An Open Source Linked Data Framework for Publishing Environmental Data under the UK Location Strategy

Arif Shaon[1], Andrew Woolf[2], Shirley Crompton[1], Robert Boczek[1], Will Rogers[1], Mike Jackson[3]

[1] e-Science Centre, The Science And Technology Facilities Council, Rutherford Appleton Laboratory, Didcot, OX11 0QX, UK
{arif.shaon, shirley.crompton, will.rogers, robert.boczek}@stfc.ac.uk
[2] The Bureau of Meteorology, Canberra, Australia
A.Woolf@bom.gov.au
[3] The Software Sustainability Institute, The University of Edinburgh, Edinburgh, UK
michaelj@epcc.ed.ac.uk

Abstract. Linked data offers a novel and more flexible means of sharing complex geospatial datasets by breaking away from the traditional domain-specific technologies used for accessing and integrating geospatial data with heterogeneous sources and disparate formats. In 2010, the UK Cabinet Office released a set of draft guidelines for exposing geospatial data as linked-data in support of the UK Open Data initiative. These draft guidelines have been proposed under the UK Location Strategy in specific recognition of the importance of geospatial data, and also with a view to promote linked-data within the EU INSPIRE community. This paper presents a customisable open-source linked-data framework developed by the GeoTOD-II project that implements these guidelines. The framework provides an efficient means for exposing both existing and new data sources in the linked-data form. We also attempt to articulate and address a number of issues and hidden assumptions with these guidelines identified during the development of the framework.

Keywords: linked-data, geospatial data, INSPIRE, DEFRA, GeoTOD

1 Introduction and Motivation

The UK government's "data transparency agenda" aims to make public sector data freely accessible on the web as linked-data. This was greatly inspired by Tim Berners-Lee's invitation in 2009 [1] to publish government data online in light of the emergence of the Linked Open Data movement. While the primary goal of this initiative is to increase accountability associated key public sector datasets, it will, more importantly, enable harmonisation of heterogeneous datasets in a standardised manner by creating a "web of data", thus supplementing the knowledge base of individuals as well as society.

For geospatial information in particular, the linked-data approach offers the potential for developing more flexible means of data sharing and accessibility. In

essence, this could help solve the traditional problems of harmonising geospatial data with heterogeneous sources and disparate formats through standardised but complex web-services. For example, an RDF[1]-based linked-data representation of a climate research dataset identified by a unique HTTP URI could be seamlessly linked to another related but external dataset also exposed as linked-data in RDF, through an appropriate vocabulary e.g. RDFS[2] 'seeAlso'. This would enable a user (whether an application or human) to seamlessly access both of these datasets through their respective resolvable URIs and/or interrogate the datasets using the linked-data recommended query language, SPARQL[3] without being constrained by the query language or access mechanism(s) specific to the underlying geospatial web-service(s) (e.g., an OGC Web Feature Service[4] instance) responsible for serving up these datasets.

There are however several caveats to effectively sharing linked resources using URI and RDF. The chief amongst these is the necessity of a specific community data model, or 'RDF vocabulary'. While RDF provides the base representation for linked-data, this is not enough to specify the internal structure of any specific dataset (much as HTML provides a flexible structure for a huge variety of web page content). As noted by Tim Berners-Lee [2], "Different communities have specific preferences on the vocabularies they prefer to use for publishing data on the Web. The Web of Data is therefore open to arbitrary vocabularies being used in parallel. Despite this general openness, it is considered good practice to reuse terms from well-known RDF vocabularies..." Unfortunately the most well-known RDF vocabularies have little to do with climate research data – they are concerned with social networking (FOAF[5]), blogs/wikis (SIOC[6]), thesauri (SKOS[7]), software projects (DOAP[8]), etc.

