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MAKING ATTRIBUTES FROM THE LINKED OPEN DATA (LOD) CLOUD A PART OF SPATIAL DATA INFRASTRUCTURES (SDIS) FOR THEMATIC MAPPING

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ABSTRACT

The creation of the linked open data (LOD) cloud has enhanced the availability of interlinked open *statistical data associated with geographic regions* (attributes) through the Web. Spatial data infrastructures (SDIs) are widely used to share, discover, visualise and retrieve geospatial data. Geoportals are the visible parts of SDIs focused on interoperability through implementing standards such OGC web services for discovery and use of geographic data and services. In the current form OGC services cannot be directly connected to the LOD cloud. This research aimed at finding novel ways of visualising linked data in the form of thematic maps over the Internet. This paper provided answers to the question of how an OGC Web Map Service (WMS) can create thematic maps by combining attributes from the LOD cloud with geometry stored in a spatial database server (SDS). This research contributed to bridging the gap between linked data, SDI and web thematic maps and further showed how existing web mapping and OGC technologies can benefit from the Semantic Web. First, the design of a geospatial web service (representing the visible part of an SDI) that accesses attribute data from the LOD cloud referred to in this paper as *SDI-LOD* is presented. *SDI-LOD* produces web thematic maps by programmatically combining attributes from the LOD cloud with geometry in an SDS. Next, the author presented implementation results of *SDI-LOD* and concluded with a discussion of the implementation. This paper has motivated future work on *SDI-LOD* to integrating data from internet of things.

Key Words: thematic map; LOD cloud; geospatial data; linked open data; geospatial web service; SDI

INTRODUCTION

A spatial data infrastructure (SDI) is an enabling platform for data sharing- based on a dynamic, hierarchic and multi-disciplinary concept that includes, people, data, access networks, institutional, policy, technical standards and human resources dimensions that aims to facilitate and coordinate the exchange and sharing of spatial data among stakeholders in the spatial data community (Rajabifard, Binns, Masserand Williamson, 2006). An SDI is an evolving concept about facilitating and coordinating the exchange and sharing of spatial data and services among stakeholders from several levels in the spatial data community (Hjelmager *et al.*, 2008, Cooper et al, 2011, 2014).

Open data refers to data or content that is free to use, reuse, and redistribute – subject only, at most, to the requirement to attribute and/or share-alike the data (Open Knowledge 2014). Increasingly, governments are supporting open data as a means to leverage the potential of publicly funded data (UK Government Open Data 2013; US Government Open Data 2014; European Environment Agency 2014). The principles of linked data (Berners-Lee 2006) have been adopted by an increasing number of data providers and application developers leading to the creation of a *web of data* (Bizer *et al.* 2009) that can be processed by machines. The linking open data (LOD) cloud is an example of such a web of data available as open data over the Web (W3C 2013f; Bizer *et al*. 2011). It contains enormous volumes of data amounting to billions of Resource Description Framework (RDF) triples. Examples of themes included in the LOD cloud are government (crime, elections, immigration statistics, economic indicators, and environment and census results, to name a few), publications, life sciences; user generated content, cross-domain, media, geographic and social web (Schmachtenberg, Bizer & Paulheim 2014).

Thematic maps typically feature a single distribution or relationship (theme) over a spatial background to visualize the distribution of the theme (Tyner 2010). There is a growing demand for thematic maps since there is increase in the collection and availability of thematic data (Durbha *et al*. 2009). The growth in data has necessitated an increase in the need to better understand the phenomena associated with the data, thus requiring, robust capability to integrate data (Janowicz *et al.* 2013). Visualizing the massive amounts of data available in the LOD cloud as thematic maps would provide a powerful spatial analysis tool for planning and decision-making. One could do this by using geospatial web services to integrate linked open data with geometry in an SDS.

