel pops-up, that allows to perform different fusion actions, (*keep both, concatenate, keep most complete, keep the most complex geometry, etc.*) for each pair of properties. Upon that, the system executes the required transformations and outputs the results as RDF triples.

Virtuoso Universal Server

Life-cycle phase	Storage/Querying
Website	http://virtuoso.openlinksw.com
Licence	GPLv2
Source	https://github.com/openlink/virtuoso-opensource



Virtuoso is an innovative enterprise grade multi-model data server for agile enterprises and individuals. It delivers an unrivaled platform agnostic solution for data management, access, and integration. Virtuoso provides a Column Store engine, with enhanced compression and data storage, ideal for RDF data storage and workloads. The unique hybrid server architecture of Virtuoso enables it to offer traditionally distinct server functionality within a single product offering that covers the following areas:

- SQL Relational Tables Data Management (SQL RDBMS)
- RDF Relational Property Graphs Data Management (RDF Triple or Quad Store)
- Content Management (HTML, TEXT, TURTLE, RDF/XML, JSON, JSON-LD, XML)
- Web and other Document File Services (Web Document or File Server)
- Five-Star Linked Open Data Deployment (RDF-based Linked Data Server)
- Web Application Server (SOAP or RESTful interaction modes)
- RDFization Middleware (Sparger Cartridges)

In the context of GeoKnow, Virtuoso has enhanced its support, performance and scalability in performing SPARQL/RDF Geo Spatial queries. Geo Spatial geometry types have been enhanced from initially just supporting points to now also supporting, MultiPoint, LineString, MultiLineString, Box, Polygon, MultiPolygon (Polygons with holes), GeometryCollection and associated geometry functions. The Geometries have been implemented to be both OGC and GeoSPARQL compliant, these being the two most dominate standards in the Linked Geo Data space. Query optimisation enhancements in the R-Tree index and Cluster plans for geometry types have been made improving the performance and scalability when performing such queries.

8. GeoKnow Generator Architecture and Implementation

The GeoKnow Generator unifies several different software tools for application users or application developers. The initial architecture is depicted in figure Figure 2. The software tools that target expert users in DB administration or designers are essentially web applications and accessible through the Debian repository of the Linked Data Stack. The Generator Workbench is GeoKnow's main application that integrates preconfigured components from the Stack according to the Linked Data life-cycle as a workflow. It provides access to public data catalogues of the domain of knowledge and the option to add proprietary datasets. It also aims to provide a layer for user administration, authorisation and provenance. The components that are integrated in this Workbench communicate using HTTP, REST or SPARQL protocols. Figure Figure 2: Current version of the GeoKnow Generator

A prototype of the GeoKnow Generator is already available at <http://generator.geoknow.eu>. It allows the user to triplify geospatial data, such as ESRI shapefiles and spatial tables hosted in major DBMSs using the GeoSPARQL, WGS84 or Virtuoso RDF vocabulary for geospatial representation of point features (TripleGeo). Non-geospatial data in RDF (local and online RDF files or SPARQL endpoints) or data from relational databases (via Sparqlify) can also be entered into the Generators triple store. Data from the Generator's triple store can be linked (using LINES), enriched (using GeoLift), queried (using Virtuoso) , visualized (using Facete) and used to generate light-weight applications as JavaScript snippets (using Mappify) for specific geospatial applications. Most steps in the Linked Data Life-Cycle have been integrated in the Generator as a graph-based workflow, which allows the user to easily manage new generated data. The current version of the GeoKnow Generator is presented in Figure Figure 2. The components comprising it are available in the Linked Data Stack (<http://stack.linkeddata.org>)

9. Applications of GeoKnow Components in E-Commerce

The E-Commerce domain is one of the primary usage scenarios in GeoKnow. Many use cases in this domain depend on explicit and detailed knowledge of geographical information, in particular in the tourism industry sector. We identified four major use cases:

- In *geographical search*, customers are searching using geospatial features and semantic knowledge, such as a "snorkelling holiday anywhere near the Mediterranean sea". Such search requests require a comprehensive knowledge base of properly interlinked information, a high accuracy, and very good query response times.
- For a *geospatial market basket analysis*, a marketing expert uses a data mining system to identify suitable products for a certain customer or entire target groups. The currently sparse internal information is not sufficient for great suggestions. Suggesting holiday regions and accommodation types similar to the ones a user preferred in the past would improve the quality of service. This depends on matching the properties of places and regions along with their geographic representation.

