Linked Data Visualization Tools

C.Ramesh[1], K. V. Chalapati Rao[2], A. Govardhan[3]
[1]CVR College of Engineering/CSE Department, Hyderabad, India
Email: hmcr.ramesh@gmail.com
[2]CVR College of Engineering/CSE Department, Hyderabad, India
Email: chalapatiraokv@gmail.com
[3]JNTUH College of Engineering/CSE Department, JNTUH, Telangana, India
Email: govardhan_cse@yahoo.com

Abstract: **In recent years, the amount of Semantic data on the Web has increased enormously. Since the initiation of the Linked Open Data project, the number of datasets added to the Web of Data has increased multifold. Although, the concept of Web of Data has been increasing in popularity, ease-to-use interfaces, to access and make sense of actual data are still far and few to accomplish the Semantic Web Vision to its full potential. Especially the non-experts in Semantic Web technologies are not benefitting from the value of Linked Data as promised by the Data providers. In this survey paper, we discuss the major prerequisites and challenges that need to be addressed by the modern Linked Data Visualization tools. In the pretext of these challenges, we present how the State-of-the-art Visualization tools from Web of Data literature, attempt to handle them. Finally, we survey and present the features of different systems developed by Semantic Web community in the context of Linked Open Data.**

Index Terms**—Semantic Web, Linked Open Data, Visualization tools, Exploration, Visualization**

I. INTRODUCTION

"The term 'Linked Data' refers to a set of best practices, introduced by Tim Berners-lee, for publishing and interlinking structured data on the Web, popularly called Linked Data principles [1]". Linked Data principles put forth by Semantic community has encouraged data providers to publish the data in structured format (machine-readable format), enabling sharing and exchanging of information. This ongoing effort from Semantic Web Community to link the different datasets, across different domains, has led to the formation of Linked Open Data Cloud (also known as Web of Data). Figure 1 denotes the current state of 'Web of Data'. Each node in this cloud diagram represents a distinct data set published as Linked data, as of January 2017. Each arc indicates the existence of link between entities in the two connected data sets. In recent years, the amount of Semantic data published on the Web has increased significantly. "Linked Open Data (LOD) is a pragmatic approach of realizing the Semantic Web vision of making the Web, a global, distributed data space called *–the Web of Data"*[2]. Today, the Linked Data paradigm has emerged as a potential enabler for shift of current Web of documents to Web of interlinked Data.

Resources on the 'Web of Data' are identified using Uniform Resource Identifiers (URIs), which are unique on the Web. Today, this global data space (Web of Linked Data) contains billions of triples and interlinks hundreds of datasets. Most of these datasets provide SPARQL endpoints for querying the datasets. In order to exploit the full value of information on the 'Web of Data', as many users as possible, with diverse background and skills need to be benefitted, not just the Semantic Web users.

However, with the growing amount of structured data, it has become a difficult task for the lay users (with little or no knowledge of the Semantic Web technologies) to access, review and explore the datasets of their interest on the 'Web of Data'. While the Linked Data is aimed at targeting machine processing agents, human agents ultimately need easy-to-interface tools to navigate and query datasets for consumption. However, there are considerable challenges in designing the browsers and Visualization tools for browsing, exploring and navigating linked data, as the requirements for browsing 'Web of Data' are different from browsing the Web of documents.

The remaining portion of the paper is structured as follows. In section 2, motivating facts to embrace the benefits of Linked Data are provided. In section 3, the challenges identified for designing the modern visualization and analysis tools that support easy navigation and exploration of Linked Data are presented. In section 4, the abstract Linked Data Visualization Model and its workflow are presented. In section 5, the existing tools are surveyed and their features are presented. In section 6, the comparative features under each category are presented. Finally, the paper is concluded with future direction of research.

II. MOTIVATION

"The Linked Data paradigm has emerged as a powerful promoter for publishing, enriching, and sharing data, information and knowledge on the Web [3]". Today, a vast variety of the application domains spanning commerce, entertainment, research, bioinformatics, tourism and society in particular are getting benefitted by Linked Data exploration and analysis.

