From Linked Data Querying to Visual Search: Towards a Visualization Pipeline for LOD Exploration

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Abstract: Over the recent years, Linked Open Data (LOD) has been increasingly used to support decision-making processes in various application domains. For that purpose, an increasing interest in information visualization has been observed in the literature as a suitable solution to communicate the knowledge described in LOD data sources. Nonetheless, transforming raw LOD data into a graphical representation (the so-called visualization pipeline) is not a straightforward process and often requires a set of operations to transform data into meaningful visualizations that suit users' needs. In this paper, we propose a LOD generic visualization pipeline and discuss the implications of the internal operations (import $\rightarrow$ transform $\rightarrow$ map $\rightarrow$ render $\rightarrow$ interact) for creating meaningful visualizations of LOD datasets. To demonstrate the feasibility of this generic visualization pipeline, we implement it as the tool LDViz (Linked Data Visualizer). We demonstrate how LDViz supports access to any SPARQL endpoint through multiple use cases, allowing the users to perform searches with SPARQL queries and visualize the results using multiple visualization techniques.

1 INTRODUCTION

The publication of Linked Open Data (LOD) using RDF (Resource Description Framework) datasets on the Web provides valuable information to support decision-making processes in diverse application domains (Gandon, 2018). Nevertheless, the value of these data depends on the capacity to find relevant information that describes the phenomenon embedded in data. We can observe an increasing interest in using visual and interactive techniques to explore LOD resources via multiple criteria and levels of abstraction by the Semantic Web community for accomplishing three main goals: (i) to explore the relevant concepts of an application domain via ontology representation; (ii) to inspect RDF Graphs (e.g., "for debugging triplets") (Antoniazzi and Viola, 2018); and (iii) to analyze the instances based on their types/classes.

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Contrariwise to typical visualizations, which uses specific datasets whose structure and nature are known, enabling one to easily define indicators and visualization techniques that are suitable to support the data exploration, visualizing linked data requires a preceding RDF graph processing to retrieve suitable data that may originate from different endpoints. Moreover, it may sometimes require combining data from different endpoints, resulting in datasets that may contain quality issues (e.g., missing data, inconsistency) and which structure and nature are unknown to the visualization. Although the design process of every visualization tool follows a well-known pipeline (i.e., import $\rightarrow$ transform $\rightarrow$ map $\rightarrow$ render $\rightarrow$ interact) (Card et al., 1999; Telea, 2014), we could not find any definition of these stages and the issues that arise from applying such visualization pipeline for LOD exploration.

Particularly, a visualization pipeline for LOD data should take into account the linked nature of these datasets by leveraging/supporting/exploiting these links, while being capable of processing and visualizing the data appropriately. This requires a high

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level of flexibility in every step of the pipeline, which could be seen in the drafting of SPARQL queries in a way that appropriately addresses the links in the linked data, the possibility of tuning the parameters of the graphic display and the associated interaction, and the availability of multiple visualization techniques that can help users see data according to diverse and complementary viewpoints.

Contributions. The primary goal of this paper is to introduce a LOD generic visualization pipeline. Our goal is to present the function and expected output of the different steps of the pipeline, and the underlying issues, so the scientific community can easily employ it to develop LOD visualization systems. As a proof of concept, we developed the Linked Data Visualizer (LDViz). This visualization tool integrates a SPARQL query management interface, a data transformation engine, and a visualization interface to support the automatic visualization of data extracted from any SPARQL endpoint. We show how our implementation allows any expert user to access the SPARQL endpoint of their choice, perform searches with SPARQL queries, and visualize the results via a visualization interface, MGExplorer, designed to assist the exploration of any multivariate network.

The remaining of this work is organized as follows. Section 2 summarizes previous contributions for LOD visualization. Section 3 presents the proposed generic visualization pipeline for LOD. Section 4 presents the tool developed as a proof-of-concept of the pipeline. Section 5 describes a set of use case scenarios to demonstrate the feasibility and generality of our approach. Section 6 discusses our results and concludes the paper.