This research explored the use of standard geospatial web services to combine geometry in a spatial database with attribute data in the LOD cloud to produce thematic maps. Different styles for integrating the attributes from the LOD cloud with geometry in the spatial database server were designed and evaluated. Integration challenges stem from the difference in heterogeneous data models in the attributes (linked data) and the geometry (object-relational). For this research standard geospatial web services were used, motivated by the widespread deployment of standardized web map services in the geospatial community and the widespread publication of alphanumeric data (e.g. by statistical agencies) in the LOD cloud.

Recently, there has been a hive of research activity in the field of geospatial linked data. Research efforts tend to focus on representing geographical phenomena as linked data and producing maps from such linked data. In these cases the geometry and attributes of a geographical phenomenon are represented in a single (linked data) model (e.g. Hartig, Mühleisen and Freytag 2009, Stadler, Lehmann, Höffner & Auer 2012). The work by T. Zhao, Zhang, Wei and Peng (2008) is an exception, as it combines linked (attribute) data with legacy (geospatial) data. The flow of data is from legacy (geospatial) source to the LOD cloud, where the maps are produced from linked data. In our research the flow of data is from the LOD cloud to the spatial database from where geospatial web services (the visible parts of an SDI) access the data to produce thematic maps.

DESIGN

In this section the author described the analysis of the requirements of a geospatial web service, representing the visible part of an SDI, referred to as *SDI-LOD* -the steps to create a web thematic map from attributes in the linked open data cloud and geometry in a spatial database server. Next, the requirements for a web service that performs these steps were described. These requirements are used later to evaluate the implementation of *SDI-LOD*. Finally, the author describes the technologies applied in this research.

Requirements of SDI-LOD

A map communication model conceptualises the steps required to communicate cartographic information (such as the cartographic information in a thematic map) to a user (Dodge, Kitchin & Perkins 2009). Slocum et al. (2010) presented the following map communication model (shown as boxes and arrows depicted with light gray in Figure 1).

1. Consider how the real world phenomenon might look like.
2. Determine the purpose of the map.
3. Collect data appropriate for the map's purpose
4. Design and construct the map
5. Determine whether users find the map useful and informative

For this, research the map communication model by Slocum et al. (2010) was adapted to illustrate the steps required to combine attributes from the linked open data cloud with geospatial data in a spatial database server to create web thematic maps. The steps were adapted as follows. The steps in our adapted model are shown as dark gray boxes and black arrows.

1. *Consider how the real world phenomenon might look like.* This is done by a cartographer and is therefore not included in our adapted model.
2. *Determine the purpose of the map*. This is presented in our adapted model as Step 1) Select a theme.A user selects a theme for the thematic map to be created; for example, population density of all countries in the world.
3. *Collect data appropriate for the map's purpose*. This step was expanded to include the three sub-steps required for data collection:

    Step 2a) Collect appropriate linked data (attributes) from the linked open data cloud, e.g. the population sizes of countries

    Step 2b) Identify relevant geometry in a spatial database server, e.g. country boundaries.

    Step 2c) Combine the attributes with the geometry, e.g. by linking country boundaries with corresponding population sizes through a unique identifier such as the country name.

4. *Design and construct the map* was expanded into five sub-steps described below. Note the feedback loop from steps 3d to 3a, which allows refinement of the thematic map, if necessary.

   Step 3a) Choose a thematic mapping technique, e.g. the choropleth mapping technique can be selected to show differences in population density.

   Step 3b) If necessary, standardise the data, e.g. by calculating the population densities of countries as a ratio of population to area.

   Step 3c) Depending on the choice of the user, the data may be presented as classified or unclassified. For classified data, classes are created according to an appropriate data classification methodology, e.g. population densities could be classified into two classes where one class includes population densities below a certain value and the other class population densities greater than or equal to that value.

