Dutta, B. (2014). Symbiosis between Ontology and Linked Data. Librarian, vol. 21, no. 2, pp. 15-24. ISSN: 0972-3978.

Symbiosis between Ontology and Linked Data*

Biswanath Dutta
DRTC, Indian Statistical Institute
Bangalore, India
E-mail: dutta2005@gmail.com

Abstract: Ontology and Linked Data are the two prominent Web technologies that we have observed in the recent past. Lot of research and development works have been taken place and is going on this area. The majority of the works are conducted and going on in parallel without exploiting the relationships between these two. In the current work, we have tried to explore the complex relationships between these two technologies. The current work reveals that these two are interdependent with lots to offer to each other for their faster growth and meaningful development. As an implication, this realization is ultimately going to boost the overall implementation of Semantic Web and applications.

Keywords: *Ontology, Linked Data, Applications, Benefits, Challenges, Limitations, Relationships.*

1. Introduction

Ontology, a formal explicit specification of a shared conceptualization (Studer, Benjamins & Fensel, 1998), is at the centre of Semantic Web (SW) (Berners-Lee, 2001**)** and applications. It is a vocabulary where the terms are expressed formally (using logic based knowledge formalism, say, OWL) and defined explicitly (in terms of their properties and constraints), which make them machine processable. Ontologies are useful for various purposes, for instance, for annotating the documents, for semantic information retrieval, reasoning and inferencing and so forth (discussed further in Section 2.1). There are immense amount of research under going in the area of ontology, especially ontology development and ontology design approaches, discovery of semantic similarity (Adhikari, Singh, Dutta & Dutta, 2015**)**, ontology evaluation, etc. On the Web, varieties of ontologies are available ranging from general purpose ontology (aka top-level ontologies, e.g., Cyc, SUMO, DOLCE), domain based ontology (e.g., Space ontology, Gene ontology, Food ontology) to application specific ontology (e.g., Restaurant ontology, Recipe ontology) (Dutta, Chatterjee & Madalli, 2013 & 2015).

Another important technology that has emerged in the recent past in the field of Semantic Web is Linked Data. A large number of researchers and practitioners from academia and business are actively working in this area. In general, Linked Data (LD) is a method of publishing structured data on the, so that they can be interlinked. The aim is to create a global database by interlinking data coming from multiple sources. The goal is to build a huge data infrastructure, on top of which the developers can build various applications, for instance, MashUp applications and many others (discussed further in Section 4.2). Linked Data can be referred as a success story. However, to have an interlinked global database, we still have to go along. Various communities are working towards creating and publishing linked dataset on the Web. Some of the popular linked dataset available on the Web are DBPedia linked dataset (DBPedia, n.d.), Freebase (Freebase, n.d.), Geonames (Geonames, n.d.), MusicBrainz (LinkedBrainz – MusicBrainz, n.d.), etc.

* This paper is based upon the work presented at the International Conference on Problems in Information Retrieval, 9th August 2014, Jadavpur University, Kolkata, India.

From the above discussions, few obvious questions would rise for example, how these two are related? Are they competitors to each other? Are they here to deprive each other? Alternatively, we may also ask, can Linked Data be benefited from ontology and vice versa? In the current work we try to find answer for those questions by analyzing the core ideas behind these two technologies, their usefulness and applications. We also explore their strengths and weaknesses and show how both of them can be mutually benefitted and can overcome some of their weaknesses. In context of the current work, we can mention about the following two related works (Studer, Simperl & Kampgen, 2011; Riga, Janowicz & Hitzler, 2013). The basic difference between these two previous works with the current work is: the current work tries to answer the above stated questions by analyzing both the technologies ontology and Linked Data at the deeper level as indicated above. The current work also exploits how these two technologies are related, and illustrates how they can be mutually benefited from each other.

The rest of the work is organized as follows: section 2 briefly discusses what is an ontology and its usefulness. The usefulness is discussed by taking some of the real world systems. Section 3 discusses some truths about an ontology. Section 4 discusses Linked Data, its usefulness and some of the real world applications that are built on linked datasets. Section 5 explores some of the challenges of Linked Data. Section 6 illustrates and explains how ontology and Linked Data get benefited from each other. Finally section 7 concludes the paper.

2. What is Ontology?

The term "ontology" is originated from metaphysics, a branch of philosophy, and more specifically from Aristotle's theory of categories (Studer, Benjamins & Fensel, 1998), where an ontology is a systematic account of existence. The purpose was to provide a categorization of all existing things in the world. Ontologies have been lately adopted in several other fields, such as Library and Information Science (LIS), Artificial Intelligence (AI), and more recently in Computer Science (CS). Many definitions of ontologies have been provided. In Information Science and Computer Science, ontology is considered as an engineering artefact and referred as a formal naming and definition of the types, properties, and interrelationships of the entities that really or fundamentally exist for a particular domain of discourse. The most prominent definition of ontology was provided by Gruber in 1993 (Gruber, 1993). According to him, ontology is an "*explicit specification of a conceptualization*". In 1998, Studer et al (Studer, Benjamins & Fensel, 1998) extended Gruber's definition stating that "*an ontology is a formal, explicit specification of a shared conceptualization*". So, in simple words, we can say that ontology is a formally represented knowledge of a domain of discourse (aka universe of discourse) based on a shared conceptualization. Here, conceptualization refers to an abstraction, a simplified view of the domain of discourse motivated by some purposes. The formal and explicit specification of the conceptualization of the domain of discourse makes the constituents of ontology machine interpretable (Dutta & Prasad, 2013).