2 RELATED WORK

In this section, we present previous LOD visualization solutions focusing on representing mainly three aspects of RDF datasets: (i) OWL or RDF Schema; (ii) the RDF graph; and (iii) custom datasets represented according to data types. Table 1 summarizes previous works according to supported data format, access methods, represented aspects of data, visualization and interaction tools.

OWL/RDF Schema Visualization. Kremen et al. (2018) represent the structure of RDF datasets and the relationship with other datasets by using class/properties statistics, spatial and temporal information, and a dataset summary. Similarly, Anutariya and Dangol (2018) use a node-link diagram to visualize schema information inferred via SPARQL queries using ontological characteristics of the triples in the LOD data sources.

RDF Graph Visualization. Aiming at simplifying the exploration of large RDF graphs, previous works support progressive visual exploration of LOD given a resource or an RDF dataset as starting point (Jacksi et al., 2018; Deligiannidis et al., 2007; De Vocht et al., 2015). Using a node-link diagram and selection operations, the user can incrementally reveal/hide neighboring resources to explore and visualize relevant data of very large RDF graphs (Deligiannidis et al., 2007), while discovering linked RDF graphs in the Web (Jacksi et al., 2018), and inspecting information and internal relations of data subsets (De Vocht et al., 2015). Chawuthai and Takeda (2015) visualize RDF graphs sparsified via graph simplification, which removes redundant triples; triple ranking according to topics interesting for the user; and graph filtering through property selection. The goal is to interpret all nodes and links as knowledge structures to keep only interesting triples.

Frasincar et al. (2006) propose an RDF data format plugin for a general-purpose visual environment for browsing and editing graph data, where users can define new operations for data processing, visualization, and interaction, and modify visual mapping by changing the shape, size, and color of nodes and edges. Likewise, Graziosi et al. (2018) provides a user-friendly SPARQL query builder to support non-programmers users in extracting data from the Web and exploring it through a node-link diagram. The nodes' shape (circle, ellipse, polygon), color, border, etc., can be modified via a customizable template for the visualization of entities and properties.

Visualization per Datatype. To improve LOD visualization by considering data characteristics, Brunetti et al. (2013); Thellmann et al. (2015); Peña et al. (2016) analyze the RDF vocabulary of the input data to visualize it accordingly, e.g., data containing properties such as `xsd:date` and `ical:dtstart` would be visualized through timeline or calendar visualizations. The S-Paths visualization tool (Destandau et al., 2021) supports the visualization of resources sets based on semantic paths by identifying and ranking a set of visualization techniques suitable to explore the data. Interaction allows to explore different resources sets and/or use different visualization techniques to get another perspective to the dataset via different semantic paths.

The Visualbox tool (Graves, 2013) generates graph, temporal and geographical visualizations to explore SPARQL result datasets; it also exports the visualization in a format suitable for incorporation in hypertextual documents. In a similar way, the JavaScript wrapper proposed by Skjæveland (2012),

Table 1: Summary of related work: publication reference, year, name (if provided), input data type, represented information, data access, visualization type (**C**: comparison, **CL**: clustering, **D**: distribution, **G**: geographical, **H**: hierarchical, **P**: proportional, **PT**: patterns, **R**: relationship, **T**: temporal, **TT**: text and table), and interaction operations (**C**: chart customization, **E**: chart export, **F**: data filtering, **M**: visual mapping, **V**: view operations).

