Linked Data: a best practice for better knowledge transaction

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Abstract. In recent years there has been much spoken, written and published about the semantic web. The main goal of this future web is to make it understandable to the machines. The traditional web is taken as a global document space where the documents are interlinked by using the hypertext links. The big question of interlinking data is still there. The fundamental prerequisite of the semantic web is the existence of large amount of meaningfully interlinked RDF data on the web. To date this prerequisite has not been widely met, leading to criticism of the broader endeavour and hindering the progress of developers wishing to build Semantic Web applications. Currently many attempts are going on to bring this data on Web like the Open Data movement which tries to bring the royalty free datasets into RDF data and interlinks them. Linked Data is about using the Web to connect related data that wasn't previously linked, or using the Web to lower the barriers to linking data currently linked using other methods. These best practices could lead to better knowledge transactions in the future.

This paper discusses the concept and technical principles of Linked Data by describing the underlying architecture, tools and frameworks available in the context of Linked Data.

Keywords: Semantic Web, Web of Data, Data Sharing, Linked Data, Knowledge Transaction

Introduction

The present web has changed the way of doing things in almost all parts of life. Be it the way one searches for information or one fills some on-line form, books the flight, orders pizza etc. The biggest impact can be seen in the way of sharing knowledge. Th Web has changed the way we publish and access the documents by eliminating the barriers in global information space. But the present web lacks the basic formalization so that the transaction of knowledge can be done without human indulgence. Whereas, the Semantic Web(SW) proposed by Tim Berner's Lee, promises to tackle these issues. The basic prerequisite of non availability of data is still not widely met. The World Wide Web has inarguably given a plethora of information in the form of documents but not in the form of processable data. The data is available as raw formats such as coma separated value (CSV) or XML, or marked up as HTML tables sacrificing much of its structure and semantics. It has been already known that the data formats like CSV, HTML are not sufficiently expressive to enable individual entities described in a particular document. There is a high need to link not only the documents by using <href> tags but; the data should also be linked.

Fortunately, in recent years the web is evolving in the same direction. This evolution has brought a set of best practices for publishing and connecting structured data on the Web known as Linked Data.(Christian Bizer, Tom Heath, & Tim Berners-Lee, 2009)

The adoption of the Linked Data best practices has lead to the extension of the Web with a global data space connecting data from diverse domains such as people, companies, books, scientific publications, films, music, television and radio programmes, genes, proteins, drugs and clinical trials, online communities, statistical and scientific data, and reviews.

There is already a lot of structured data accessible on the Web through Web 2.0 Application Programming Interfaces (APIs) such as the eBay[1], Amazon[2], Yahoo[3], and Google Base[4] APIs. Compared to these APIs, Linked Data has the advantage of providing a single, standardized access mechanism instead of relying on diverse interfaces and result formats. This allows data sources to be:

- more easily crawled by search engines,
- accessed using generic data browsers, and
- enables links between data from different data sources. (Chris Bizer, Cyganiak, & Tom Heath, 2007)

This Web of Data enables new types of applications. There are generic Linked Data browsers, which allow users to start browsing in one data source and then navigate along links into related data sources. There are Linked Data search engines that crawls the Web of Data by following links between data sources and provide expressive query capabilities over aggregated data, similar to how a local database is queried today. The Web of Data also opens up new possibilities for domain-specific applications. Unlike Web 2.0 mashups, which work against a fixed set of data sources, Linked Data applications operate on top of an unbound, global data space.

1 http://www.programmableweb.com/apis/directory
2 http://www.programmableweb.com/apis/directory
3 http://www.programmableweb.com/apis/directory
4 http://www.programmableweb.com/apis/directory

This enables them to deliver more complete answers as new data sources appear on the Web (Tim Berners-Lee, 2006). The other tools are explained elaborately in tools section.

What is Linked Data ?