Figure 1: A map communication model

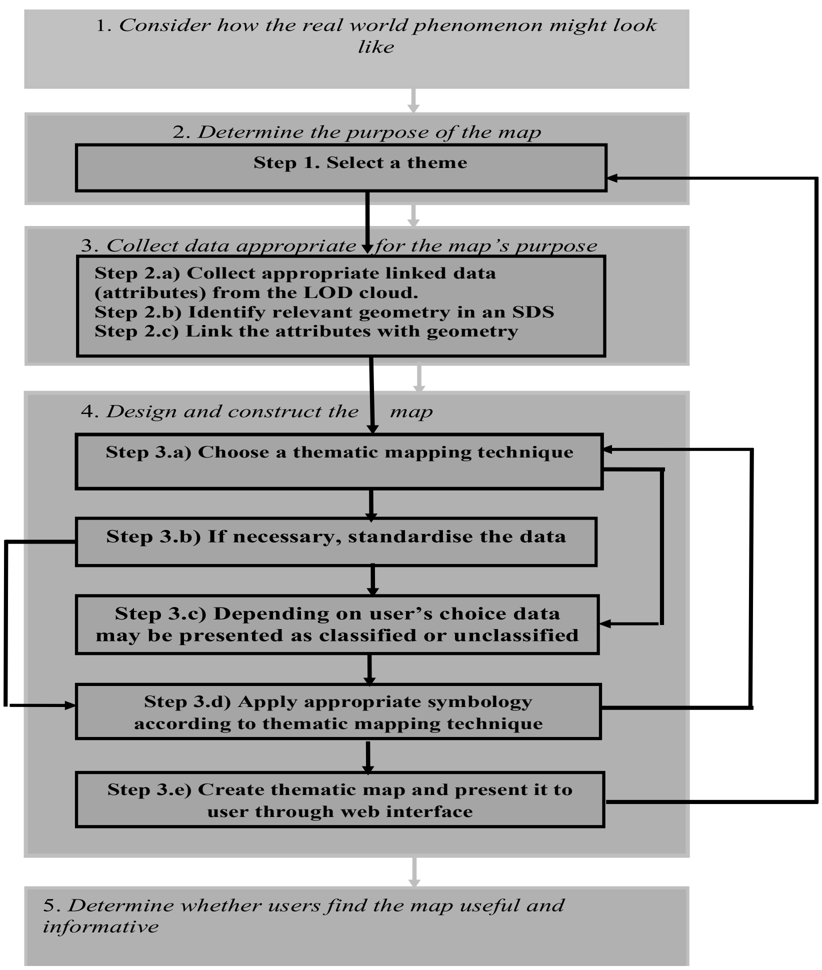


Figure 1: A map communication model adapted for combining attributes from the linked open data cloud with geospatial data for web thematic mapping (dark gray boxes with black arrows), adapted from Slocum et al. (2010) (light gray in the background)

Step 3d): Appropriate symbolisation is then applied to the data according to the choice of thematic mapping technique, e.g. for a choropleth map a different colour is assigned to each class.

Step 3e): Finally, the thematic map is created and presented to the user through a web interface.

5. *Determine whether users find the map useful and informative.* This was included in our adapted model as a feedback loop from Step 3e to Step 1allowing refinement of the thematic map, if the user does not find the map useful and informative.

Eight requirements for a web service that combines attributes from the linked open data cloud with geometry in a spatial database server to produce thematic maps are described below. The requirements were identified with reference to the adapted map communication model. The process flow of such a web service is illustrated in Figure 2.

1. A client shall request a thematic map from a web map server (i.e. the client sends a map request to the service).
2. A client shall specify a theme and a thematic mapping technique in a map request (step1 and 3a).
3. The service shall identify the attributes to be used for the theme in the linked open data cloud (step 2a).
4. The service shall identify the geometry to be used for the theme in a spatial database server (step 2b).
5. The service shall combine the attributes with the geometry (step 2c).
6. The service shall standardise and classify data, as required (steps 3a and 3b).
7. The service shall apply symbology appropriate for the specified thematic mapping technique (step 3d).
8. The service shall create a thematic map image and return it to the client (step 3e).