It is also important with linked-data to strike the right balance with URI structure between completely opaque identifiers and excessive human-readable semantics[9]. To address this issue, the UK Cabinet Office has released a set of draft recommendations [3] for designing URI identifiers for location data in support of the UK Open Data initiative. These draft guidelines extend more general ones [4] for publishing public sector data (under data.gov.uk), and have been proposed under the UK Location Strategy in specific recognition of the importance of geospatial data, and also

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[1] Resource Description Framework (RDF) - http://www.w3.org/RDF/

[2] RDF Schema - http://www.w3.org/TR/rdf-schema/

[3] SPARQL Query Language for RDF - http://www.w3.org/TR/rdf-sparql-query/

[4] Open Geospatial Consortium (OGC) Web Feature Service - http://www.opengeospatial.org/standards/wfs

[5] The Friend of a Friend (FOAF) vocabulary - http://xmlns.com/foaf/spec/

[6] Semantically-Interlinked Online Communities (SIOC) - http://sioc-project.org/ontology

[7] Simple Knowledge Organization System Reference (SKOS) - http://www.w3.org/TR/swbp-skos-core-spec

[8] http://code.google.com/p/baetle/wiki/DoapOntology

[9] W3C, "Cool URIs don't change", http://www.w3.org/Provider/Style/URI

recognising parallel work at the European level on deploying the INSPIRE[10] 'spatial data infrastructure' (which uses web services, but not linked-data principles).

In addition, a linked-data service should integrate (e.g. as a layer over or an additional component) with existing data sources (e.g. web services, databases) without the need to make substantial changes to the underlying infrastructure. For example, it may not be desirable to significantly modify an existing Web Feature Service serving up external data from a third party database; or to replace it with a linked-data service to provide linked-data representations of these data. What might be more efficient and practical in this scenario is to implement a linked-data service that wraps the Web Feature Service and leverages it as a "proxy" data source for exposing linked-data.

This paper presents an open-source geospatial linked-data framework developed by the GeoTOD-II[11] project that implements the UK Cabinet Office's draft guidelines for exposing geospatial data as linked-data. This framework provides an efficient means for exposing existing data sources as linked-data using the approach proposed above.

2 Key Concepts

In this section, we provide an overview of the key concepts pertinent to the work of the GeoTOD-II project presented in this paper.

2.1 Linked-data
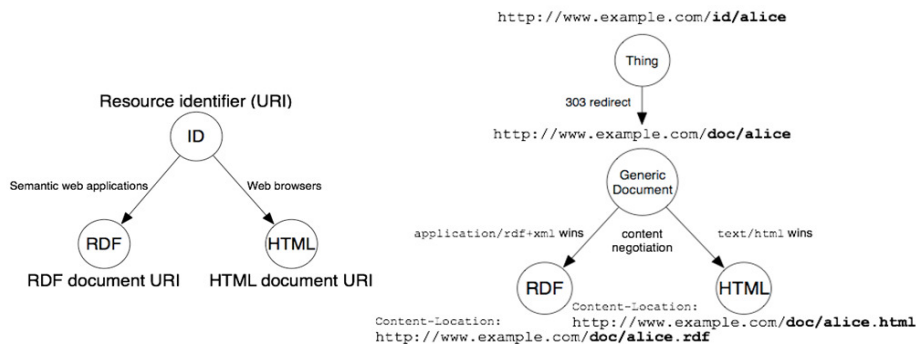
Fig. 1. Linked-data principles: client-dependant resource identification through HTTP URI and resource retrieval through content negotiation. (Source: http://www.w3.org/TR/cooluris/)

The success of today's web results from two core functionalities: the ability to identify and link documents using the HTTP protocol. Simple to implement, widely deployed, and with ubiquitous client support, these two elements provide an obvious model for moving beyond text and documents to a web of data. The 'linked data principles' [5] adopt this model by using URIs to identify data objects (or the real-

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[10] INSPIRE Directive - http://inspire.jrc.ec.europa.eu/

[11] Geospatial Transformation with OGSA-DAI (GeoTOD-II), SourceForge
http://geotod.sourceforge.net/about.html

world 'things' that they represent), and creating a data web by linking together related data objects. While HTML provides the *lingua franca* for the web of documents, RDF plays that role for data (Fig. 1). Common to both is the use of HTTP to access information (linked-data also recommends a human-readable representation e.g., HTML, if accessed via a web browser, using 'content negotiation'[12] – Fig. 1). The adoption of the four elements of linked data (URIs, RDF, HTTP, links between data) has already led to a massive 'linked data cloud'[13] connecting hundreds of datasets and billions of individual data items.