2.1 Ontology Usefulness and Applications

Ontology is in the core of the *semantic* based applications. It has immense importance in semantic applications. For instance, as a controlled vocabulary, which can be used by both humans and computers to communicate and access information, can be used for knowledge sharing within and between domains. An ontology can also be used for representing and storing data, reasoning and inferencing knowledge. Ontology can also be used to organize, navigate and manage Web content, can be used as a tool for NLP tasks, such as, for sense disambiguation (Sanderson, 1994). In the following we illustrate some of the real applications that are based on ontologies.

Content organization - ontology can be used for content organization and navigation. One such real world example is BBC's Education system (Figure 1). It uses a curriculum ontology (*available here*: http://www.bbc.co.uk/ontologies/curriculum) to organize the learning contents. The ontology provides data model and vocabularies for describing the national curricula within the United Kingdom (UK).

Beside the education system, BBC uses ontologies for organizing contents, such as, music, general news, etc.

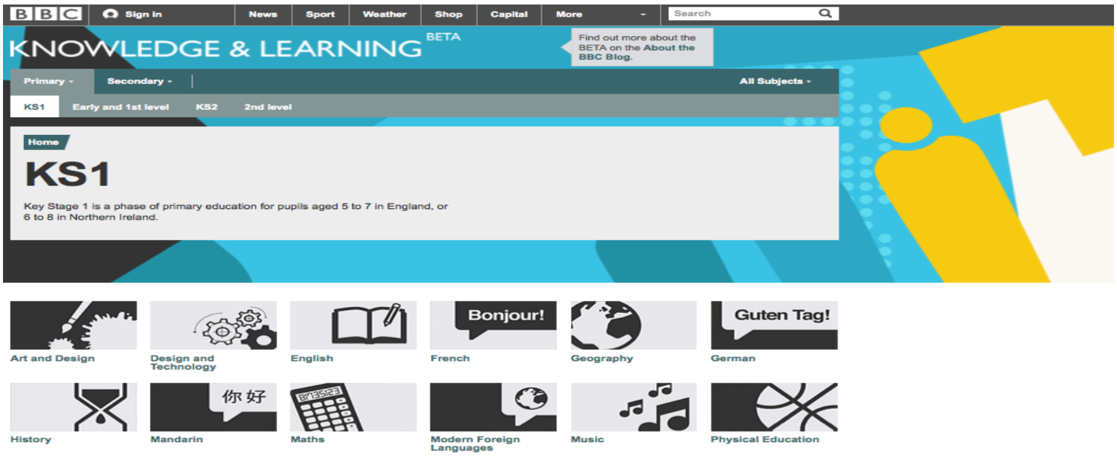

Figure 1: BBC's educational site (http://www.bbc.co.uk/education)

Entity Markup - ontology is used to markup entities (e.g., person, organization, location, music) exist in the webpages. The marked up webpages are easy to interpret by software programs. Search engine, like, Google, uses the marked up information to display the content in search results in a useful way, for instance, showing rich snippets (Enabling rich, n.d.). Figure 2 presents a snippet of recipe retrieved from Google. In this context we can name *schema.org* (Schema.org, n.d.), a vocabulary supported by the major search engines like, Google, Yahoo! and Bing. It is designed to create structure data markup. The content creators can use this vocabulary to markup a wide range of entities such as, person, organization, location, event, book, recipe, music, video, and so forth.

Figure 2: Google snippet for recipe

Content publication - ontology use in content publication increases the visibility of the sites and the content itself. The use of ontology also increases the ranking of the sites significantly in the search results. Many online commercial websites are using ontology to structure and publish their content. For instance, Best Bye (Best Buy, n.d.) (Figure 3). It uses GoodRelations (GoodRelations, 2011), a standard vocabulary, to describe product, price, store, and company data.

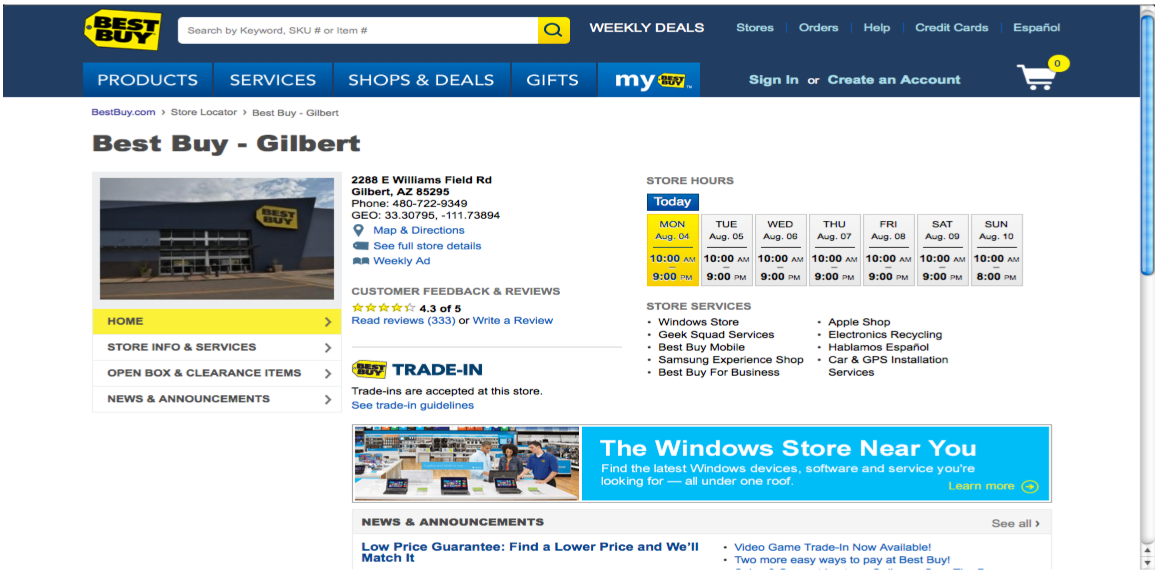

Figure 3: Best Buy using GoodRelations

Content annotation - ontology is used in annotating content. One such example is BioPortal Annotator (BioPortal, 2015). The annotator annotates biomedical text with concepts from the ontologies. To annotate content, we need to enter text in the text box and press the submit button. The system matches words in the text to terms in ontologies by doing an exact string comparison (i.e., a "direct" match) between the text and ontology term names, synonyms, and ids. Following figure 4 presents a screenshot of the annotator system presenting the result of annotations for a piece of text that we copied from Wikipedia and pasted in the annotator box. The annotation result shows with details of class from the text and their corresponding matching classes within the ontologies used to annotate the text and the context.