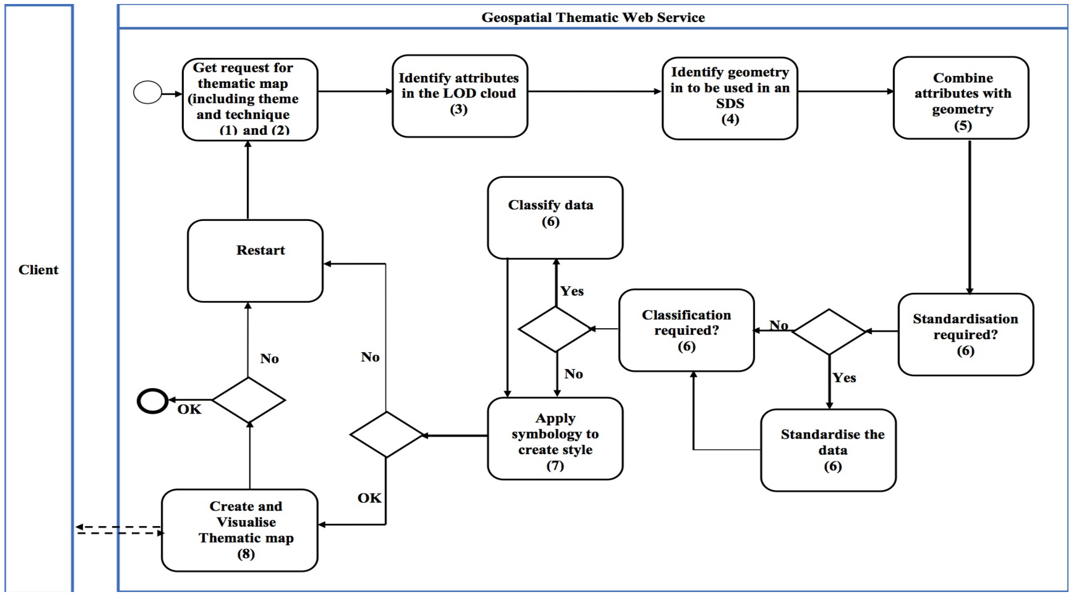


Figure 2: Process flow model of a web service that creates thematic maps

In addition to the requirements for this research standard technologies for web mapping above, linked data and spatial databases were used. This was motivated by the widespread deployment of standardized web map services in the geospatial community and the widespread publication of alphanumeric data (e.g. by statistical agencies) in the LOD cloud.

Geoportals are World Wide Web gateways that organise content and services such as directories, search tools, community information, support resources, data and applications (Maguire and Longley, 2005) to discover and access geographic Web services (Tait, 2005). They are the most visible part of SDIs (de Longueville, 2010). Today's geoportals are focusing on interoperability through implementing standards for discovery and use of geographic data and services (de Longueville, 2010). SDIs are widely used to share, discover, visualise and retrieve geospatial data through OGC web services (Giuliani, Ray and Lehmann, 2011). OGC web services can be combined to provide a technical infrastructure for an SDI with SOA (Coetzee, 2009).

ISO/TC211, *Geographic information/Geomatics*, and the Open Geospatial Consortium (OGC) have been developing standards in the field of geographic information, amongst others for web mapping, since the mid 1990s.Standards published by ISO/TC 211 and the OGC are widely used in the geospatial community (Kresse &Fadaie, 2010; Goodchild et al. 2012). Three of these standards are used in the implementations of the three integration styles presented in this article. ISO/TC 211 and OGC jointly published ISO 19128:2005, Web Map Server Interface (WMS), a specification for a web service that dynamically produces maps from spatially referenced data (ISO19128:2005). It describes a standard interface for requesting maps over the Internet. The OGC's Styled Layer Descriptor (SLD) defines an encoding that extends the WMS standard to allow user-defined symbolization and coloring of geographic features and coverages (OGC Styled Layer Descriptor 2007).