2.2   Designing 'URI Sets' for Location

The European Union's INSPIRE Directive requires public authorities across Europe to provide access to their environmental datasets through the adoption of a common framework for uniquely identifying the datasets within a pan-European 'spatial data infrastructure'. The UK Cabinet Office's guidelines for "Designing URI Sets for Location" [3] "is focussed on the use of http: URI by the UK public sector to meet that INSPIRE objective". To that end, the guidelines define three different types of resources identified by three different Uniform Resource Identifier (URI) schemes.

Fig. 2. HTTP URI identifiers for 'Spatial Things' and 'Spatial Objects'

Spatial Thing. The guidelines define this as anything that has a spatial extent, i.e. size, shape or position, and is a subset of 'real-world' phenomena associated with a location, e.g. the 'River Thames'. To uniquely identify a Spatial Thing, the guidelines recommend the following URI scheme, referred to as the "Id" URI:

http://location.data.gov.uk/id/{INSPIRE theme}/{concept}[/{codeset}]/{reference}[/{version}]
([] denotes an optional term).

An example URI for the 'River Thames':

http://location.data.gov.uk/id/HY/Watercourse/Thames/v1

According to the guidelines, the URI for a Spatial Thing, if de-referenced, should be re-directed to a web document containing metadata about the Spatial Thing (Fig. 2). The granularity of the metadata is implementation or provider specific. The URI pattern for identifying this metadata document should be that for the Spatial Thing but with the term "id" replaced with the term "doc" – hence, it is referred to as the "Doc" URI.

An example "Doc" URI for the 'River Thames':

http://location.data.gov.uk/doc/HY/Watercourse/Thames/v1

In addition, a metadata document about a Spatial Thing could also include a list of relevant, known, Spatial Objects (described below) through appropriate vocabulary (e.g. RDFS 'seeAlso' or OpenVocab[14] 'similarTo' – Fig. 2).

Spatial Object. This is essentially a concrete digital representation of a 'real-world' phenomenon associated with a specific geographical location. Notably, this is a direct proxy of the INSPIRE definition of a Spatial Object[15]. The guidelines propose the following URI scheme (referred to as the "So" URI) for uniquely identifying a Spatial Object in an INSPIRE compliant way:

http://location.data.gov.uk/so/{INSPIRE theme}/{Ontology Class}/{Ontology Namespace}/{local id}[/{version id}][/{rendition}]

For example, the URI for a Spatial Object representation of the 'River Thames' could be:

http://mydata.co.uk/so/HY/Watercourse/hy-p/1234/v1

As illustrated in Fig.2, multiple representations of the same Spatial Object could be provided by using an efficient content negotiation mechanism.

Ontology. In addition, the guidelines also define a number of URI patterns for querying the concepts used within a description of a Spatial Thing or Spatial Object. These concepts are essentially the Classes and their associated properties defined within an OWL Ontology[16] or RDF Schema representation of an INSPIRE conceptual model (typically formulated in UML[17]) underpinning the description of a Spatial Thing or Spatial Object. These URI schemes (referred to as the "Def" URIs) are:

- URI for a class

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[14] http://open.vocab.org/docs/similarTo

[15] INSPIRE Glossary item 67 in https://inspire-registry.jrc.ec.europa.eu/registers/GLOSSARY/items

[16] OWL 2 Web Ontology Language Document Overview - http://www.w3.org/TR/owl2-overview/

[17] Unified Modelling Language (UML) - http://www.uml.org/

http://location.data.gov.uk/def/{theme}[/{package}][/{concept|class}][/{version}]/{class}