The term Linked Data refers to a set of best practices for publishing and connecting structured data on the Web. (Christian Bizer et al., 2009) More specifically, Wikipedia defines Linked Data as "a term used to describe a recommended best practice for exposing, sharing, and connecting pieces of data, information, and knowledge on the Semantic Web using URIs and RDF."("Linked Data - Wikipedia, the free encyclopedia," 2010)

With linked data, one can find related data when one is having some of it. It is just like the present web where one can get related documents if they have some of it. Linked Data is about employing the Resource Description Framework (RDF) and the Hypertext Transfer Protocol (HTTP) to publish structured data on the Web and to connect data between different data sources, effectively allowing data in one data source to be linked to data in another data source (C. Bizer, T. Heath, Idehen, & T. Berners-Lee, 2008). The glue that holds together the traditional document Web is the hypertext links between HTML pages. Likewise the glue of the data web is RDF links. An RDF link simply states that one piece of data has some kind of relationship to another piece of data. These relationships can have different types (C. Bizer et al., 2008, pp. 1265-1266)For instance, an RDF link that connects data about people can state that two people have worked with each other; an RDF link that connects information about a person with information about publications in a bibliographic database might state that a person is the author of a specific paper.

Linked Data principles

The Linked Data is based on four popular principles these principles are not actually rules but they are expectations of behaviour. Which means breaking them doesn't destroy anything, but misses an opportunity to make data interconnected. Thus, it limits the way it can be later reused. It is this reusability of information which is value added by this web of data.

The linked data principles are as follows:

1. All items should be identified using URI references (URIrefs[5]), which implies that ideally no blank nodes are used. In simple terms use URIs as names for things.

[5] http://www.w3.org/TR/rdf-concepts/#section-Graph-URIref

2. All URIrefs should be dereferenceable—using HTTP URIs allows looking up the items identified through URIrefs. In other words use HTTP URIs so that people can look up those names.

3. When looking up an URIref—that is, a property is interpreted as a hyperlink—it leads to more data, which is usually referred to as the follow-your-nose principle. In similar terms, when someone looks up a URI, provide useful information, using the standards like RDF, SPARQL[6] etc.

4. Links to other URIrefs should be included in order to enable the discovery of more data. In other words, include links to other URIs. So that they can discover more things. (Christian Bizer et al., 2009; Hausenblas, Halb, & Raimond, 2008)

These principles provide the basic recipe for publishing and connecting data using the infrastructure of the Web while adhering to its architecture and standards.

The first rule says to identify things with URIs this is a first prerequisite for anything on semantic web. The URIs should use the universal standard set of symbols.

The second rule, use HTTP URIs is also taken as de facto standard in semantic web. But since the beginning of the web people used, developed and derived new URI schemes like LSIDS[7], HDL[8], DOIs[9] etc. for various reasons. The W3C Technical Architecture Group (TAG) ("Dereferencing HTTP URIs," 2007) recommends the use of HTTP URIs.

The third rule states, that one should serve information against the URI. One can, in general lookup the classes and properties one finds in data and get information from the RDF, RDFS, and OWL ontologies including the relation between the terms in the ontology. But there are many deviations from this as it is well known that there were many projects on ontology creation of different domain in some previous years but their data is not open or linked.

For example, typical social networking sites do not provide links to other sites, nor expose their data in a standard form. The simple example can be like I can give Orkut[10] profile link for my friend S on my foaf profile. So a machine or a person can follow that link and can find all the friends of S viz., T, U, W. Again this is not the conclusive list of all S's friends this is the list of only those friends whose profiles are there on Orkut. The system doesn't allow him to store the URIs of people on different systems. So, while the social networking is open to incoming links and while it is internally browsable, it doesn't make outgoing links.

The fourth rule, to make links elsewhere, is necessary to connect the data we have into a web.

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6 http://www.w3.org/TR/rdf-sparql-query/
7 http://lsids.sourceforge.net/
8 http://www.handle.net/
9 http://www.doi.org/
10 www.orkut.com

1 Architecture of Linked Data

As Linked Data is closely aligned to the general architecture of the Web, the basic architecture of it should be understood. The architecture is made up of three pillars.

- Resources
- Resource Identifiers
- Representations

1.1 Resources:

These are the items of interest from a particular domain and whose properties and relationships must be described. The W3C Technical Architecture Group (TAG) ("Dereferencing HTTP URIs," 2007) describes two kinds of resources: information resources and non-information resources(also called 'Other resources'). The deference is simple the information resources are the documents which we find on traditional Web like images, media files, etc. The non-information resources are the things whose data we want to share but they are not present on the Web like people, places, products, scientific concepts and so on. So, in the Linked Web of data the first requisite is to identify the resources, ie., the items of our interest.