- In order to *support strategic decisions*, similar information is required for planning suitable regions that are most promising for establishing new products, such as building a new hotel.
- A *spatial-semantic visualisation* would help a customer with vague and non-specific ideas about a holiday to find a suitable product. Again, this typically requires a coherent knowledge consisting of internal data, e.g., on hotel properties, and geographic properties like the distance of mountains, beaches, or cultural activities.

The components implemented in GeoKnow can be applied for generating the knowledge base and visualising the data required for these use cases. In contrast to existing solutions, the geospatial RDF data integration and query optimisation enables a much more coherent search infrastructure compared to the previously required different databases. On that foundation, provided by the Virtuoso RDF Quad Store, we can apply the components developed along the Linked Data Life Cycle:

- the *Storage* and associated query capabilities on the vast amount of RDF data is crucial for our use cases.
- *Authoring* enables domain experts to adapt available information. Since data quality is crucial in our use cases, we typically have to limit direct modifications on the knowledge base by the public.
- via *Interlinking* we can connect data from different resources, including geospatial and non-geospatial properties. Since we are considering hundreds of thousands of places from many databases, this task requires specialized methods, such as the geospatial interlinking algorithms implemented in LIMES.
- *Classification* is required to cluster the potential large result set and gain further insights, for example with regards to the geospatial market basket analysis use case.
- for *Quality* assurance and *Evolution/Repair*, we can apply RDFUnit and ORE in order to filter out erroneous data and provide a high quality knowledge base required for any serious application.
- *Search/Browsing/Exploration* functionalities benefit from components like Mappify, which can be integrated in search result pages on tourism portals to visualize the points of interest in the suggested regions.

In general, GeoKnow provides the means for generating an interlinked semantically annotated geospatial knowledge base, on which novel E-Commerce applications can be built. We already tested the currently available tools on a subset of the E-Commerce datasets in the project in order to validate their general functionality, and plan to create a knowledge base using entire data sets as a validation of GeoKnow's scalability.

10. Application of GeoKnow Components in Supply Chain Management

One of the most promising application areas for spatial Linked Data is supporting the supply chain. Large manufacturers such as for example Volkswagen or Daimler have many thousands of suppliers making the rendering of information flows accompanying these supply chains (or networks) a real Big Data challenge. Facilitating the information flows between these suppliers and accompanying flows of material and product logistics is one of the most challenging and most promising areas of Enterprise Data Integration.

The aim of this use case is to give enterprises collaborating in supply chains a unified spatial view on the logistics in the supply chain. In order to realize this aim, we connect information from Electronic Data Interchange (EDI) transactions to the Data Web. EDI is an inter-organizational standard for exchanging business data between trading partners. EDI is in use across the automotive industry for various processes in supply chain management, such as tracking orders.

The GeoKnow Supply Chain Dashboard allows the user to search, browse and to explore supply chain data and thus helps decision making for supply chain managers. Figure 3 shows a screenshot of the dashboard. Incoming EDI messages are visualized