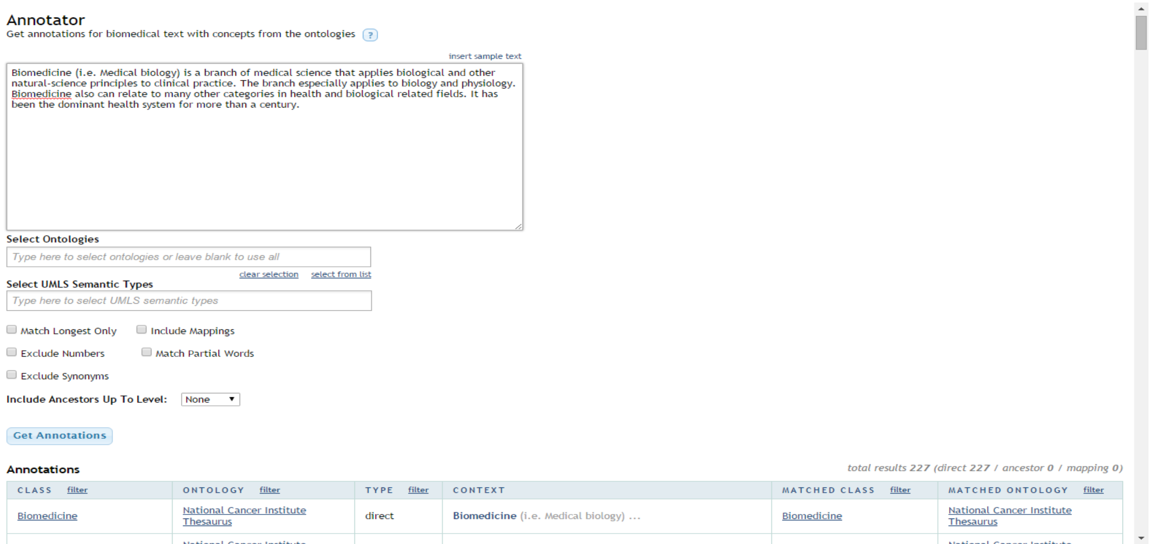

Figure 4: BioPortal annotator

Content navigation - ontology is used for content navigation. For example, BioPortal, a largest repository for biological ontologies, provides enhanced content navigation and search facilities as shown in figure 5.

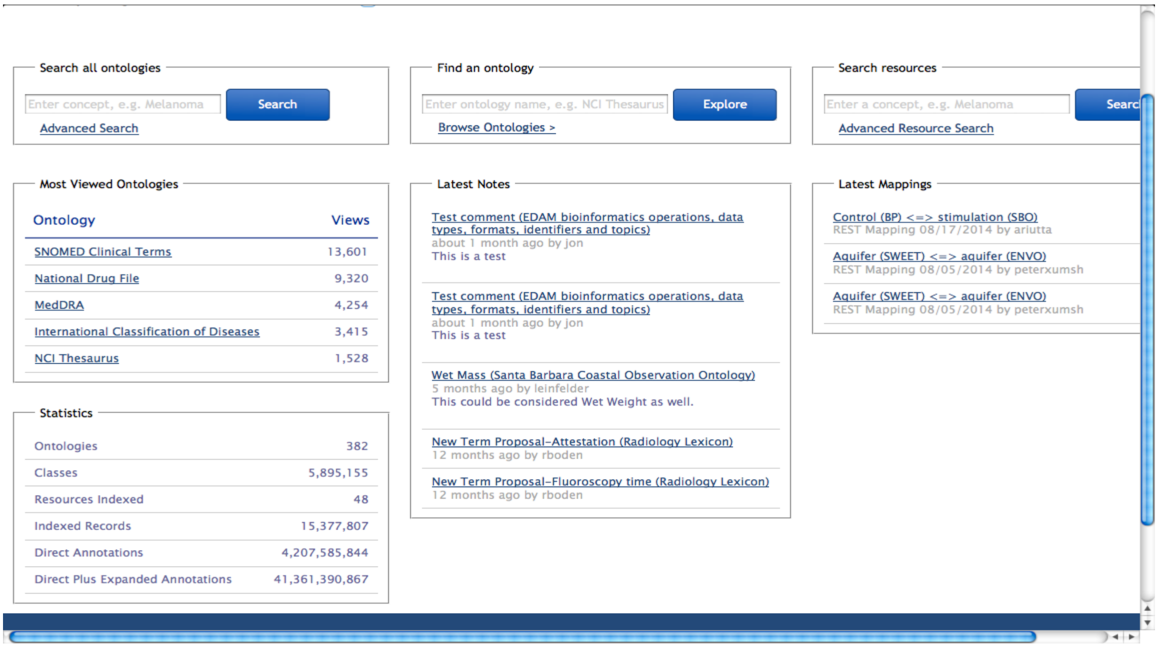

Figure 5: Content navigation in BioPortal

Besides the above applications, there are many other semantic applications where ontology is used. For instance, applications for topic exploration, query enhancement, query expansion, and so forth. These applications based on ontologies show that how ontologies are used to build semantic based information spaces. On the other hand, it also gives us a hint on how ontologies can be used to add semantics to data, which software programmes can process and retrieve meaningful information.