The result of this effort is the creation of the Linked Open Data Cloud, which is a huge repository containing more than 35 billions of RDF triples and interlinks datasets, having around 504 million links [3]. Despite having such an impressive wealth of semantically enriched data, Web of Data fails to reach more users, especially the non-expert users who do not have in-depth knowledge of Semantic Web technologies. Though SPARQL endpoints provide enormous flexibility regarding the querying of

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Linked Data, there are several challenges posed, making the consumption of data difficult:

i. Data contained in Linked Data repository is usually accessible for users in Semantic Web technologies having expertise in RDF programming and writing SPARQL queries.
ii. At times, it is quite laborious task even for experienced users to write complex SPARQL queries for navigating and exploring unacquainted SPARQL endpoints.

To better enable the users to query, explore, navigate and analyze the Linked Data in user friendly manner, visualization tools need to address the aforementioned challenges which are surfaced due to the vast influx of structured data by organizations.

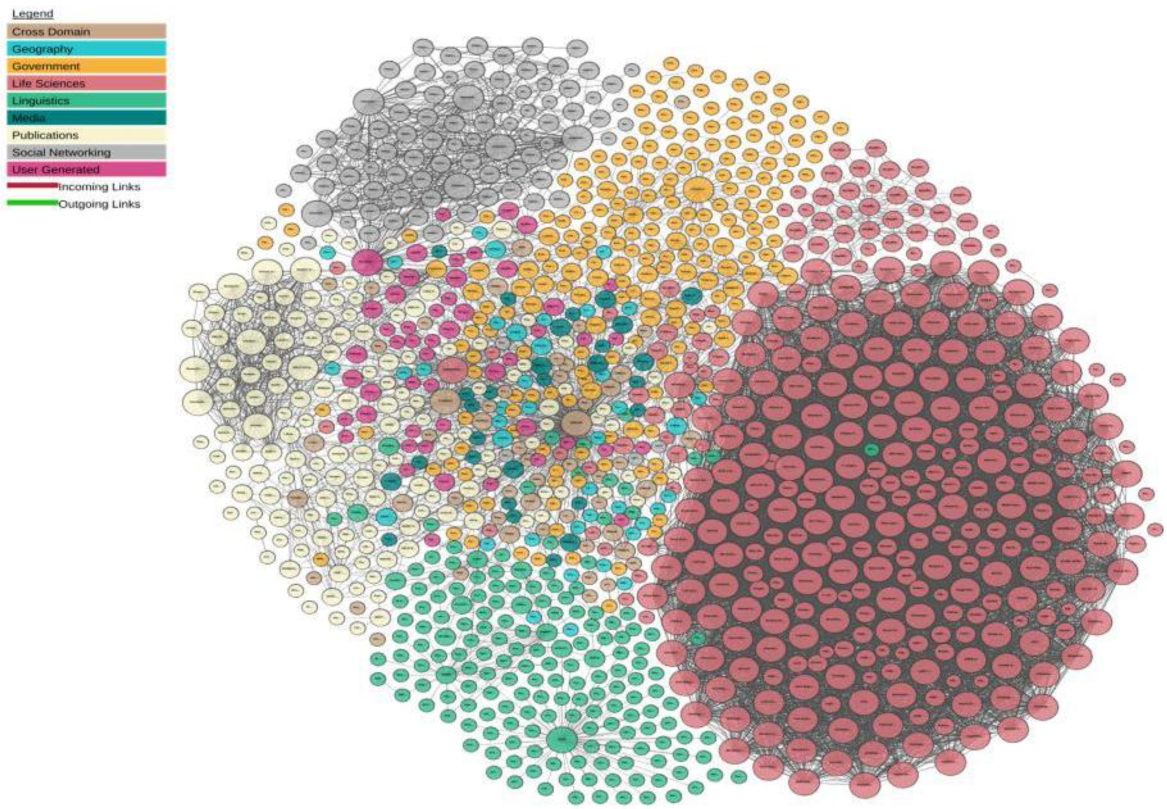

Figure 1. Linked Open Data Cloud [4]

III. Linked Data Visualization Challenges

The Domain of Linked Data poses some challenges in the context of Linked Data Visualization.

Scalability: Scalability issue is foreseen as the frontier challenge, especially when the datasets are large. The data of interest, for example the data returned from the SPARQL query on the dataset could be enormous. The Visualization techniques opted should address the scalability issue also while exploring the dataset.

Time scale: The Visualization tools also need to be efficient enough to render the information within an acceptable timeline. One way to tackle this issue is to support user interaction facility to the end-user.

Reusability: Linked Data Visualization and software applications used in developing them, should be reusable. Developing tools to implement maps and timelines involve lot of effort. Therefore reusability of tools plays a significant role in Linked Data Visualizations.