The linked open data cloud is built on standards published by the World Wide Web Consortium (W3C). Relevant standards for this research are the Resource Description

Framework (RDF), an encoding for linked data (W3C 2014a, 2014b), SPARQL (W3C 2013b, 2013c), a query language for linked data, SPARQL-Federated Query (W3C 2013a), SPARQL Query Results XML format (W3C 2013d) and SPARQL Query Results CSV and TSV formats (W3C 2013e). GeoSPARQL (OGC GeoSPARQL 2012), an emerging standard for querying geospatial data encoded in RDF, was not used because according to the requirements the geometry is stored in non-RDF format in a object-relational spatial database server.

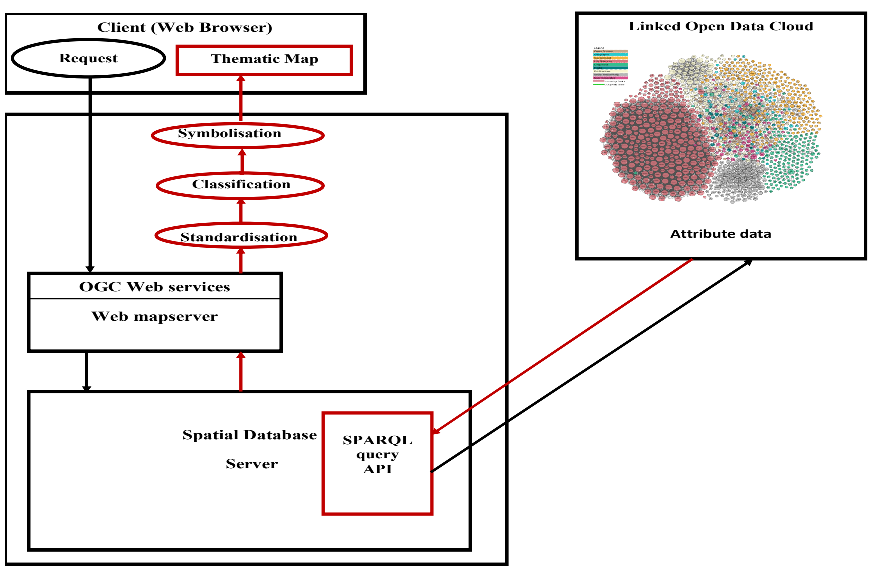
One characteristic of an 'ideal' SDI is that geospatial data can be integrated with many other kinds or sets of data to produce information useful for decision makers and the public, when appropriate (Nebert, 2004). As a result of current technologies, there are ever increasing volumes of diverse data that need to be integrated with SDIs (Harvey, Iwaniak, Coetzee and Cooper, 2012). Users expect SDI data to be available through new technologies (Coetzee, Harvey, Iwaniak & Cooper, 2013).

Design of SDI-LOD

In this section the author introduce the design of a geospatial web service (representing the visible part of an SDI) that accesses attribute data from the LOD cloud referred to in this paper as *SDI-LOD* is presented. *SDI-LOD* produces web thematic maps by programmatically combining attributes from the LOD cloud with geometry in an SDS. *SDI-LOD* produces web thematic maps by programmatically combining attributes from the LOD cloud with geometry in an SDS. SDI-LOD connects directly to the LOD cloud via a SPARQL query API.

In the SDI-LOD design option the spatial database server connects directly to the LOD cloud through a SPARQL query enabled extension to a spatial database, as shown in Figure 3. The extension acts as an extractor of linked data. The extension retrieves RDF triples (attribute data) directly from a remote SPARQL service and integrates them with geometry in a spatial database.

Figure 3: Design of SDI-LOD



IMPLEMENTATIONS AND RESULTS

In this section the implementation of the geospatial web service which is part of SDI-LOD is discussed. The detail implementation of the programmatic access capabilities of SDI-LOD is also presented.