3. Truths about an Ontology

Besides the above success stories of an ontology, there are also some grey sides as discussed below.

- *Expensive* - ontology construction is an expensive affair. A usable ontology demands lots of human resources, infrastructural support and time.
- *Growth is slow* - ontology is a mental process. Quality ontology involves an immense amount of human labour and thus the growth of ontology is very slow.
- *Formal ontology* - building heavyweight formal ontology is a complex task. It is not easy to build and use. It is also hard to find enough tool support for these ontologies for the tasks like, reasoning and inferencing knowledge. On the other hand, lightweight ontology (*an ontology having thesaurus like structure and is based on minimal level of logic constructors* (Giunchiglia, Dutta, & Maltese, 2009), which provides a minimum level of semantics, but is relatively easy to understand and implement, is generally recommended to use for semantic operation. According to Hendler, "A Little Semantics Goes A Long Way" (Hendler, n.d.)."
- *Ontology reuse* - Ontology reuse is a real concern of the Semantic Web community (Dutta, Nandini & Shahi, 2015; Obrst et. al., 2014). Since ontology is an expensive affair, the ideal situation would have been to be able to "reuse" the existing ontologies developed for similar kinds of applications. However, it is hard to find the consensuses among the ontologists in terms of knowledge modelling and representation. As a result, often we end up with creating ontologies from a scratch every time we build applications.

4. Linked Data

Linked Data, in general, refers to data published in accordance with principles designed to facilitate linkages among datasets, element sets, and value vocabularies (Berners-Lee, 2006). It is about linking the Web of data in a way, so that both human being and machine can explore and make optimum use of available data on the Web. According to Tim Berners-Lee, the vision of Semantic Web will come true by not just putting data on the Web, but by making relations between data. The relations between data will facilitate us, both machine and human being, to explore and know more about a thing (or a resource) and its related data even when we know little about that thing. The goal is to evolve the Web like a *single global database* to provide integrated access to data from a wide range of distributed and heterogeneous data sources. A global database which can answer complex queries, like, for example, "*give me books on ontology related topics that are written by an Indian author who worked with an Italian professor from University X.*"

Linked Data uses the Web technologies Uniform Resource Identifies (URI), HTTP URI (HyperText Transfer Protocol URI) and Resource Description Framework (RDF) and Simple Protocol and RDF Query Language (SPARQL) (SPARQL, 2008). Uniform Resource Identifiers (URIs) (Berners-Lee, 2006) to name things (i.e., any resource) to globally and uniquely identify them. This is similar to how identifiers are used for authority control in traditional librarianship. In Linked Data, URIs may be Internationalized Resource Identifiers (IRIs), that is, Web addresses that use the extended set of natural-language scripts supported by Unicode. HTTP URIs, so that people can look up those names. Standards like RDF and SPARQL are to provide meaningful information when someone looks up a URI.

4.1 Usefulness of Linked Data

Linked Data can be better understood by exploring its significance from various aspects, such as, data accessibility, federated search, data currency, contribution to science and research (Benefits of the, 2011). These are further discussed as follows.

- *Integrated access to data* – the fundamental strength of Linked Data lies in its capability of integrating the geographically scattered data and provide an integrated data access. Through this the navigation across information sources becomes more sophisticated.
- *Data enrichment* – Linked Data technology has enabled us to enrich the data in the knowledge bases in an easy way. The technology has enabled us to enrich our data by just linking with the data that is already available somewhere on the Web. In other words, the technology has enabled us to avoid re-entering the data and duplicate our efforts.
- *Independency from specific data format* – Linked Data method has brought a fundamental change in the way we share, retrieve and mix our data. All data published as Linked Data on the Web has a common and consistent data format i.e., RDF. So, the data mixing has become easy.
- *Decentralization* – Linked Data technology provides decentralized platforms where data development, creation and structuring are not centrally located.
- *Data sharing* – data sharing has become easy, which was never before. Linked data technologies and linking and publishing tools have made data sharing easy. For any organization, data sharing and publishing have become cost effective.
- *Data reuse* – cost effectiveness in data sharing and publishing also has influenced and has increased the chances of data reusability.
- *Data maintenance and data currency* – Linked Data technology has also made it possible for easy data update. Data update at the source gets affected on run time.

4.2 Applications based on Linked Data

We have immense amount of available Linked Data on the Web, numerous efforts are underway to research and build applications based on these data. We provide here the glimpses of these applications. We have classified these applications into two broad categories: (A) *general Web applications* and (B) *domain specific applications*.

A. General Applications

The applications those are of general kinds. For instance, Linked Data browsers and search engines, review and rating systems.

Linked Data Browser

Linked Data browsers are similar like the traditional browsers. The main difference between these two is: in traditional browser we navigate between HTML pages following the hyperlinks links. In Linked Data browser we navigate between data and data sources following the links expressed as RDF triples. For instance, we start with a search on "Rabindranath Tagore" from a dataset on "Poets in Bengal" maintained by Sahitya Academy and reach to a place "Kolkata" (where Tagore was born) and from Kolkata we reach to "Presidency College" that belongs to a dataset on "Academic institutions" maintained by Govt. of West Bengal. So, Linked Data enables us to start from a dataset and traverse to another one following RDF's HTTP URI links rather than HTML links. Some of the notable Linked Data browsers are Marbles (Marbles, 2009), Tabulator (Tabulator, n.d.), etc. (*more can be found here*: http://www.w3.org/wiki/TaskForces/CommunityProjects/LinkingOpenData/SemWebClients)

Search engines

Search engine is a place where navigation starts. The Linked Data browsers allow us to navigate information space, while search engines are often the place where navigation starts (Bizer, Heath & Berners-Lee, 2009). Some of the notable search engines are Sig.ma (http://sig.ma), FalconS (FalconS, n.d.), Swoogle (Swoogle, n.d.), Watson (Watson, n.d.), etc. Figure 6 presents FalconS search interface.