Heterogeneity of Information: The data of interest may be present in different repositories, say for example, a SPARQL query may involve more than one dataset. Integration of data and visualization, from multiple datasets, has to deal with the heterogeneity of information, semantics and schema format issues.

Multiple Datasets, Modeling the same concepts in different ways: Data accessed from multiple data repositories i.e., integrated heterogeneous data, may

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surface the problem of modeling the concepts in different alternate ways.

Missing Data: Visualization techniques used should be able to handle the level of missing data and should indicate the user data that cannot be represented by the visualization tools.

Dadzie and Rowe [5], in their survey work, identified the major requirements for consuming and publishing the Linked Data. Their analysis follows the approach of Shneiderman [6], who broadly classified users into three types: Lay users, Technical users and Domain experts for which the visualization tools are meant.

IV. Linked Data Visualization Model

"Visualizing and interacting with Linked Data has been an issue that has been recognized from the beginning of the Semantic Web [2]". Adopting Information Visualization techniques in Semantic Web Applications can equip users with exploration and interaction capabilities and aid in better understanding of the data. Visualization models are useful for obtaining an overview of the datasets, their main types, properties and relationship between them. The Linked Data Visualization Model (LDVM) presented in [7], provides an abstract visualization process of Linked datasets. It allows user to connect different linked datasets with different visualization types in dynamic way. The model was adopted by many data Visualization tools in transforming structured data into graphical form.

The Visualization process follows a four stage workflow, originating with raw RDF data and ending with the Visualization. Figure 2 presents a high level overview of the process.

1. **RDF Data**: The raw data, which adheres to RDF data model, e.g. instance data, vocabularies, ontologies, taxonomies.
2. **Analytical extraction:** Data extractions obtained from raw data, such as aggregate values.
3. **Visualization abstraction:** Information is processed using visualization techniques.
4. **View:** presentation of the results of the process in graphical representation, e.g. plot, Treemap, Timelines, and Maps etc.

While data is propagated through different stages, different transformation operators are applied. Data transformation, visual transformation and visual mapping transformation are three different operators applied correspondingly. An example scenario showing the visualization workflow involved in LDVM is shown in figure 3. The RDF data is fetched from the SPARQL endpoint posing the SPARQL query. LOD Visualization tool is the prototype of the Linked Data Visualization Model.