- URI for a property exclusively associated with the given class
http://location.data.gov.uk/def/{theme}[/{package}][/{concept|class}][/{version}]/{class}/{property}

- URI for a shared or re-usable property
http://location.data.gov.uk/def/{theme}[/{package}][/{concept|class}][/{version}]/{property}

So, to access the definition of the 'Watercourse' class in the above 'River Thames' Spatial Object example, the URI would be:

http://mydata.co.uk/def/HY/rivers-package/Watercourse

3 Key Issues and Challenges

3.1 Pragmatic Interpretation of the "Designing URI Sets for Location" guidelines

The key challenge faced by the GeoTOD-II project was interpreting the Cabinet Office's guidelines in a pragmatic and implementable fashion, as there had so far been little practical application of these guidelines. There are a number of issues and hidden assumptions in the guidelines that needed to be articulated by the project.

For instance, a key question raised by the URI scheme proposed for identifying a 'Spatial Thing' is: in an operational context what information should be available at the 'Doc' URI which describes a Spatial Thing? We choose to regard this as a 'master catalogue' of individual Spatial Objects available from different providers and which relate to the associated Spatial Thing, e.g. all registered representations of the River Thames.

Similarly, it is necessary to clarify matters relating to governance and ownership of concepts: e.g. who is the owner of the concept 'River Thames' with responsibility to maintain the 'id/Doc' URI? There is an implied 'registration' process – all owners of 'River Thames' objects must register them with the owner of the concept 'River Thames'.

3.2 Legacy Geospatial Data Sources

Another issue is how to achieve linked-data representation of legacy geospatial data sources with minimal cost to data providers. As highlighted before, the recommended practice is for linked-data representations to co-exist with any current data sources and representations in order for it to be useful. Therefore, a linked-data solution would effectively sit on top of existing data sources and be configured to use those data sources without changing their underlying data structures or storage formats.

3.3 Ontology Representations of the INSPIRE Conceptual Models

Additionally, there is also the question of representing geospatial data in RDF, which requires developing RDF ontologies based on the UML conceptual information models adopted by INSPIRE (and their underpinning ISO standards) to describe these legacy data sources. There are a number of issues related to the "mappings" between the INSPIRE UML models and their OWL/RDF Ontology/Schema representations. For instance:

- There is a need to define a canonical transformation from geospatial UML conceptual models to an ontology representation. In general, the 'closed-world' semantics of UML are more restrictive than the 'open-world' model of OWL and RDFS. As well, the UML meta-model does not support properties as first-class entities. Nevertheless, UML bears similarities to frame-based knowledge modelling systems, and the Object Modelling Group has developed the Ontology Definition Metamodel (ODM) as a mechanism for modelling UML-based ontology development.

- Developing an ontology representation of an INSPIRE UML model would need also to address the 'import' of already-existing information models developed as international standards by ISO's Technical Committee 211 (e.g. ISO 19107 for spatial schemas, ISO 19108 for temporal schemas, ISO 19115 for geospatial metadata, etc.). It would require the development of ontologies for these 'imported' models as well. These are substantial tasks in their own right requiring considerable involvement of the wider standards community.

- In order to provide conventional GML[18] as a specific representation of INSPIRE geospatial data under a linked-data server (through content negotiation), further work is required on developing open-source implementations of the INSPIRE web services (i.e. the OGC 'Web Feature Service').

Notably, there have been a few such ontologies, albeit unofficial and generally incomplete, emerging from the INSPIRE and other related communities. For instance, the W3C Semantic Sensor Network Incubator Group (SSN XG)[19] developed an ontology based in part on the ISO 19156 'Observations and Measurements' conceptual model. And the UK Environment Agency has developed a linked-data representation of Bathing Water Quality including 'sampling points'[20] motivated by the INSPIRE 'Environmental Monitoring Facility' theme. The OGC GeoSPARQL working group is developing a SPARQL extension to include spatial query predicates[21] (touches, disjoint, overlaps, contains, etc.). In addition, the draft specification includes a number of OWL class definitions for geometry, topology, and geospatial 'features'.