Figure 6: Search result in FalconS

B. Domain Specific Applications

Besides the above general applications based on Linked Data, there are many domain specific services also we observe on the Web. These applications are mostly built by mashing up data from various Linked Data sources. Some of the significant applications are discussed in the following.

Revyu

Revyu (Revyu, n.d.) is a live, publicly accessible generic reviewing and rating system. It allows reviewing and rating any named entity (Giunchiglia & Dutta, 2011), for instance, person, location, song, movie and event. The system is designed based on the Linked Data principles (Berners-Lee, 2006) and Semantic Web technologies, namely, RDF and SPARQL. One of the key design goals of

Revyu system is to improve the user experiences by minimizing the burden on users and maximizing the reuse of external data sources by consuming the data available on the Web. For instance, when we review a song, the system automatically retrieves, where a match is found, additional information about the song, say, *lyricists* of the song from DBPedia. This reduces the job of a human being from re-entering the data that is already available in the Web of Data. On the other side, the system also makes sure that it also blossom the Linked Data Web by making links in RDF (Heath & Motta, 2008). So, we can say that Revyu system not only uses and exploits the existing Linked Data resources, but also contributes and adds data into the Linked Data Web. The data created in Revyu is open to the other systems to exploit further.

Bio2RDF

Bio2RDF (Bio2RDF, n.d.) is a mashup system with largest network of Linked Data for the Life Sciences. It uses a three step approach to create mashup data from a diverse set of heterogeneously formatted sources obtained from multiple data providers. The system uses the Semantic Web technologies, such as, rdfizer (RDFizers, n.d.), Sesame open source triple store (Sesame, n.d.) and an OWL ontology. At present it has more than 11 billion triples across 35 databases. Some of the notable databases it uses are clinicaltrials.gov, dbSNP, GenAge, GenDR, PubMed, SIDER and WormBase. The repository is available to query at http://bio2rdf.org/.

RDF Book Mashup

The RDF Book Mashup (RDF Book MashUp, n.d.) demonstrates how Web 2.0 data sources like Amazon, Google and Yahoo can be integrated into the Semantic Web. Following the principles of linked data, the RDF Book Mashup makes information about books, their authors, reviews, and online bookstores available on the Semantic Web. This information can be used by RDF browsers and crawlers, and other publishers of Semantic Web data and can set links to it.

From the above discussion we can observe that Linked Data is going to change the way present search systems work. In the Linked Data Web, searching information on a thing would be simpler and most of the time would be bounded to a single page result. Single page result because all the data sources dealing with same/different aspects about a thing are linked. This will also essentially reduce the number of searches as we need not to visit multiple sites to find and gather information on a thing.

5. Truths about Linked Data

There is a viral growth of Linked Data. Millions of triples are available on the Web. For instance, as mentioned in (DBPedia Blog, n.d.), DBpedia 3.9 release consists of 2.46 billion RDF triples, out of which 470 million were extracted from the English edition of Wikipedia, 1.98 billion were extracted from other language editions, and about 45 million are links to external data sets. Linked Data also has given a momentum to the Open Data movement (Auer, Bizer, Kobilarov, Lehmann, Cyganiak, & Ives, 2007). However, like many other things, Linked Data is also not free from limitations. Some of the limitations of Linked Data are as follows.

- *Missing semantics* - one of the main concerns of linked data is its missing semantics. For instance consider a RDF triple <http://example.org/abu rdf:type http://example.org/bank>. According to this statement ‘abu’ is a ‘bank’, but now what is ‘bank’? Is it a financial institution, or a river bank? The answer cannot be provided unambiguously unless the meaning of a concept bank is stated explicitly.
- *Data quality* - This is a very common and well defined issue of Linked Data. Linked Data suffers from various data quality problems, for instance, inconsistency, representational, accuracy, conciseness and interoperability issues (Hogan, Umbrich, Harth, Cyganiak, Polleres & Decker, 2012).
- *Social trust* - Linked Data is a community effort and this is the most positive side of it. Because of community participation, the vision of Linked Data or Data Web is going to be fulfilled in the near future. In fact we have already started seeing various applications, as discussed above, based

on Linked Data. But still there is a lack of social trust on Linked Data. May be the Linked Data with provenance information will help to achieve the social trust. More research needs to be done in this area.

- *Data reuse* - Publishing Linked Data as part of the Linked Data Cloud (LDC) does not make it reusable by itself. The data needs to be described. We need to have metadata about data itself (Berners-Lee, 2006).

6. Ontology and Linked Data: Made for Each Other

Ontology and Linked Data, both can be mutually benefited. It can be said that they are complementary to each other. Ontology has lots to offer to Linked Data and vice-versa as discussed below.

5.1 Ontology for Linked Data

In the following we discuss on how ontology can be a useful tool to Linked Data.

Integration of semantics into data - Publishing data with ontology helps in adding semantics to data. For instance, in case of the following figure 7, the data (below the dotted line) becomes more meaningful and would be easy to interpret and process by software programmes in presence of an ontology (above the dotted line consisting of classes and properties). In presence of the ontology, we can say that both the resources Mauna Loa and Mount Vesuvius are volcanos. In addition we can also say from their class information that they are not the same types of volcanos. In the figure 7, the properties (written within the parenthesis) of the class Volcano, which also get propagated into its subclasses and their instances, are marked with prefix a_. In the figure, the classes and instances are indicated with the solid and hollow circles, respectively.