Ref	Year	Tool	Input Data	Rep.	Data Access	Visualization	Interaction
Destandau et al. (2021)	2020	S-Paths	RDF Dataset	Per Datatype	RDF Dump	C, G, H, P, PT	C, F
Frasincar et al. (2006)	2018	N/A	RDF Dataset	RDF Graph	RDF Dump	H, PT, R	C, F, M
Anutariya and Dangol (2018)	2018	VizLOD	RDF Dataset	OWL/RDF Schema	SPARQL / RDF Dump	R	F, V
Kremen et al. (2018)	2018	Dataset Dashboard	RDF Dataset	OWL/RDF Schema	RDF Dump	R, TT	F, V
Jacksi et al. (2018)	2018	LOD Explorer	RDF Dataset	RDF Graph	JSONP	R	D, F
Graziosi et al. (2018)	2018	JLO/GIG	SPARQL Result Sets	RDF Graph	SPARQL	CL, R	C, F, M, V
Chawuthai and Takeda (2015)	2016	N/A	RDF Dataset	RDF Graph	SPARQL construct	R	C, F
Peña et al. (2016)	2016	N/A	SPARQL Result Sets	Per Datatype	SPARQL / RDF Dump	C, G, P, R	?
Thellmann et al. (2015)	2015	LinkDaViz	RDF Dataset	Per Datatype	RDF Dump	C, D, G, P, T	C, E, M, V
De Vocht et al. (2015)	2014	LOD/ VizSuite	RDF Dataset	RDF Graph	SPARQL	R	C, F
Graves (2013)	2013	VisualBox	SPARQL Result Sets	Per Datatype	SPARQL	G, R, T	E, F
Brunetti et al. (2013)	2012	LDVM	Non/RDF Dataset	Per Datatype	RDF Dump	G, H, P	F, M, V
Skjæveland (2012)	2012	Sgvizler	SPARQL Result Sets	Per Datatype	SPARQL select	C, D, G, H, R, P, T	?
Deligiannidis et al. (2007)	2007	PGV	RDF Dataset	RDF Graph	SPARQL	R	C, F, V

generates visualizations of SPARQL result sets via HTML elements embedded with SPARQL SELECT queries, which are rendered to contain the specified visualization type on page load or function call.

Although a visualization pipeline is necessary to build any visualization (Munzner, 2014), previous works on LOD visualization do not describe how they deal with the different steps of the pipeline, which are often tuned to represent the results of a particular query. Hence, we provide a description of every step of the pipeline and ways of applying it to linked data using multiple queries. Furthermore, the advantage of our approach compared to existing solutions relies on the flexibility that enables users to define meaningful datasets via SPARQL SELECT queries applied to any SPARQL endpoint, so that they can explore multiple aspects of RDF datasets and the LOD Cloud. It also allows users to perform exploratory searches using various complementary visualization techniques instantiated on demand according to the task at hand, instead of a single visualization technique that represents the whole dataset, restraining the analysis to a single view to the data.

3 LOD VISUALIZATION PIPELINE

A visualization pipeline is a step-wise process of creating visual representations from data. It usually follows a data-driven approach as shown in Fig. 1 and includes *import, transform (optional), mapping, and rendering* steps. Additionally, the *interaction* step allows the users to intervene in the data processing chain according to their needs. Hereafter, we describe a generic visualization pipeline and discuss the implications and design challenges at each step for the visualization of LOD datasets.

Import. This step refers to identifying triplestores and queries that allow retrieving relevant data to support the resolution of domain-related tasks. For that, users must know which endpoints are available and which RDF vocabulary compose them. Data can be extracted from endpoints via querying interfaces using SPARQL templates or SPARQL query builders to create SPARQL queries interactively or via online published RDF. Moreover, they might take advantage of the linked data principles (dereferencing, "follow you nose") and semantic Web standards by using the GRAPH and SERVICE SPARQL clauses to retrieve