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[18] Geography Markup Language - http://www.opengeospatial.org/standards/gml

[19] W3C Semantic Sensor Network Incubator Group - http://www.w3.org/2005/Incubator/ssn/

[20] http://location.data.gov.uk/def/ef/SamplingPoint/SamplingPoint

[21] The so-called Egenhofer relations.

4 Existing Linked-data Servers

We assessed the suitability of a number of existing open-source linked-data servers for publishing geospatial datasets in accordance with the Cabinet Office's guidelines discussed above. These servers included D2R[22], Virtuoso[23], Triplify[24], SquirrelRDF[25] and Pubby[26]. In general, these existing products enable exposing RDF views of datasets residing in relational databases through customisable HTTP URLs and querying them using SPARQL. In all cases, the desired mappings between an RDF schema and a relation database schema are specified in some form of mapping file(s) written in RDF/Turtle based languages with varying levels of syntactical and conceptual complexity. Additionally, some of these servers, such as D2R and Virtuoso support automated generation of the mapping files based on the schema of the relational database specified.

We also reviewed a number of geospatial linked-data services that are based on some of the aforementioned linked-data servers. This included the UK Environmental Agency's linked-data server[27] that implements the Cabinet Office's guidelines, and the "GeoLinked Data" service developed by the Ontology Engineering Group (OEG)[28] for publishing environmental data held by the National Geographic Institute of Spain.

Generally, most of the existing linked-data servers and services reviewed provide complete (and in some cases, complex) solutions for publishing linked-data. However, the major drawback of these solutions is the limited scope for their functional extensibility. For instance, adding a non-relational data source, such as a Web Feature Service for rendering GML representation of a geospatial resource, to any of these servers would likely require substantial re-implementation of its underlying architecture. Such a task, while achievable as most of these servers are open-source products, may not be practical within the related scope of work.

Providing alternative non-RDF representations (e.g. XML) of a linked-data resource is recommended in the linked-data principles. And considering that RDF is not a prevalent format for encoding geospatial datasets, there is added value for a geospatial linked-data server to have the capability to provide both non-RDF (such as GML) and RDF representations of a resource. Notably, the provision of GML-encoded environmental data is also not supported by either of the two geospatial linked-data services mentioned above.

To this end, we concluded that there would be merit in developing an open-source linked–data server for publishing geospatial datasets with the key features of the

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[22] http://www4.wiwiss.fu-berlin.de/bizer/d2r-server/

[23] http://virtuoso.openlinksw.com/linked-data/

[24] http://triplify.org/

[25] http://jena.sourceforge.net/SquirrelRDF/

[26] http://www4.wiwiss.fu-berlin.de/pubby/

[27] http://data.gov.uk/linked-data

[28] http://geo.linkeddata.es/web/guest/home

aforementioned servers but crucially with appropriate extensibility points for adding new functionality as needed.