Resource Identifiers :

These are the strings which are used to identify the items of interest ie. Resources. These strings are known as Uniform Resource Identifiers (URIs). In Linked Data architecture the http URIs are used and the use of other schemes like Uniform Resource Name (URN) or Digital Object Identifier (DOI) are discouraged. There are two reasons for choosing HTTP URIs.

i. They provide a simple way to create globally unique names without centralized management; and

ii. URIs work not just as a name but also as a means of accessing information about a resource over the Web. (C. Bizer, T. Heath, Ayers, & Raimond, n.d.)

Representations :

The information resources can have representations. A representation is nothing but the format in which the resource is represented. In other words it is a string of bytes in a particular format. For example, a list of employees of a particular firm is an information resource. Now, this can be represented as an HTML page, as a printable PDF, or as an RDF document. A single resource can have many different representations in different resolutions, formats, natural languages, etc.

2 The Best Practices and Frameworks

This section describes the best practices which should be used while publishing the Linked Data and the frameworks which should be followed for better visibility and interoperability.

Interlinking

The base for the Web of Data is the interlinking of RDF data. Interlinking is the process of publishing linked data and creating links to other datasets. There can be two basic approaches to interlink the data viz. manually or generated by automated linking algorithms for large datasets (Hausenblas et al., 2008). Whereas the latter depends on many factors to give good results, like the complexities of the target dataset should be known, disambiguation techniques should be used and others.

The Underlying Data Model : RDF

The information about the resources is represented by using the Resource Description Framework(RDF). Resource Description Framework (RDF) is a foundation for processing metadata; it provides interoperability between applications that exchange machine-understandable information on the Web. RDF emphasizes facilities to enable automated processing of Web resources. RDF can be used in a variety of application areas; for example: in resource discovery to provide better search engine capabilities, in cataloging for describing the content and content relationships available at a particular Web site, page, or digital library, by intelligent software agents to facilitate knowledge sharing and exchange, in content rating, in describing collections of pages that represent a single logical "document", for describing intellectual property rights of Web pages, and for expressing the privacy preferences of a user as well as the privacy policies of a Web site. RDF with digital signatures will be key to building the "Web of Trust" for electronic commerce, collaboration, and other applications ("Resource Description Framework (RDF) Model and Syntax Specification," 1999).

In RDF, a description of a resource is represented as a number of triples. The three parts of each triple are called its *subject*, *predicate,* and *object*. A triple mirrors the basic structure of a simple sentence, such as this one:

vinit	has email address	vinit@drtc.isibang.ac.in
(subject)	(predicate)	(object)

The subject of a triple is the URI identifying the described resource. The object can either be a simple literal value, like a string, number, or date; or the URI of another resource that is somehow related to the subject. The predicate, in the middle, indicates what kind of relation exists between subject and object. These predicate is a URI too. They can be picked from vocabularies, which are discussed later.

Benefits of using the RDF Data Model in the Linked Data Context

The main benefits of using the RDF data model in a Linked Data context are that:

- Clients can look up every URI in an RDF graph over the Web to retrieve additional information.
- Information from different sources merges naturally.
- The data model enables you to set RDF links between data from different sources.
- The data model allows you to represent information that is expressed using different schemata in a single model.
- Combined with schema languages such as RDF-S or OWL, the data model allows you to use as much or as little structure as you need, meaning that you can represent tightly structured data as well as semi-structured data. (Chris Bizer et al., 2007)

The underlying control: Vocabularies

A vocabulary is a collection of URIs that can be used to represent information about a certain domain. A set of well known vocabularies has evolved in the Semantic Web community. For better and easy processing of the data it is recommended to reuse the terms from already existing vocabularies wherever possible. Some of them are:

- Friend-of-a-Friend (FOAF)[11], vocabulary for describing people.
- Dublin Core (DC)[12] defines general metadata attributes. See also their new domains and ranges draft.
- Semantically-Interlinked Online Communities (SIOC)[13], vocabulary for representing online communities.
- Description of a Project (DOAP)[14], vocabulary for describing projects.
- Simple Knowledge Organization System (SKOS)[15], vocabulary for representing taxonomies and loosely structured knowledge.
- Music Ontology[16] provides terms for describing artists, albums and tracks.
- Review Vocabulary[17], vocabulary for representing reviews.
- Creative Commons (CC)[18], vocabulary for describing license terms.