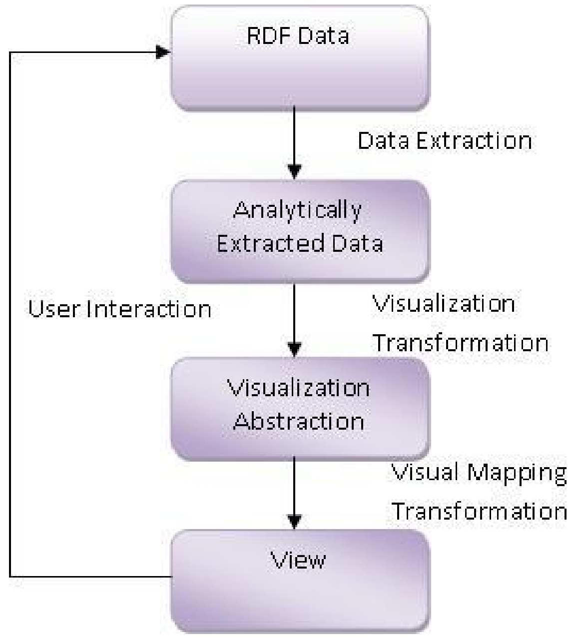

Figure 2. High level overview of the Linked Data Visualization Model

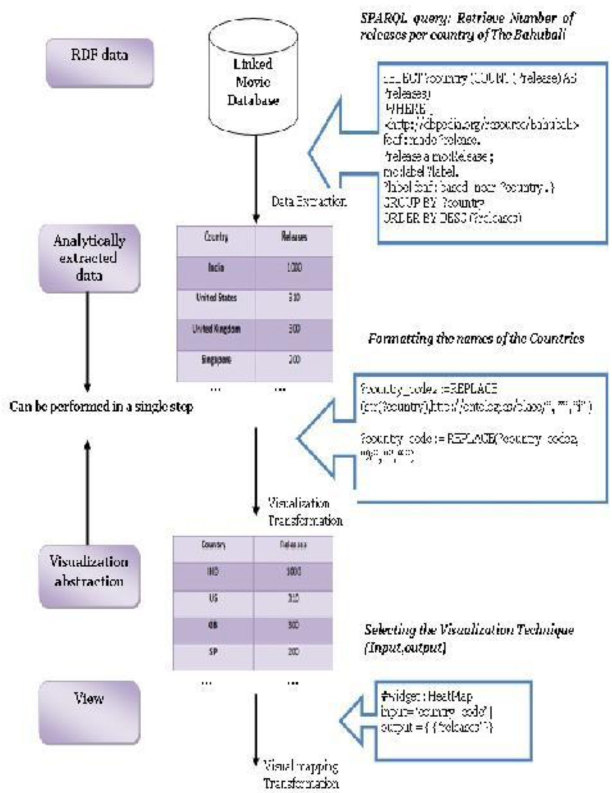

Figure 3. Example scenario showing the Visualization Workflow of the LDVM

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V. LINKED DATA VISUALIZATION TOOLS

Linked Data is made available to users via the SPARQL endpoints or Data repositories (Data dump). In recent years there has been an increased amount of literature on Linked Data exploration and visualization tools, focusing on the features, benefits and their limitations.

In what follows, we categorize these works into following classes: (1) Linked Data browsers with text-based representations, (2) Generic Linked Data Visualization Systems, (3) Graph-based Linked Data Visualization systems, (4) Visualization Libraries and (5) Domain and Vocabulary specific Visualization Systems.

A. Linked Data browsers supporting text-based representation

These browsers use textual structures such as lists and tables to render the Linked Data entities, properties and relationship between them. Some of these browsers also provide faceted browsing to support intuitive rendering and navigation of data as surveyed in [8].

The *Disco* [9] is a hyper data browser that renders all the information present in RDF resource as HTML table with property-value pairs. It follows an approach of the traditional Web browsers to navigate the Linked data resources between RDF links and can be seen as a direct application of the hypertext navigation paradigm to the Web of Data. It supports navigation between Semantic Web resources by dereferencing HTTP URIs and by following the *rdfs:seeAlso* links.

Sig.ma [10] (**S**emantic **I**nformation **MA**shups) is a text based browser, which allows user to explore datasets by giving URI as input. It also supports simple free text search. *Sig.ma* is built on top of *Sindice* [11], a semantic search engine that allows user to search for resource description. A snapshot of *Sig.ma* linked Data browser is shown in figure 4. *Piggy Bank* [12] is a Web browser plug-in which converts the standard HTML content into Semantic Web content. It uses a series of customized screen scrapers to turn HTML into structured code.

URI Burner [13] is a service that retrieves structured data about Web resources by generating an RDF graph of the retrieved RDF data. It exploits the ontologies and background knowledge of the web resources, while retrieving the data.

Zitgist Data Viewer [14] is a RDF browser. This tool is a sort of information shape-filter, provides different shapes based on the data at hand, giving a better interface and browsing experience. *Marbles* [15] formats the RDF triples using the Fresnel Vocabulary (a Vocabulary that renders RDF resources as HTML). Also it supports the retrieval of information about a resource using the Semantic Web indexes and Search engines. *Dipper* [16] provides a public interface to retrieve and browse Linked Data resources from a set of repositories stored on the Talis platform and present the retrieved data in a human readable format.

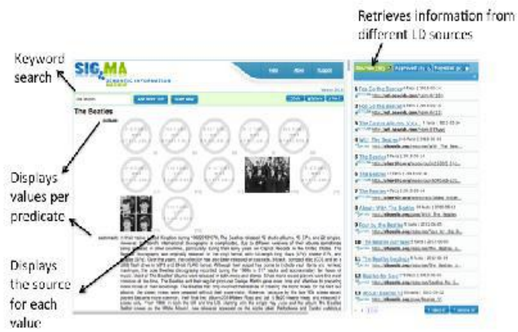

Figure 4. Sig.ma Linked Data browser

B. Generic Linked Data Visualization Systems

In this section, we outline the best known generic visualization frameworks, which are offering a wide range of visualization types and operations.

The Linked Data Visualization Model (LDVM) is an abstract model for visualizing RDF data. A detailed discussion on LDVM is given in section 4. *Payola* [17, 18] is a generic framework for Linked Data visualization and analysis. It provides an elegant implementation of LDVM and offers a large number of domain specific visualization techniques and plug-ins to support the visualization of RDF based data. It was experimented on Czech LOD cloud for generating visualization. Payola tool provides a support for customizing the visualization by referring the ontologies defined for the resulting dataset.