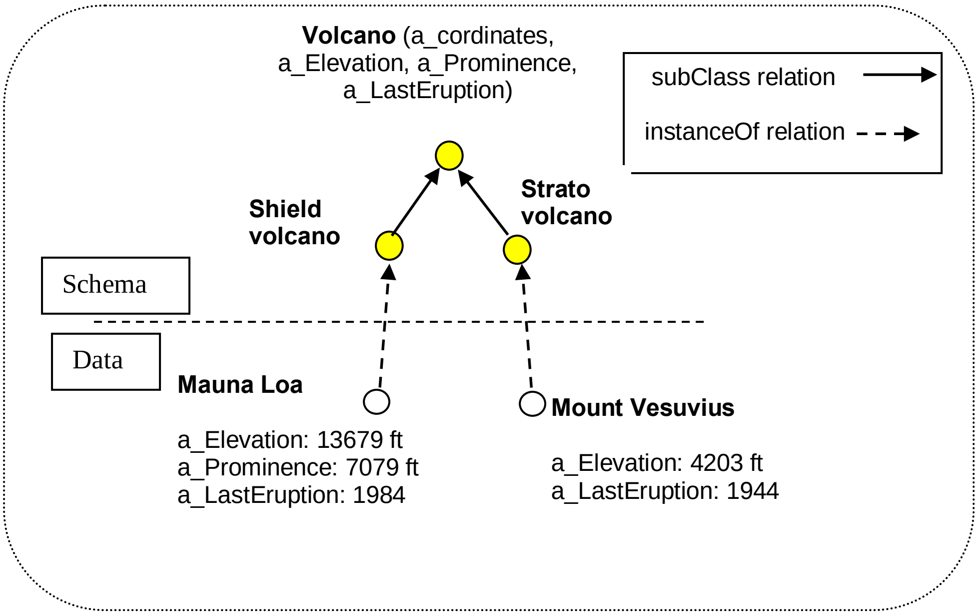

Figure 7: Semantic integration to data

Integration and alignment at instance level and schema level - The use of ontologies in publishing Linked Data helps in data integration and schema alignment. For instance, in the following figure 8, resources Mount Vesuvius and Vesuvius belonging into two different datasets D1 and D2, respectively, are basically a same entity. The sameness is established based on their matching attribute values and is further confirmed by their class information, i.e., both of them are type of Strato Volcano as indicated in the ontologies O1 and O2. Since Mount Vesuvius and Vesuvius are the same entities, we can link them, say, through a semantic property *owl:sameAs* (a property defined in OWL language (OWL Web Ontology Language, 2004). This linking enriches the data source D1 by adding an additional attribute, i.e., a_AgeOfRock to its entity Mount Vesuvius.