Implementation of the Geospatial Web Service

The following software packages were used in the implementation of the web mapping component ofSDI-LOD: GeoServer 2.1.4, PostgreSQL 9.1.4 and PostGIS 2.0. GeoServer was required to set up a WMS, which provided support for styling through SLD and SLD extensions, and to establish a direct connection to the PostGIS database. PostGIS is a spatial extension to the open source PostgreSQL object-relational database management system. The packages were chosen after a critical evaluation of available technologies and a review of literature. The review findings showed that GeoServer and PostgreSQL/PostGIS were the most suitable free and open source geospatial software for web mapping.

A data set of all the countries was stored in a table called world_countries in a PostGIS spatial database. A connection to the database was created in GeoServer from where the table was published as a layer through GeoServer's implementation of OGC WMS 1.3.0. The layer can then be visualized by sending a GetMap request to the WMS.

Implementation and Results of SDI-LOD

The implementation of SDI-LOD required programmatic access to the LOD cloud through SPARQL extension to a PostgreSQL/PostGIS spatial database server. SDI-LOD uses an *RDF query interface,* which processes SPARQL and SPARQL-FED queries to a remote SPARQL service and feeds the results into the spatial database. The *RDF query interface* was created using ARQ. ARQ is a query engine application programming interface (API) for Jena that supports SPARQL (Apache Software Foundation, 2013b) and SPARQL-FED for querying a remote SPARQL service (Apache Software Foundation, 2013c). Jena is a Java framework for building Semantic Web applications. Amongst others, Jena has a programmatic environment for RDF and SPARQL (Yue et al, 2011), as well as a number of application programming interfaces (APIs) for processing RDF (Apache Software Foundation, 2013a). Since Jena is a Java framework, the application and other components of SDI-LOD were implemented in Java.

Figure 4 shows the implementation of SDI-LOD. SDI-LOD consists of a lightweight Java application, an *RDF query interface* and a *loader*. The Java application queries a remote SPARQL query service in the LOD cloud via the *RDF query interface.*The *loader*makes use of Java Database Connectivity (JDBC) to migrate RDF triples into the (relational) PostGIS spatial database.

The SDI-LOD implementation utilized SPARQL queries were executed programmatically via the RDF query interface to retrieve country names and the number of ethnic groups per country from DBpedia. The result set was formatted into XML (eXtensible Markup Language) based on the SPARQL query result XML format (W3C 2013d) and cached locally on the server machine. The *loader*createsa table inPostgreSQLand reads the XML content into the table. Each row in this table is a triple. The unique identifier of the table, in this case the name of the country, is the *subject* of the triple. The column headers represent the *predicates* and the column values represent the *objects* (values). After populating the table, the *loader* creates a new table in PostGIS by joining world_countries with the table containing the triples on the country name. SLD files were created to style (standardise, classify and symbolise) the data in the spatial database server. Figure 5is an example of a thematic map (created with SDI-LOD) showing human development index (HDI) of various countries in the world using RDF triples from DBpedia.Table 1 gives an overview of how the requirements are met by the design option.