Rhizomer [19] provides Semantic Data exploration using zooms and filter workflows. It also offers different types of visualizations such as maps, treemaps, timelines and charts. *VisBoard* [20, 21, 22] is an information visualization workbench for Linked Data that is build on mashup platform, presents the RDF data in dashboard-like interactive visualization.

SynopsViz [23, 24] is a Web-based visualization tool built on top of generic tree-based model. It supports multilevel exploration of data by performing hierarchical aggregation over large RDF datasets. *VisWizard* [25] is a Web based Visualization tool that exploits semantics of the underlying dataset to simplify the visualization process. It supports analysis of multiple datasets using brushing and linking methods. Similarly *LinkDaViz* [26] finds the appropriate visualization for the given part of a dataset. It facilitates the automatic binding between data and visualization options by employing the visualization model and performing heuristic data analysis. *LODWheel* [27] is a Web based visualization tool that enables the visualization of RDF data in graphical form by making use of the Java script libraries. *SemLens* [28] is a visualization tool that offers a visual discovery of correlations and patterns in data by combining the features of scatter plots and semantic lenses.

Comparative features of various Generic Linked Data visualization tools are well presented in table 1.

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C. Graph based Linked Data Visualization Systems

These browsers use visual or graphics structures such as maps, timelines, images and graphs (individually or in combination) to represent Linked Data. We outline the best tools in this category.

DBpedia Mobile [29] is a location-centric DBpedia client application for mobile phone use. It allows user to query and access the real world entities such as cities, streets and landmarks that have described and asserted in DBpedia knowledge base, using his current location as input. It also allows users to access other resources linked from DBpedia. Based on the current GPS location of the mobile device, it renders a map indicating the locations of different objects nearby to user's current location, which are accessible from the DBpedia datasets.

IsaViz [30] is an interactive RDF browser and editor, allowing user to browse and edit RDF data as graph objects. It allows user to zoom, filter and navigate over the RDF graphs. It enables user to interact with RDF graphs, such as by clicking on a vertex node of the RDF graph, textual descriptions of the vertex is rendered. Features such as addition and deletion of RDF graph nodes and links is well supported by this application. In the same context *graphVizdb* [31, 32] is built on top of the spatial and database techniques, allows interactive visualizations over large RDF graphs. *RDF graph Visualizer* [33] employed a node-centric approach to visualize RDF graphs.

Open Link Data Explorer (ODE) [34] is a Web based RDF data browser, preferred mainly for performing search of RDF documents by taking resolvable URI or text string (for which it will attempt to match the resource URI) as input. It also supports extracting metadata from the RDF document. It provides a number of perspectives (or views) to facilitate user with more number of navigational features. *When, grid view, SVG graph, image*, *tag cloud* are some of the views. *RDF Gravity* [35] visualizes RDF and OWL data. It offers services like keyword search, filtering and manipulating the RDF graphs. It offers the user the flexibility to change the color of the nodes of the RDF graph. It also allows the user to visualize the ontologies. *Relfinder* [36] is a web based application, that supports discovery of graph covering relationships between two Linked Data objects of interest and visualizes them in a force-directed graph layout. It provides user interaction mechanism like previewing, filtering and highlighting the relationships found. *Tabulator* [37] is a RDF browser and editor. It supports browsing and exploring of RDF data. It allows RDF data providers to visualize, how their data interacts with the rest of the Semantic Web. Additionally it also provides Maps and Timelines visualizations.

Information Workbench [38] is a platform supporting the whole life cycle of Linked Data application development including integration, managing, analyzing and exploring the Linked Data. It is enriched with a large set of widgets supporting navigation, data authoring, data access, visualization as well as data mashups with different external linked data sources.

The main advantage offered by this tool is that the structure and behavior of user interfaces can be easily customized to build domain specific applications. Further the tool supports rich user interaction capabilities and provides a number of visualization techniques such a Google maps, timelines, pie charts, bar charts etc.

Code Linked Data Query wizard [39] provides a Web based interface to access, explore, filter and navigate Linked Data available through SPARQL endpoints. The main advantage offered by this tool is that it converts the Linked Data graph into tabular form and provides easy-to-use interaction possibilities to end user. *CODE Linked Data Vis Wizard* [40] enables a visual analysis of Linked Data and supports the user in automating the visualization process. Further the tool suggests visualization channels for the already analyzed data for representation. A snapshot of *CODE- Linked Data Vis Wizard* is shown in figure 5.