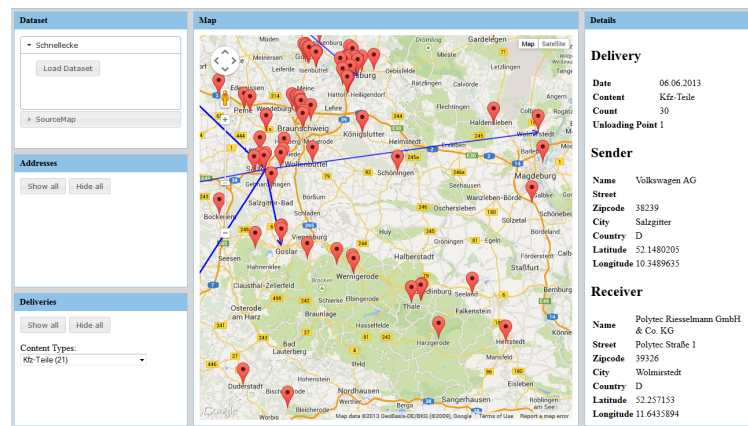


Figure 3. Supply Chain Dashboard.

on-the-fly on an interactive map. A supplier score card allows the performance assessment of each supplier based on various metrics. Traditional supply chain metrics, such as the suppliers timeliness, are included. In addition, a visual builder for supply chain scoring rules, which allows the specification of advanced performance metrics through an intuitive interface. The integration of external background knowledge using the GeoKnow Generator allows for advanced analysis of historic information. Integration of background knowledge can help to identify reasons for delays or incomplete delivery where sole internal information was not helpful to drill down to the root cause.

The Supply Chain Dashboard is based on a data flow based architecture. Figure 4 show the data flow in the supply chain scenario:

1. Supply chain messages, such as orders and shipments, are interchanged between suppliers. The supply chain infrastructure intercepts these messages and maps them to RDF in real-time. Provided background knowledge is transformed to RDF as well using custom mappings.
2. A link discovery process generates links between supply chain messages and related background knowledge, such as weather information.
3. Performance metrics are evaluated. This step is supported by an graphical metrics builder that allows to specify custom (supply chain) KPIs based on supply chain and background knowledge.

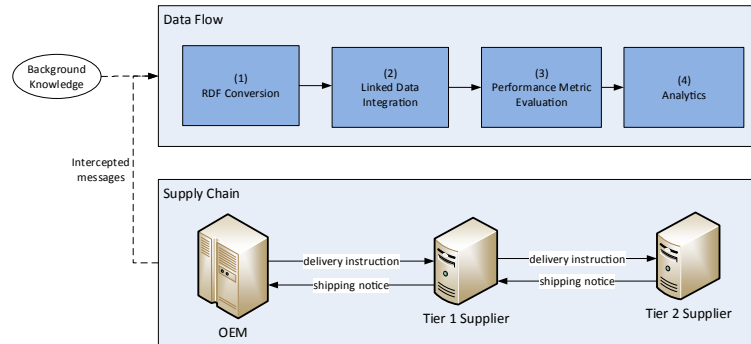


Figure 4. Data flow in the supply chain scenario.

4. The integrated RDF graph that has been annotated with performance scores can be analyzed using external BI tools. In our scenario we used the open source version of RapidMiner²² together with the LOD extension from the University of Mannheim²³.

11. Related Work and Projects

11.1. Related Funded Projects

Next, we present some prominent projects that handle several aspects of managing Linked Data, emphasizing mainly on projects handling geospatial Linked Data.

LOD2²⁴ is a large-scale 4-year project aiming to address the following challenges: improve coherence and quality of data published on the Web, close the performance gap between relational and RDF data management, establish trust on the Linked Data Web and generally lower the entrance barrier for data publishers and users. The project is undergoing its final year, having developed a stack of tools and methodologies for exposing and managing, interlinking and fusing, searching, browsing and authoring very large amounts of Linked Data. The implemented technologies are applied on three use case scenarios: media and publishing, corporate data intranets and eGovernment. GeoKnow project builds on, extends and enriches the technologies developed in LOD2, emphasizing on the geospatial aspect of Linked Data.