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11 http://www.foaf-project.org/
12 http://dublincore.org/documents/dcmes-xml/
13 http://sioc-project.org/
14 http://usefulinc.com/doap/
15 http://www.w3.org/2004/02/skos/
16 http://musicontology.com/
17 http://purl.org/stuff/rev#
18 http://creativecommons.org/

- (“TaskForces/CommunityProjects/LinkingOpenData/CommonVocabularies - ESW Wiki,” 2007)

The references(URIs) for geographical names, research areas, etc. can be borrowed directly from the already available various interesting open data sets on the Web. Examples include:

- Wikipedia,[19]
- Wikibooks,[20]
- Geonames,[21]
- MusicBrainz,[22]
- WordNet,[23]
- The DBLP bibliography[24]
- and many more which are published under Creative Commons or Talis licenses. (“SweoIG/TaskForces/CommunityProjects/LinkingOpenData - ESW Wiki,” 2010)

Content Negotiation :

Content Negotiation is the process of getting the resource from a server in a preferred representation. In the present day Web the clients (Web browsers) just display html pages and they render RDF files in their raw code form. This is not very useful for the clients on Web of Data. In the Web of Linked Data the process of 'Content Negotiation' is used where the clients send the request to the server about their preferred representation. The server then inspects the header and generates the requested representation and can serve. If the headers indicate that the client prefers HTML, then the server can generate an HTML representation. If the client prefers RDF, then the server can generate RDF.

This simply signifies that for non-information resources the server will have to store three URIs :

- URI identifying the non-information resource A,
- information resource with an RDF/XML representation describing A and;
- information resource with an HTML representation describing A.

19 http://www.wikipedia.org/
20 http://www.wikipedia.org/
21 http://www.geonames.org/
22 http://musicbrainz.org/
23 http://wordnet.princeton.edu/online/
24 http://www.informatik.uni-trier.de/%7Eley/db/

3 Tools

The tools which are used to attain the target of interlinking data across the web can be divided into four broad categories:

- Linked Data Publishing Platforms/Frameworks
- Linked Data/RDF Editors and Validators
- Tools for Consuming Linked Data
- Linked Data Applications for End Users

3.1 Linked Data Publishing Platforms/Frameworks

This category discusses some of the state-of-the-art tools available for the publishing of Linked Data.

3.1.1 D2R Server:

D2R Server is a tool for publishing relational databases on the Semantic Web a global information space consisting of Linked Data. It enables RDF and HTML browsers to navigate the content of the database, and allows applications to query the database using the SPARQL query language. It is developed at Freie Universitat, Berlin.

The data on the Semantic Web is modelled and represented in RDF. D2R Server uses a customizable D2RQ mapping to map database content into this format, and allows the RDF data to be browsed and searched – the two main access paradigms to the Semantic Web.

It has three interfaces viz.

- Using the 'linked data Interface' the RDF description of various resources available over the HTTP protocol. Using a Semantic Web browser like Tabulator (slides) or Disco, one can follow links from one resource to the next, surfing the Web of Data.
- Using the 'SPARQL interface' the semantic web applications can search and query the database using the SPARQL over the SPARQL protocol.
- Using the 'HTML interface' the traditional web browsers can access the page.

This sever has got many installations at various institutions. (“D2R Server – Publishing Relational Databases on the Semantic Web,” 2009)

Similar tools like OpenLink Virtuoso and Triplify are available to publish relational database as Linked Data.

3.1.2 Talis Platform:

The Talis Platform weaves Data with the Web to create a highly available and adaptable environment for data sharing. It provides cloud based hosting for both structured and unstructured data, query interfaces to enable data exploration and manipulation, Future-proofing for data and applications, through the latest industry standards. (“Talis Platform - Home,” 2010)

The Talis Platform is already being used to power a number of next generation library management (Prism) and education applications(Aspire). (“Talis Platform - Solutions,” 2010)

3.1.3 Pubby:

Pubby makes it easy to turn a SPARQL endpoint into a Linked Data server. It is implemented as a Java web application.