LODLive [41] and *Fenfire* [42] are exploratory tools that allow users to browse Linked Data resources using interactive graphs. Starting from a seed URL, the user can explore other resources using links. *LODLive* also allow users to have, live access to SPARQL endpoints. *LODVisualization* allows users to create visual hierarchies of data, fetched via SPARQL endpoint. Treemaps, maps and timelines are graph structures used in RDF visualization. Comparative features of various graph based Linked Data visualization systems are presented in table 2.

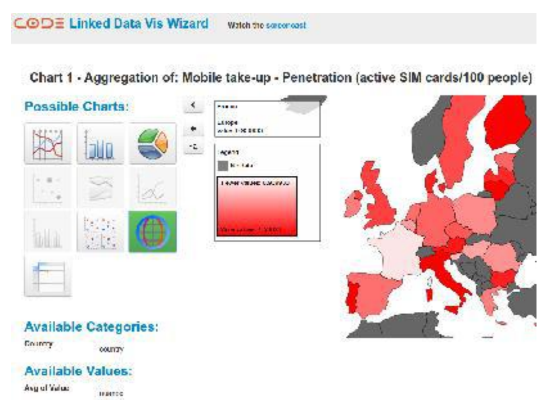

Figure 5. CODE Linked Data Vis Wizard

D. Visualization Libraries

Sgvizler [43] is a JavaScript library that allows SPARQL query results to be embedded in HTML elements. It uses Google Charts to offer numerous types of visualizations for SPARQL results such as graphs, charts, treemaps and timelines.

VisualBox [44] provides a novel interface for building and debugging SPARQL queries for retrieving Linked Data. It recommends visualization templates for visualizing results. It uses libraries like Google charts and D3 [45]. It offers nearly 14 various types of visualization.

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TABLE I.
GENERIC LINKED DATA VISUALIZATION SYSTEMS

System	Data Types*	Vis.Types**	Visual Recomm#	Domain	Application Types	SPARQL Query support	Vis.Cust.***	Target users##
LDVM	S	H,B,M,T	✓	Generic	Web	✓	✓	L,T,E
VizBoard	N	H,S,C	✓	Generic	Web		✓	L
LODWheel	N,S	G,C,M,P		Generic	Web			T,E
Payola	N,T,S	H, G,T,TL,C,CI,M		Generic	Web	✓	✓	L,T,E
Rhizomer	N,T,S	H, G,C,M,T,TL	✓	Generic	Web			L,T,E
LinkDaViz	N,S,T	B,C,M,P,S	✓	Generic	Web			L,T,E
LDVizWiz	S	H, G,M,P	✓	Generic	Web	✓		L,E
SynopsViz	N,T	H,P,TL	✓	Generic	Web		✓	E
VisWizard	N,S,T	B,C,M,P,S	✓	Generic	Web		✓	E
SemLens	N	S		Generic	Web			E

*Data Types- N: Numeric, S: Spatial, T: Temporal;
**Vis.Types (Visualization Types) - CI: Circle, C: Chart, B: Bubble Chart, G: Graph, S: Scatter Plot, SG: Stream Graph, M: Map, T: Treemap, H: Hierarchical, TL: Timeline; #Visual Recomm- Visual Recommendation; ***VisCust- Visualization Customization;
##Target users- L: Lay Users, T: Technical Users, E: Domain Experts;

TABLE II.
GRAPH BASED LINKED DATA VISUALIZATION SYSTEMS

System	**Keyword**	**Filter**	**Visualization type**	**Domain***	**Application Type****	**Detail on Demand**
DBpedia Mobile	✓	✓	Graph	Generic	Web (Mobile)	✓
OpenLink Data Explorer	✓	✓	Graph, Grid view, Map View	Generic	Web	✓
IsaViz	✓	✓	Graph	Generic	Desktop	✓
Fenfire			Graph	Generic	Desktop	✓
RelFinder	✓		Graph	Generic	Web	✓
ZoomRDF			Graph	Generic	Desktop	✓
LODlive	✓		Graph	Generic	Web	✓
graphVizdb	✓	✓	Graph	Generic	Web	✓
RDF Graph Visualizer	✓		Graph	Generic	Desktop	✓
RDF-Gravity	✓	✓	Graph	Generic	Desktop	✓
Tabulator	✓		Map, Timelines	Generic	Web	✓