5 Methodology and Implementation

5.1 GeoTOD Linked-data Server Framework

To address the issues of the existing linked-data servers, in the GeoTOD project we developed a highly-extensible framework for a linked-data server, namely the GeoTOD Linked Data Server (GLS), which implements a set of Linked Resource interface specifications compliant with the Cabinet Office guidelines for the publication of geospatial data.
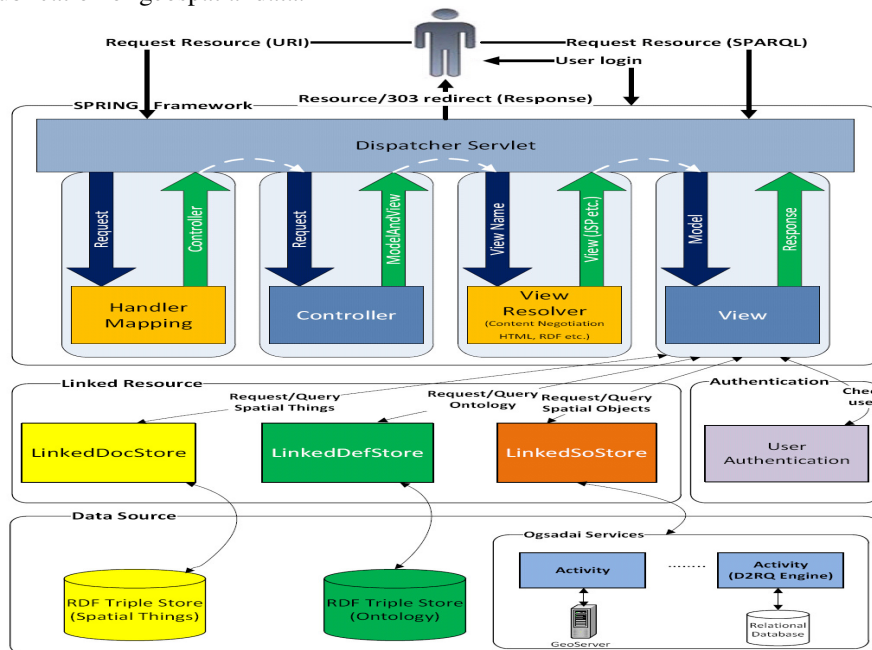

Fig. 3. An architectural view of the GLS Framework

The GLS architecture (Fig. 3) follows the Spring Model-View-Controller (MVC)[29]-based Java EE6[30] framework with four different layers of components: Spring MVC framework, Linked Resource, Authentication and Data Source. Of particular note is the Linked Resource layer, which integrates within the GLS framework three Linked Stores (*LinkedDocStore, LinkedSOStore and*

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[29] The Spring MVC Framework - http://static.springsource.org/spring/docs/3.0.x/spring-framework-reference/html/mvc.html

[30] Java Enterprise Edition 6- http://www.oracle.com/technetwork/java/javaee/tech/index.html

LinkedDefStore) representing the three resource types (Spatial Thing, Spatial Object and Ontology respectively) specified in the Cabinet Office's guidelines (Section 2.2).

In general, the Spring MVC layer of the GLS framework receives requests related to any of the three Linked Stores as either HTTP URIs or SPARQL queries, and determines the appropriate response to be sent to the client. Formulation of the response to a client's request mainly involves identification of and communication with an appropriate implementation of the Linked Store in question. The mode of communication between the Spring MVC layer and the Linked Resource layer depends on the type and output format (e.g. HTML, RDF etc.) of the resource requested.

In addition, the GLS Spring Framework handles authentication of users with administration privileges with the help of the "Authentication" layer. User authentication in GLS is required to perform administration related functions (e.g. adding, removing Spatial Objects etc.) in the "Linked Resource" layer.
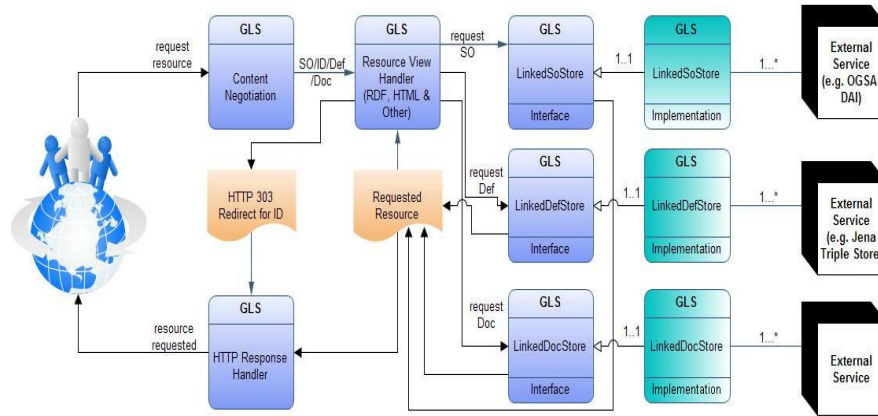
Fig. 4. Integration of the "Linked Stores" within the GLS Framework