TELEIOS²⁵ was an EU FP7 project that implemented technologies for developing Virtual Earth Observatories promoting the use of ontologies and linked geospatial/temporal data. The TELEIOS advances to the state of the art have been demonstrated in two use cases: (a) A Virtual Earth Observatory for the TerraSAR-X archive of DLR. and (b) Wildfire monitoring and burnt scar mapping based on satellite images and relevant geospatial data. In this use case, the National Observatory of Athens used TELEIOS technologies to reengineer its real-time wildfire monitoring and burnt scar mapping

²²<https://rapidminer.com/>

²³<http://dws.informatik.uni-mannheim.de/en/research/rapidminer-lod-extension/>

²⁴<http://lod2.eu/Welcome.html>

²⁵<http://www.earthobservatory.eu/>

services. Among the outcomes of the project are Strabon spatiotemporal RDF store and Sextant visualization tool.

LEO²⁶ builds on and continues the work of TELEIOS in order to develop software tools that support the whole life cycle of reuse of linked open EO data and related linked geospatial data. This includes publishing, interlinking, searching, browsing, visualization, tools. The project's use case consists in the development of a precision farming application that is heavily based on such data.

SmartOpenData²⁷ aims at creating a Linked Open Data infrastructure (including software tools and data) fed by public and freely available data resources, existing sources for biodiversity and environment protection and research in rural and European protected areas and its National Parks. It will focus on how Linked Open Data can be applied generally to spatial data resources and specifically to public open data portals, GEOSS Data-CORE, GMES, INSPIRE and voluntary data (OpenStreetMap, GEPWIKI, etc.).

The goal of SemaGrow²⁸ project is to develop a framework for querying distributed triple stores containing large, live, constantly updated datasets and streams that are published in heterogeneous formats. The project focuses on the following key challenges: (a) Develop novel algorithms and methods for querying distributed triple stores (b) Develop scalable and robust semantic indexing algorithms (c) Investigate how to optimize the effectiveness of schema translations.

DIACHRON²⁹ takes on the challenges of evolution, archiving, provenance, annotation, citation, and data quality in the context of Linked Open Data and modern database systems. DIACHRON intends to automate the collection of metadata, provenance and all forms of contextual information so that data are accessible and usable at the point of creation and remain so indefinitely. The results of DIACHRON are evaluated in three large-scale use cases: open governmental data life-cycles, large enterprise data intranets and scientific data ecosystems in the life-sciences.

11.2. Related Work in regard to the Geospatial Linked Data Life-cycle

In this section, we review relevant related work for each phase of the Linked Data Life-cycle.

11.2.1. Extraction

There are various approaches for transforming/extracting conventional data to RDF. Indicatively, some approaches are presented next. Sparqlify³⁰ is a SPARQL-SQL query rewriter that allows the definition of RDF views using a *Sparqlification Mapping Language*. This way, it enables SPARQL queries on relational databases. Similarly, D2RQ³¹ allows querying relational database with SPARQL, by creating virtual RDF graphs and exploiting a mapping language for mapping relational database schemas to RDF vocabularies and OWL ontologies. In [5], the authors present SPARQL2XQuery, a framework that provides a mapping model for the expression of OWL-RDF/S to XML Schema mappings as well

²⁶<http://linkeddeodata.eu/>

²⁷<http://www.smartopendata.eu/>

²⁸<http://www.semagrow.eu/>

²⁹<http://www.diachron-fp7.eu/>

³⁰<https://github.com/AKSW/Sparqlify>

³¹<http://d2rq.org/>

as a method for SPARQL to XQuery translation. Through the framework, XML datasets can be turned into SPARQL endpoints. TripleGeo [49] is an ETL utility that can extract geospatial features from various sources (shapefiles and DBMSs) and transform them into Basic Geo or GeoSPARQL compatible RDF triples. Apart from approaches that can robustly handle large volumes of data, there are also tools that focus on simplicity and graphical user interfaces, such as OpenRefine³².