Pubby handles requests to the mapped URIs by connecting to the SPARQL endpoint, asking it for information about the original URI, and passing back the results to the client. It also handles various details of the HTTP interaction, such as the 303 redirect required by Web Architecture and content negotiation between HTML, RDF/XML and N3 descriptions of the same resource. It is developed by Freie Universitat, Berlin. (“Pubby – A Linked Data Frontend for SPARQL Endpoints,” 2007)

Paget:

Paget is a framework for building Linked Data applications. It is released under GNU/GPL. Paget can automatically represent semantic data in various formats such as XML, JSON, Turtle and HTML. It is used to do content negotiation. (Devis, 2009)

3.2 Linked Data/RDF Editors and Validators

The ability to edit RDF graphs in the web is very important. It allows individual participation, and allows "crowd-sourcing" of data collection and data review. Therefore it is good to build interfaces which allow users who can correct or add to a collection of data the ability to do so intuitively. Apart from editing there is a need to validate the editions also. For this some editors and validators are available like,

3.2.1 Hyena:

Hyena is an RDF Editor. It is available in the form of web-based application and desktop application as well. It helps in editing the RDF data collected from different users via Web. It is developed by Axel Rauschmayer of LMU München (Germany). (“Axel Rauschmayer,” 2010)

3.2.2 Vapour:

Vapour is a validation service to check whether semantic web data is correctly published according to the current best practices, as defined by the 'Linked Data principles', the 'Best Practice Recipes' and the 'Cool URIs'. Vapour is available as a public web service[25], but also as open source software under the terms of the W3C License. It is written in Python. It is maintained by The CTIC Foundation (Center for the Development of Information and Communication Technologies in Asturias).

Vapour contains three modules:

- **cup :** provides the web interface of the application
- **teapot :** is the core of the application that launches HTTP dialogs, evaluates the responses and stores the results into the (in-memory) RDF store
- **strainer:** generates the reports, both in XHTML and RDF/XML ("Vapour, a Linked Data validator," n.d.)

3.3 Tools for Consuming Linked Data

With the significant amount of Linked Data being published on the Web, numerous efforts are going on to develop the applications that can consume this Web of Data. These applications can be broadly devided into three broad categories: ("TaskForces/CommunityProjects/LinkingOpenData/SemWebClients - ESW Wiki," 2009)

- Linked Data Browsers
- Linked Data Mashups
- Linked Data Search Engines and Indexes

Linked Data Browsers:

Just as traditional Web browsers allow users to navigate between HTML pages by following hypertext links, Linked Data browsers allow users to navigate between data sources by following links expressed as RDF triples (Christian Bizer et al., 2009).

Some of the examples are: ("TaskForces/CommunityProjects/LinkingOpenData/SemWebClients - ESW Wiki," 2009)

- **razorbase**[26] A browser for LOD data which employs facets and set-based browsing
- **Tabulator**[27] A browser for analysing and exploring linked Linked Data.
- **Disco**[28] server-side Linked Data browser.
- **OpenLink Data Explorer**[29] a Web browser extension, and a server-side component of the OpenLink Ajax Toolkit.

25 http://validator.linkeddata.org/
26 http://www.razorbase.com/
27 http://dig.csail.mit.edu/2005/ajar/ajaw/About.html
28 http://sites.wiwiss.fu-berlin.de/suhl/bizer/ng4j/disco/
29 http://esw.w3.org/topic/OpenLinkDataExplorer

- **Zitgist RDF Browser**[30]
- **DBpedia Mobile**[31] Linked Data browser for mobile devices using DBpedia locations as starting points for exploring the geospacial Semantic Web.
- **Marbles**[32] tabular Linked Data browser supporting Fesnel.
- **iLOD**[33], a simple linked data browser for the iPhone, made by Alexandre Passant.
- **Fenfire**[34] Linked Data browser displaying information as a navigable graph.
- **Objectviewer**[35] by Troy Self (Semantic Web Central).
- **zLinks**[36] Technology for embedding Linked Data backed pop-ups into textual web content.
- **Sigma**[37], Live views on the Web of Data

Live Data Mashups:

The interlinking ability of the Linked Data and the use of standards provides wide scope to develop domain specific facility by 'mashing up' different already available datasets. There are many Linked Data Mashups available like Revyu[38] uses Linked Data from DBpedia to augment reviews, for instance with information about a director of a film and some like DBpedia Mobile combines the Linked Data from DBpedia, the flicker wrapper and Revyu whereas some like Music Mashup combines Linked Data from various music related datasets.