*Domain- Generic / ontology/ specific domain; **Application type – Web based / Desktop

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E. Domain and Vocabulary specific Visualization Systems

These systems provide visualizations according to the types of data, domains and RDF vocabularies of the data at hand.
In literature there are several systems focusing on exploration and visualization of geo-spatial linked data. *Map4rdf* [46] is a faceted browsing tool that enables the visualization of the RDF datasets using Google maps. The *LinkedGeoData* browser [47] is a faceted browser and editor used for manipulating and visualizing linked geo data. *DBpedia Atlas* [48] also offers exploration over the DBpedia dataset by making use of the dataset's spatial data. *SexTant* [49] and *SpaceTime* [50] are tools that focus on exploration and visualization of time-related geo-spatial data.
VISUalization Playground [51] is an interactive tool for exploring and visualizing Linked University data. It offers a novel SPARQL interface for querying the data and uses Google charts for visualizing the query results. *CubeViz* [52] and *OpenCube Toolkit* [53] are tools used for exploring and visualizing statistical Linked data. The Open Cube Map view (part of *Open Cube Toolkit*) offers map based visualizations of RDF data cubes based on their geo-spatial dimensions.

VI. DISCUSSION

In this section, we highlight the relative capabilities of the Linked Data tools with regard to the handling, exploration and visualization of different types of data in a qualitative way, catering to all categories of users.

Our reviews regarding text–based browsers found that these browsers are unbound to RDF visualizations and provide only HTML representation of RDF Data. However, some degree of detailed exploration of the data at hand is supported by almost all the text-based browsers. In comparison to the remaining text-based browsers under review, *Marbles* additionally supports the feature of highlighting of links across selected data, adopting visual paradigm. It showcases the color marbles to differentiate among data sources under view.

Other browsers like *URI Burner, Disco* and *Zitgist* presents the RDF data in the form of "Entity-attribute-value" pairs. We conclude that the text description does not provide a good level of support for generation of overviews, compared to visual clues. It is evident from table 1, that generic linked data visualization systems support several of data types (e.g., numeric, spatial, temporal, graph) and supports a plethora of visualization features. Additionally some systems such as *LinkDaViz, LDVM, VizWizard, VisBoard* and *SynopsViz* support recommendation mechanisms also. Particularly, these systems mainly recommend the most suitable visualization types considering the selected data. Though SynopsViz offers five types of charts, timelines and treemaps for visualization of data, it has intricate interface that is not so user-friendly for lay users to interact with it. Systems like *Payola, LDVizWiz* benefits all type of users (lay, technical and domain experts) in exploring and visualizing the linked data.

An overview of the main features of Graph-based Linked Data Visualization Systems is presented in Table 2. When compared to other visualization tools, this group of tools provides more user interaction capabilities. They support various types of graph structures, visual sharing, visual recommendations, and visual customizations in addition to providing access for SPARQL queries.

Map4rdf, DBpedia Atlas and *LinkedGeoData* are domain specific faceted browsers, supporting manipulation and visualization of geo-spatial linked data. *SexTant* and *Spacetime* focus on visualizing time-evolving geo-spatial linked data. *CubeViz* and *OpenCube Toolkit* are tools dedicated for visualizing and exploring statistical linked data.

Sgvizler and *Visualbox* expect user to have knowledge on SPARQL language to retrieve and visualize the data in HTML pages.

VII. CONCLUSIONS

In order to realize the Semantic Web vision, many communities under the realm of World Wide Web are advocating the use of RDF data and Linked data as standard formats for publishing the data on the Web. This has provided an easy path for integration and sharing of heterogeneous data on the Web. However, the rising popularity of Linked Data is posing new challenges, related to visualization and exploration of Linked data.

Several ongoing research efforts have offered a wide range of tools for exploration and visualization of linked data. The paper surveys the most common Linked Data Visualization tools proposed in the literature. The main aim of this work is to present the different features provided by various tools in literature, related to user interaction, in particular those features which benefit the lay-users and technical users, in exploring and consuming the Linked Data.
Finally, considering users' perspectives, beyond visualization recommendations, modern Linked data tools should employ smart techniques that capture users' preferences and assist them throughout exploration and analysis tasks.

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