11.2.2. Storage

There is a series of RDF store implementations, varying on the supported querying facilities, the indexing schemes used and the performance [48,13,10,59], as well as benchmarking initiatives that evaluate and compare these approaches [60,6,48,16]. [48] provides a thorough presentation of RDF stores with geospatial support, such as Virtuoso³³, Parliament³⁴, Strabon [28], AllegroGraph³⁵, OWLIM³⁶, uSeekM³⁷, while [10] compares NoSQL approaches for storing RDF data. [59] presents stores that have proven to handle large volumes of RDF data and [60] gathers several benchmarks, as well as benchmarking results for several stores.

11.2.3. Authoring

On authoring of Linked Data, OntoWiki [15] facilitates the visual presentation of RDF data as an information map and enables intuitive authoring of semantic content. RDFauthor allows users to edit information on arbitrary RDFa-annotated web pages, extending RDFa with representations for provenance and update endpoint information. PoolParty [52] allows the enrichment of resources utilizing several Linked Data sources, such as DBpedia, WordNet, etc.

11.2.4. Interlinking/Fusion

The studies of [55,14] present and compare interlinking tools on various factors: *degree of automation, matching method and algorithm logic, input/output format and access methods*, etc. Currently, there are two prominent approaches for interlinking: Silk [58]³⁸ and LINES [39]³⁹. The former allows users to define types of RDF links to be discovered between data sources and to combine various similarity metrics through a graphical user interface. LINES applies space tiling and approximation techniques to compute estimates of the similarity between entities, reducing the number of comparisons and, thus, runtime, by orders of magnitude. Further, it applies indexing and bounding techniques to efficiently interlink entities based on their spatial distance. On the other hand, fusion approaches on Linked Data are less sophisticated and mostly adopt state of art techniques for data fusion. A brief overview of RDF-specific fusion tools is provided in [17]. Indicatively, these include Sieve [35], ODCleanStore [25], and KnoFuss [46]

³²<http://openrefine.org/index.html>

³³<http://virtuoso.openlinksw.com/>

³⁴<http://parliament.semwebcentral.org/>

³⁵<http://www.franz.com/agraph/allegrograph/>

³⁶<http://www.ontotext.com/owlim>

³⁷<https://dev.opensahara.com/projects/useekm/>

³⁸<http://wifo5-03.informatik.uni-mannheim.de/bizer/silk/>

³⁹<http://aksw.org/Projects/LINES.html>

11.2.5. Classification/Enrichment

There are several directions w.r.t. Linked Data enrichment and classification. Tools such as DL-Learner [29] aim at learning concepts in Description Logics from user-provided examples, so as to support users in constructing knowledge and learning about the data they created. GeoLift⁴⁰ aims at extracting implicit geographical information and making it explicit, through dereferencing, interlinking and Natural Language Processing. Plato [22] identifies partonomic relations (e.g. part of, member of, located in) between entities utilizing WordNet and linguistic patterns identified in web corpora, enriching both the schema and the data. PoolParty [52] allows the enrichment of resources utilizing several Linked Data sources, such as DBpedia, Geonames, WordNet, etc. An extensive overview of research works on ontology enrichment is given in [9].

11.2.6. Quality Analysis

The authors of [62] present a thorough review of Quality Assessment methods on Linked Data. 26 quality dimensions are identified and categorized into six classes: *Contextual*, *Trust*, *Intrinsic*, *Accessibility*, *Representational* and *Dataset dynamicity* dimensions. Indicatively, some of the latest approaches are briefly presented next. Sieve⁴¹ [35] is a platform that focuses on quality assessment and fusion of Linked Data, and constitutes part of a larger framework for Linked Data integration. LODRefine⁴² is a LOD-enabled version of Google Refine, which is an open-source tool for refining messy data. Although this tool is not focused on data quality assessment per se, it is powerful in performing preliminary cleaning of raw data. ODCleanStore⁴³ [25] is another framework that supports linking, cleaning, transformation and quality assessment operations on Linked Data. Finally, RDFUnit⁴⁴ [27] is a test driven data-debugging framework that can run automatically and manually generated test cases against a SPARQL endpoint.