Figure 4: Implementation of SDI-LOD

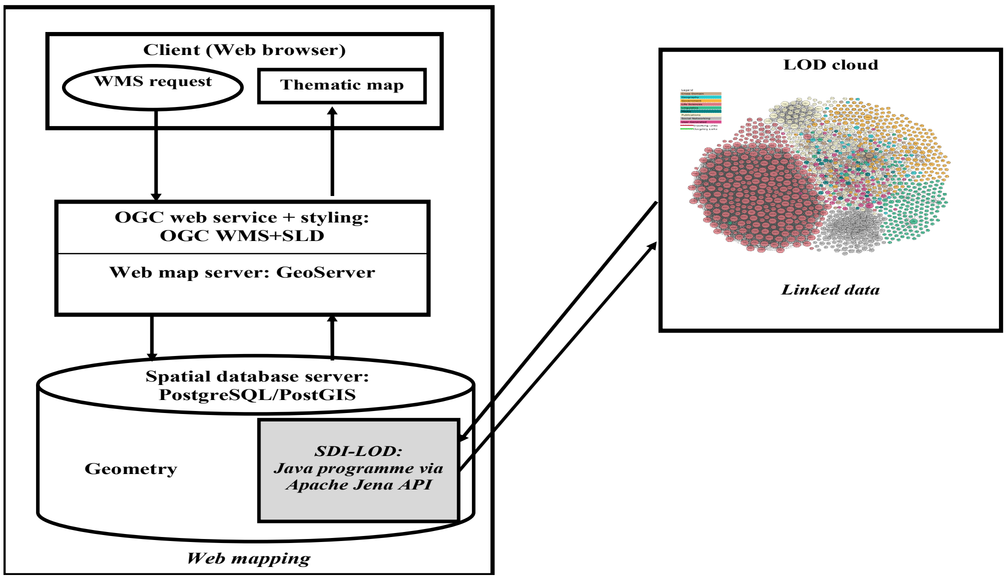


Figure 5: Thematic map (created with SDI-LOD) showing human development index (HDI) of various countries in the world using RDF triples from DBpedia.

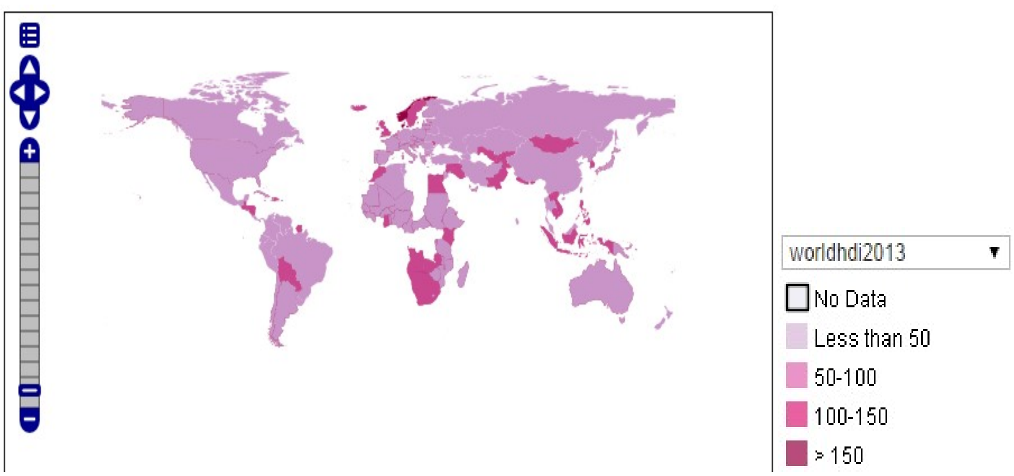


Table 1: Overview of requirements met by SDI-LOD

Requirement	**SDI-LOD**
1. A client shall request a thematic map from a web map service (i.e. the client sends a map request to the service).	WMS request
2. A client shall specify a theme and a thematic mapping technique in a map request (see steps 2 and 4.1).	Specified as style in a WMS request
3. The service shall identify the geometry to be used for the theme in a spatial database server (see step 3.1).	Geometry is published to service
4. The service shall identify the attributes to be used for the theme in the linked open data cloud (see step 3.2).	Service has translucent access through extension of the spatial database server.
5. The service shall combine the attributes with the geometry (see step 3.3).	Done via spatial database server extension
6. The service shall standardise and classify data, as required (see steps 4.1 and 4.2).	Done via styling
7. The service shall apply symbology appropriate for the specified thematic mapping technique (see step 4.4).	Done via styling
8. The service shall create a thematic map image and return it to the client (see step 4.5).	Done via web map server hosting a WMS

DISCUSSION

With SDI-LOD, a client is able to request for a thematic map from the web map server (GeoServer) hosting a WMS. SDI-LOD uses an extension to directly access linked from the LOD cloud and combines them with geometry in a spatial database server.