As illustrated in Fig. 3 and Fig. 4, depending on the implementation, a GLS Linked Store can act as an interface to any type of service or data store within the GLS Data Source layer. For example, a GLS Linked Store could be implemented as an interface to a single service responsible for serving up linked resources in various supported output formats; or a set of aggregated services, where each service is responsible for producing a specific representation of a linked resource. In other words, the GLS can be integrated with any concrete implementations of Linked Stores conforming to the Linked Resource interface specifications. Thus, the GLS framework enables the publication of both existing and new geospatial data sources as linked-data.

5.2 Prototype Implementation

We implemented a prototype of the GLS framework for a demonstration dataset (described later in Section 6) with the *LinkedSoStore* implemented using OGSA-

DAI[31] - an open source framework for distributed data management. OGSA-DAI provides the *LinkedSoStore* with an uniform interface to access and integrate third-party heterogeneous relational as well as web data sources (Fig. 3). We extended OGSA-DAI to support RDF resources using the D2RQ platform[32] (the mapping engine behind the D2R server). Relational data sources are transformed into virtual RDF graphs using a mapping file, which describes the relation between an ontology and a relational data model. D2RQ also provides RDF/SPARQL access mechanisms to support different types of linked-data query on the legacy geospatial data resources. With this extension to OGSA-DAI, we are able to exploit different types of third party data services and convert their output into linked data representations using configurable OGSA-DAI workflows. With OGSA-DAI open framework, new data services can simply be wrapped and deployed into these workflow via software configuration. The *LinkedDocStore* and *LinkedDefStore* were implemented as interfaces to two native RDF triple stores (Fig. 3). The prototype GeoTOD Linked data server is available at: http://tiger.dl.ac.uk:8080/geotodls/index.htm

5.3 RDFS Generator

To support the provision of ontologies via RDF, we also developed a simple *UML to RDFS conversion* tool for converting UML-based conceptual models of a domain, such as INSPIRE thematic data specifications, to an RDF schema (ontology).
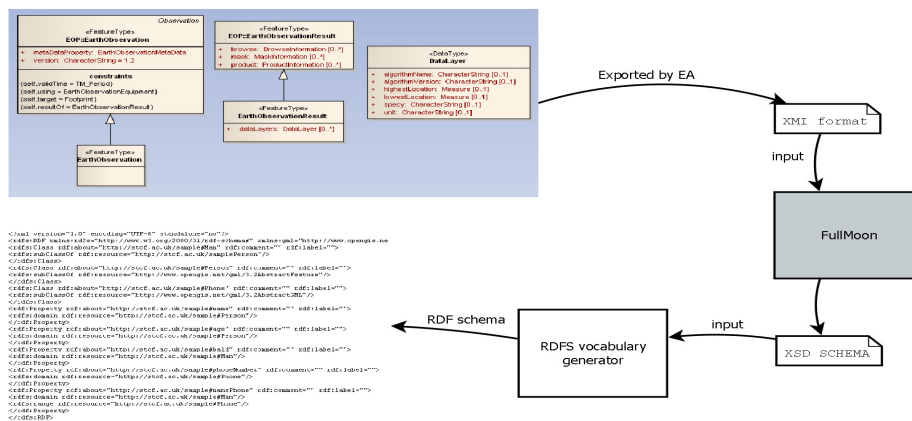
Fig. 5. Generation of RDFS vocabulary from UML Models created using Enterprise Architect (EA)[33]

In general, this tool allows generating RDFS vocabulary from an XML Schema transformation of an INSPIRE UML model (Fig. 5). It is mainly designed to support the GML application schemas (XML schemas) generated by FullMoon[34] - a widely

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[31] OGSA-DAI - http://www.ogsadai.org.uk/

[32] D2RQ - http://www4.wiwiss.fu-berlin.de/bizer/d2rq/

[33] Enterprise Architect - http://www.sparxsystems.com/

[34] FullMoon - https://projects.arcs.org.au/trac/fullmoon/wiki/FullMoon

adopted tool for generating (GML-based) XML Schema representations of the ISO 19000 series (adopted by INSPIRE) UML models. (It proved easier to generate RDFS from the XSD representation, rather than directly from UML.)