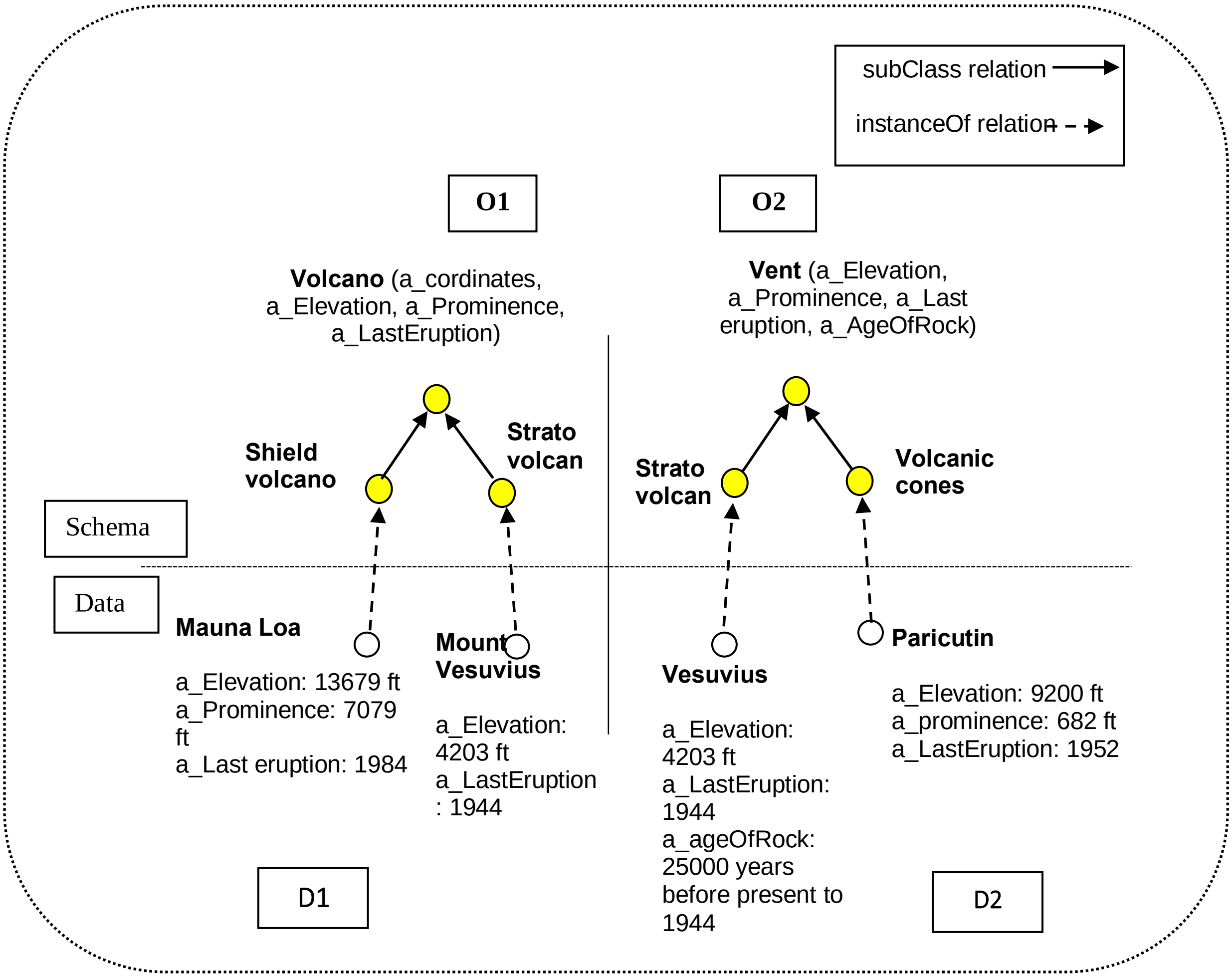

Figure 8: Integration and alignment at instance and schema level

Similarly, publishing Linked Data with ontology is also helpful in schema alignment. For instance, in figure 8, the root classes of both the ontologies O1 and O2 have two different names, namely, Volcano and Vent respectively, but conceptually both refer to a same meaning "*a rupture on the crust of a planetary-mass object, such as Earth, that allows hot lava, volcanic ash, and gases to escape from a magma chamber below the surface*." Since both of them referring the same, we can consider them as equivalent classes and hence can be aligned and linked through a semantic property *owl:equivalentClass* (a property defined in OWL language). This linking increases the number of classes at the sub-class level in both of the ontologies. Because, in O1, initially we had two types of volcanos, namely, Strato volcano and Shield volcano, whereas, in O2, we had initially two types of volcanos, namely, Strato volcano and Volcanic cones. After the linking, in O1, one more volcano type, i.e., Volcanic cones will be added. Similarly, in O2, one more volcano type i.e., Shield volcano will be added. This linking also enhances the datasets by adding the corresponding data resources for the added classes.

Disambiguating entities and bringing transparency in data linking - Following the above discussions, we can also see that ontology brings transparency in data linking. The data publication with ontologies helps in disambiguating and linking the relevant resources across the datasets. For instance. Abu (a mountain) and Abu (a Person). Although the two resources have the same names, but in presence of the ontologies and specifically from the class information, we can easily distinguish them.

Modelling and publication of data – Ontology helps in understanding, modelling and publishing domain knowledge and data meaningfully. Ontology can be considered as a domain realization, which allows to prepare and publish data for a domain.

Inferencing new knowledge - Since ontology brings semantics into data, data becomes amenable to infer implicit knowledge by the inference engines. For instance, in the above figure 8, "*Mauna Loa is a Shield Volcano*" and "*Shield Volcano is kind of Volcano*," so, an inference engine can conclude that "*Mauna Loa is a Volcano*."

5.2 Linked Data for Ontology

Linked data also has a lot to offer to ontology. Some of the important contributions that Linked Data can provide to ontology are discussed below:

Data driven ontology construction – at present majority of the ontology development process is based on top-down approach, where the domain concepts are taken to construct an ontology. In presence of Linked Data, ontology can be designed based on data. Data driven ontology would be most efficient as the domain modelling will be based on raw and evidential data and not mere theoretical conceptualization of a domain.

Linked Data as an enriched source of domain terminologies - one of the biggest problems of ontology development is finding the domain terminologies (Dutta, 2005; Dutta, Madalli & Prasad, 2009). To extract a good amount of domain terminologies, an ontologist consults multiple resources. This is quite a cumbersome job. Linked Data can be used as a great source and this will effectively reduce the manual effort of ontology creation.

Linked Data boosts the ontology construction - Linked Data can guide us to identify domains for ontology development. In the ontology development, it is always a complex task to decide the domain. Because ontology is a time consuming process, we cannot have luxury of building an ontology for which we will not have an immediate use. Linked Data can be used to foresee the domain requirement of the community and develop the ontology accordingly.

Linked Data cloud for ontology alignment - Ontology alignment is a complex task. Since Linked Data cloud consists of a vast amount of data, it can be used to disambiguate the word senses and align the ontologies.

Incremental and easy ontology extension - more reuse of Linked Data sources and availability of dereferenceable links will enable the easier extension of the ontologies. Each time we find new dataset for a given domain, we can cross check the data elements and their availability in the ontology. In case of their unavailability, we add them in the ontology, which ensures the extension of the existing ontology.

Hence, from the above discussion, we can say that truly these two technologies are made for each other. They indeed have lots to offer each other which ultimately will boosts the overall growth of Semantic Web.

6. Conclusion

In this paper we have discussed the two prominent Web technologies, namely, Ontology and Linked Data and their real world applications. We have also illustrated the mutual relationships and interdependence between them. Our observation is that these two technologies are equally important to fulfill the vision of Semantic Web. With their help we will be able to build up a true semantic information retrieval system.

References

Adhikari, A., Singh, S., Dutta, A. and Dutta, B. (2015). A novel information theoretic approach for finding semantic similarity in WordNet. In Proc. of IEEE International Technical Conference (TENCON - 2015), 1-4 November 2015. (Accepted).

Auer, S. R., Bizer, C., Kobilarov, G., Lehmann, J., Cyganiak, R. and Ives, Z. (2007). DBpedia: A Nucleus for a Web of Open Data. The Semantic Web. Lecture Notes in Computer Science 4825. p. 722. doi:10.1007/978-3-540-76298-0_52. ISBN 978-3-540-76297-3.