The first requirement, *a client shall request a thematic map from a web map server (i.e. the client sends a map request to the service), is* met by SDI-LOD. In the current implementation this is done through a WMS request. The client can request for maps and styles that the service (WMS) advertises. Therefore the requirement: *a client shall specify a theme and a thematic mapping technique in a map request is* met by specifying the theme and mapping technique through SLD styling.

The requirement that the *service shall identify the geometry to be used for the theme in a spatial database server* is satisfied by the design of SDI-LOD. In this design the geometry from the spatial database server are published as layers to the web map server as pertains generally in web mapping. However, in the current form, SDI-LOD is able to access attributes directly from the LOD cloud. The mode of accessing attributes is still oblique to the web map server (service). In this regard, the requirement; *the service shall identify the attributes to be used for the theme in the linked open data cloud,* is met through the programmatic access via the SPARQL API.

Similarly, the requirement which states that *the service shall combine the attributes with the geometry* is met. In the current implementation of SDI-LOD, the attributes are combined with the geometry during the process of integration in the spatial database. The web map server only accesses the global view of the heterogeneous data (geometry and attributes) from the spatial database server. Attributes are linked to geometry via a unique identifier; the country name in this article. If the country names stored together with the geometry do not exactly match the names used in the LOD cloud, the corresponding attributes are not included in the table join. This problem can be overcome for country names by using standardized codes for country names as published in ISO 3166-1, *Codes for the representation of names of countries and the subdivisions – Part 1: Country codes*. However, for other geographic features (e.g. rivers, water bodies, roads, addresses, etc.) standardized codes or names are not necessarily published, which could result in a join with a low percentage of matching identifiers. Intervention would then be required to improve the join. For example, semantic technologies could be used to match the features in the two datasets.

The web map server (WMS) creates the thematic maps according to the WMS requests from the client. The standardisation, classification and symbology are specified as OGC SLD files and used by the web map server (hosting the WMS) to present thematic maps to the client. The following requirements are therefore satisfied: t*he service shall standardise and classify data, as required; the service shall apply symbology appropriate for the specified thematic mapping technique;* and t*he service shall create a thematic map image and return it to the client*.

Even though these requirements are met, the standardisation, classification and symbology are done with the help of the developer who manually creates the SLD files and store it on the server. The research described in this thesis aims to create thematic maps by integrating linked data from the LOD cloud with geospatial data held in a spatial database. This will then enable current SDIs to uptake attribute data from the LOD cloud.

CONCLUSION AND FUTURE WORK

This paper has shown that though OGC web services cannot be connected directly to the LOD cloud, there are novel ways of overcoming this challenge by making use of existing technologies. Existing technologies benefit from research and development over time and are therefore robust. The paper shows that web mapping and OGC technologies have to be improved in order to visualise linked data in the form of thematic maps over the Internet on-the-fly. The author has presented the requirements and the design of SDI-LOD) to connect OGC WMS to the LOD cloud in order to retrieve and link attribute data with geometry for web thematic maps to be created. This paper further presented the implementation of SDI-LOD, with results of choropleth map.

This paper provided answers to the question of how an existing WMS can create thematic maps by retrieving attributes from the LOD cloud and combining them with geometry in an SDS. From the perspective of SDI, this research will contribute to how open diverse sources of data, such as linked data can be integrated with existing spatial data managed in national and regional SDIs. The LOD cloud contains data from government (and other official sources) and non-official sources. Integrating the LOD cloud as part of SDIs will require more research in data quality, data security, policies and standards. This research has contributed to bridging the gap between linked data, SDIs and web thematic maps thereby laying foundation for further research into how web based thematic cartography and existing geographic information systems can benefit from the Semantic Web and other emerging trends such as *Internet of Things*.

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