There are some other mashups also like Talis Aspire (“Talis Platform - Solutions,” 2010)which is web based resource management application and BBC Programmes and music which uses Linked data from Dbpedia and MusicBrainz as controlled vocabularies to connect content about the same topic residing in different repositories and to augment content with additional data from the Linking Open Data cloud (Christian Bizer et al., 2009).

3.3.1 Live Data Search Engines and Indexes

The traditional web provides two broad ways of using it one can either browse by following the http links or one can search by using the available search engines and indexes. In the Web of Linked Data also there are browsers which provide the way to navigate and the search engines provide the point from which the navigation begins. In Linked data, a number of search engines are developed that crawl the Web of Data

30 http://browser.zitgist.com:8890/
31 http://wiki.dbpedia.org/DBpediaMobile
32 http://wiki.dbpedia.org/Marbles?v=71e
33 http://i.linkeddata.org/
34 http://fenfire.org/
35 http://objectviewer.semwebcentral.org/
36 http://zlinks.zitgist.com/index_extended.html
37 http://blog.sindice.com/2009/07/22/sigma-live-views-on-the-web-of-data/
38 http://revyu.com/

and provide the search capabilities. These services are broadly classified into two types: human-oriented search engines, and application oriented indexes (Christian Bizer et al., 2009).

Human-oriented search Engines:

The human oriented search engines provide the keyword based search where users are presented with a search box into which they can enter keywords related to the item or topic in which they are interested and the service returns a set of results that may be relevant to the query. Some examples are:

- **Falcons**[39] developed by IWS China, currently indexes 7 million RDF documents.
- **Semantic Web Search Engine** (SWSE)[40] developed by DERI Ireland. (Chris Bizer et al., 2007)

However, rather than simply providing the links from the search results these search engines provide a more detailed interface to the user that exploits the underlying structure of the data. For example: Falcons provides the option for searching for objects, concepts and documents. While the object search is suited for people, places and other more concrete items, the concept search is oriented to locating classes and properties in ontologies published on the web. The document search is more or less similar to traditional search engine experience (Christian Bizer et al., 2009).

Application-oriented Indexes:

There are many APIs available through which Linked Data applications can discover RDF documents on the Web that reference a certain URI or contain certain keywords. For Example:

- **Sindice**[41] developed by DERI Ireland, currently indexes over 20 million RDF documents.
- **Watson**[42] developed by KMi, UK.
- **Swoogle**[43] developed by ebiquity group at UMBC USA, currently indexes 2.3 million RDF documents (Chris Bizer et al., 2007)

The rationale for such services is that each new Linked Data application should not need to implement its own infrastructure for crawling and indexing all parts of the Web of Data of which it might wish to make use. Instead, applications can query these indexes to receive pointers to potentially relevant documents which can then be retrieved and processed by the application itself.

39 http://iws.seu.edu.cn/services/falcons/
40 http://www.swse.org/
41 http://www.sindice.com/
42 http://watson.kmi.open.ac.uk/WatsonWUI/
43 http://swoogle.umbc.edu/

Conclusion

Since the beginning of the semantic web a lot of work has been done in regard to the basic layers of the famous brick layer diagram. The prerequisite for the semantic web is structured data the Linked Data is an attempt to bring the all the existing data in the datasets to the Semantic Web. Linked data is essential to actually connect the semantic web.

There are many ongoing projects in this regard some to mention is the one mighty *Linking Open Data Project* which tries to bring the royalty free datasets into RDF data and interlinks them. Another one *riese* (Hausenblas et al., 2008) brings RDFized and interlinked version of the Eurostat data. The aim of these attempts is to provide the basic prerequisite of structured data from the existing web of documents to the Semantic Web. This will further provide the base for the developers to concentrate on functionality rather than configuration and heavy framework-study.

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