The underlying algorithm for performing the XML Schema-to-RDFS conversion is tightly coupled to the naming convention of XML type definitions and element declarations. However, these conventions arise from UML-to-XML encoding rules specified in ISO 19136 ('Geography Markup Language', Annex E), from which the underlying UML classes may directly be inferred. The RDFS Generator is available at: http://tiger.dl.ac.uk:8080/rdfsgenerator.

6 Demonstration Datasets

We have tested our prototype implementation of the GLS framework using the Ordnance Survey's 'Strategi'[35] dataset in order to demonstrate the transformation of an existing resource into linked-data form. The Strategi data is relevant to the UK, containing a view of the whole UK including natural and man-made features. This dataset has been made freely available online under the Ordnance Survey's OpenData™ initiative in support of the UK government's 'data transparency agenda'.

For this, we have used an ontology auto-generated from relevant INSPIRE conceptual models (i.e. the 'Hydrography' and 'Transport Networks' themes), using the RDFS Generator described above. Additionally, it was necessary to convert the Strategi data from the original ESRI Shapefiles[36] to relational data format (i.e. SQL) using a freely-available tool, namely shp2pgsql[37], and then store it in a PostgreSQL[38] database. As well as following the UK URI guidelines for spatial data, our prototype provided several representations of Spatial Objects through HTTP content negotiation – RDF, HTML, and GML. The latter was provided through the Geoserver[39] open-source Web Feature Service application.

7 Conclusions

The most significant outcome of the work presented here is a customisable linked-data framework that is aligned with the UK Cabinet Office's draft guidelines on applying linked-data in the geospatial context. In developing this framework, we have identified and attempted to articulate and address a number of issues and hidden assumptions with these guidelines. In addition, we have learned key lessons that should be considered by other members of the geospatial linked-data community. Foremost amongst these is the requirement to more fully develop mechanisms for mapping geospatial conceptual information models (normally formulated in UML) to

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[35] http://www.ordnancesurvey.co.uk/oswebsite/products/strategi/index.html

[36] http://en.wikipedia.org/wiki/Shapefile

[37] http://postgis.refractions.net/docs/ch04.html

[38] http://www.postgresql.org/

[39] http://www.geoserver.org

RDF schemas and ontologies. Further, our implementation of the demonstrator provides an optimal solution combining both the strengths of OGSA-DAI for implementing database-to-linked data transformation together with a linked-data server that can be customised to support other both existing and new data stores and data formats.

On the whole, the work presented should benefit those organisations looking to deploy their geospatial data assets as linked-data among. While a number of industry players are developing commercial tools for linked-data, the availability of a conformant open-source framework will provide substantial benefit both to organisations wishing to publish their geospatial data as linked-data, and to the linked-data community (and Cabinet Office CTO Council itself) in developing best practice in this new field. Notably, the GeoTOD framework was used in a recently completed high-profile project, namely ACRID[40] that has developed a linked-data approach to publishing complex scientific workflows associated with climate research datasets held by the Climatic Research Unit of the University of East Anglia.

However, in order to fully exploit the work described here, further engagement with key players in both the linked-data and geospatial communities will be required, especially those involved with the UK Location Programme and INSPIRE. Furthermore, the initial development and proof-of-concept presented in this paper is only a small part of the effort required to develop hardened software – significant extra development resource would be required to take the project outcomes the next step to a fully tested, efficient, and reliable software product. Future work will need to address these issues.

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[40] Advanced Climate Research Infrastructure for Data (ACRID) - http://www.cru.uea.ac.uk/cru/projects/acrid/