11.2.7. Evolution/Repair

An overview of several ontology repair approaches is given in [31]. The same paper also presents ORE, a tool that supports the detection of ontology modelling problems and allows users to improve OWL ontologies by fixing inconsistencies and making suggestions for adding further axioms in a semi-automatic way. LODRefine, a LOD-enabled version of Google Refine, enables cleaning, reconciling and augmenting Linked Open Data with data from Freebase and other registered services. The surveys presented in [23,61] provide an overview of several ontology evolution approaches. [34,47] present a linked data approach for the preservation and archiving of open heterogeneous datasets that evolve through time both at the structural and the semantic layer.

11.2.8. Browsing/Exploration

There are numerous approaches for visualization and exploration of Linked Data. An overview of several of them is given in [11]. Indicatively, some recent tools are presented next. Facete⁴⁵ offers advanced faceted search techniques and visualization of geospatial

⁴⁰<http://aksw.org/Projects/GeoLift.html>

⁴¹<http://sieve.wbsg.de/>

⁴²<http://code.zemanta.com/sparkica/index.html>

⁴³<http://www.ksi.mff.cuni.cz/~knap/odcs/>

⁴⁴<http://aksw.org/Projects/RDFUnit.html>

⁴⁵<http://aksw.org/Projects/Facete.html>

RDF data. Sextant⁴⁶ [45] allows the visualization and exploration of time-evolving linked geospatial data and the creation, sharing, and collaborative editing of temporally-enriched thematic maps. Mappify⁴⁷ facilitates the creation of simple map applications based on RDF data retrieved from a SPARQL endpoint. rdf:synopsViz⁴⁸ [4] provides facilities for hierarchical charting and visual exploration of Linked Open Data, as well as on the fly statistic computations, using aggregations over the ontology hierarchy levels. CubeViz⁴⁹ utilizes the RDF Data Cube vocabulary to visualize statistical data in RDF in charts.

11.3. Linked Data Platforms

In the past years several Linked Data platforms were developed as part of funded research projects. The most prominent ones are the LOD2 Linked Data stack⁵⁰, DataLift⁵¹ and the commercial solution TasorONE⁵². The LOD2 stack can be entitled as the predecessor of the GeoKnow workbench covering the full linked data life-cycle. The French funded project DataLift focuses mainly on the transformation to RDF, interlinking and publishing the data. TasorONE is a cloud-based solution supporting the collaborative development of ontology, triplifying the data and publishing it as SPARQL endpoint. LEO builds on and extends the results of TELEIOS project, aiming to develop a stack of tools⁵³ handling the complete life-cycle of Linked Earth Observation data.

12. Conclusion and Future Work

After 1.5 years in the project, there have been several advancements of the state of the art in geospatial Linked Data through the GeoKnow project. GeoSPARQL compliance and performance in Virtuoso has been significantly improved with full support for OGC geometries and the GeoSPARQL standard in the near future. The performance of link discovery frameworks has been improved by at least an order of magnitude on large datasets. FAGI has been developed to support fusion of thematic and geospatial meta-data of resources, either manually or automatically. The RDFUnit quality assessment framework has been created and applied to several large datasets and ontologies. Existing standards such as GeoSPARQL have been extensively evaluated to identify shortcomings and challenges. Facet-based browsing techniques have been refined and the Mappify tool for lightweight geospatial web application development created. All of those components will be refined and further mature within the project. The major focus of future work will be the validation of those technologies in the project and third party use cases as well as the further establishment of the Linked Data Stack as a community tool repository.

⁴⁶<http://sextant.di.uoa.gr/>

⁴⁷<http://mappify.aksw.org/>

⁴⁸<http://83.212.125.131:8084/synopsViz/>

⁴⁹<http://cubeviz.aksw.org/>

⁵⁰<http://stack.linkeddata.org/>

⁵¹<http://datalift.org/>

⁵²<http://tasorone.com/>

⁵³<http://linkedearth.eu/misc/LEO-D1.1.pdf>

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