Benefits of the Linked Data Approach (2011). http://www.w3.org/2005/Incubator/lld/wiki/Benefits

Berners-Lee, T. (2006). Linked Data. http://www.w3.org/DesignIssues/LinkedData.html

Berners-Lee, Tim (2001). "The Semantic Web". Scientific American.

Best Bye (n.d.). http://www.bestbuy.com/

Bio2RDF (n.d.). http://bio2rdf.org/

BioPortal Annotator (2015). http://bioportal.bioontology.org/annotator

Bizer, C., Heath, T. and Berners-Lee, T. (2009). Linked Data - the story so far. Heath, T., Hepp, M., and Bizer, C. (Eds.). Special Issue on Linked Data, International Journal on Semantic Web and Information Systems (IJSWIS). http://linkeddata.org/docs/ijswis-special-issue

DBPedia (n.d.). http://dbpedia.org/datasets

DBPedia Blog (n.d.). http://blog.dbpedia.org/?p=72

Dutta, B. (2005). Semantic Web Based eLearning. In Proceedings of the National Conference on ICT for Digital Learning Environment, Bangalore, India.

Dutta, B., Chatterjee, U. and Madalli, Devika P. (2013). From Application Ontology to Core Ontology. In the Proceedings of International Conference on Knowledge Modelling and Knowledge Management (ICKM 2013), Bangalore, India. ISBN: 978-93-5137-765-8.

Dutta, B., Chatterjee, U. and Madalli, D. P. (2015). YAMO: Yet Another Methodology for Large-scale Faceted Ontology Construction. Journal of Knowledge Management. Vol. 19, no. 1, pp. 6 – 24.

Dutta, B., Madalli, D. P. and Prasad, A. R. D. (2009). Ontology supported personalized eLearning repositories. In Proceedings of the International Conference on Semantic Web and Digital Libraries, Italy, pp 193-206.

Dutta, B., Nandini, D. and Shahi, G. (2015). MOD: Metadata for Ontology Description and publication. In Proceedings of DCMI International Conference on Dublin Core and Metadata Applications (DC-2015), Sao Paulo, Brazil, 1-4 September 2015, pp. 1-9. Available at: http://dcevents.dublincore.org/IntConf/dc-2015/schedConf/presentations

Dutta, B. and Prasad, A. R. D. (2013). Semantic e-learning system: theory, implementation and applications. Germany: LAP, pp. 216. ISBN 978-3-659-18318-8.

Enabling Rich Snippets for Recipes. https://support.google.com/webmasters/answer/173379?hl=en

FalconS (n.d.). http://ws.nju.edu.cn/falcons/

Freebase (n.d.). http://datahub.io/dataset/freebase

Geonames (n.d.). http://www.geonames.org/

Giunchiglia, F. and Dutta, B. (2011). DERA: a Faceted Knowledge Organization Framework. Available online: http://eprints.biblio.unitn.it/archive/00002104/

Giunchiglia, F., Dutta, B. and Maltese, V. (2009). Faceted lightweight ontologies. Conceptual Modeling: Foundations and Applications. A. Borgida, V. Chaudhri, P. Giorgini and Eric Yu (Eds.),Lecture Notes in Computer Science (LNCS), Springer-Verlag, Vol. 5600, pp 36-51.

GoodRelations: the Web vocabulary for e-commerce (2011). http://www.heppnetz.de/ontologies/goodrelations/v1.html

Gruber, T. R. (1993). A Translation Approach to Portable Ontologies. Knowledge Acquisition, 5(2):199–220.

Hogan, A., Umbrich, J., Harth, A., Cyganiak, R., Polleres, A. and S. Decker (2012). An empirical survey of Linked Data conformance. Journal of Web Semantics.

Janowicz, K. and Hitzler, P. (2013). Thoughts on the Complex Relation Between Linked Data, Semantic Annotations, and Ontologies. In Proceedings of the 6th International workshop on

Exploiting Semantic Annotations in Information Retrieval (ESAIR 2013), pp. 41-44, ISBN: 978-1-4503-2413-7.
LinkedBrainz - MusicBrainz in RDF and SPARQL (n.d.). http://linkedbrainz.org/
Marbles (2009). http://mes.github.io/marbles/
Obrst, et. al. (2014). Semantic web and big data meets applied ontology. Applied Ontology, 9, 155-170.
OWL Web Ontology Language Overview: W3C Recommendation (2004). Deborah L. McGuinness and Frank van Harmelen (eds.). http://www.w3.org/TR/owl-features/
RDF Book MashUp (n.d.). http://wifo5-03.informatik.uni-mannheim.de/bizer/bookmashup/
RDFizers (n.d.). http://simile.mit.edu/repository/RDFizers/
Revyu (n.d). http://revyu.com/
Sanderson, Mark (1994). Word sense disambiguation and information retrieval. In Proc. of the 17th annual international ACM SIGIR conference on Research and development in information retrieval, Springer-Verlag, New York, USA, 142-151.
Schema.org (n.d). http://schema.org/
Sesame (n.d). http://rdf4j.org/
SPARQL Query Language for RDF: W3C Recommendation (2008). Prud'hommeaux, E. and Seaborne, A. (eds.). http://www.w3.org/TR/rdf-sparql-query/
Studer, R., Benjamins, V.R. and Fensel, D. (1998). Knowledge engineering: Principles and methods. In Data and Knowledge Engineering, 25 (1-2), 161-197.
Studer, R., Simperl, E. and Kampgen, B. (2011). Linke Data and ontologies. Presented in STI Semantic Summit, 6-8 July, 2011, Riga, Latvia.
Swoogle (n.d.). http://swoogle.umbc.edu/
Tabulator (n.d.). http://dig.csail.mit.edu/2005/ajar/ajaw/About.html
Watson (n.d.). http://watson.kmi.open.ac.uk/WatsonWUI/