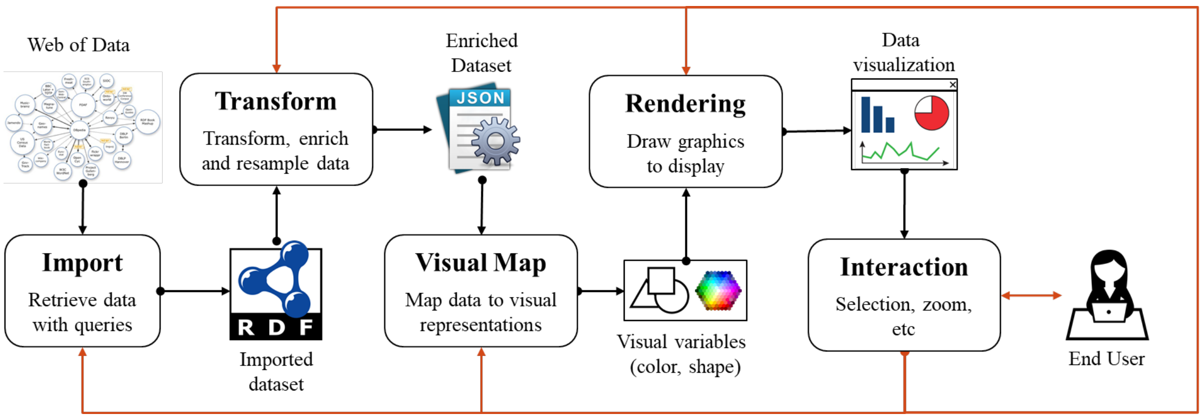


Figure 1: LOD generic visualization pipeline. Based on Telea (2014).

and combine data from different knowledge graphs possibly in different endpoints.

Transform. This step deals with data quality issues due to the data on the Web is often incomplete, redundant, and inconsistent. For that, operations like filter, enrich, re-sample, and calculate are needed to transform the dataset according to what is expected in the visualization. LOD connectivity can be used to complete the dataset (e.g., by retrieving data from different endpoints) or via disambiguation algorithms (i.e., by determining the contradictions or inconsistencies in the dataset). Existing solutions in the literature often deliver visualizations based on the data type (e.g., numeric, categorical, temporal, geographic, etc.), which provide little added value to solve domain-related tasks. Thus, this step should include algorithms capable of deriving interesting indicators to the application domain, ensuring the delivery of meaningful visualizations capable of supporting decision-making processes.

Visual Mapping. This step addresses the visual representation of every transformed data via visualization techniques capable of representing the relationship between data items (e.g., hierarchy, grids, etc.) and a meaningful mapping to visual variables (e.g., shape, color, etc.). One should also choose whether and how to visualize the links within LOD data (e.g. via graphs). The mapping can be performed as part of the query setup (by associating SPARQL query variables to visual variables) or interactively on the user interface. In any case, allowing the user to modify the visual mapping is a suitable strategy to include semantic meaning in the application domain (e.g., using standard color codes in the domain).

Rendering. The goal here is to make the best use of screen space to display data. The graph nature of LOD implies that information can be retrieved via alternative paths. Thus, a suitable visualization approach is the usage of multiple views that are synchronized (via linking and brushing operations (Keim, 2002)) and (i) can be freely arranged on the display or (ii) are placed in a tab-based interface where each view is rendered in a separated window.

Interaction. Once the data is visually represented, the user should be able to interrogate the data through interactive operations (e.g., selection, pan and zoom, linking and brushing, and text search). The connectivity property of LOD also allows the dynamic enrichment of the analysis by allowing the user to query endpoints during the exploration phase. It is interesting to notice that user interaction might affect any previous steps in the visualization pipeline.

4 LINKED DATA VISUALIZER

In this section, we present the Linked Data Visualizer (LDViz), an implementation of the proposed generic visualization pipeline for LOD datasets based on web technologies, i.e., JavaScript, the D3 (Data-Driven Documents) library to create visualizations, and the nodejs library to manage the linked data access server that handles data retrieval through SPARQL queries. LDViz covers the steps of the pipeline as follows.

Import. Data import is handled via SPARQL queries. The generality of LDViz relies on the fact that users can query any SPARQL endpoint as long as it can return result sets in a JSON format. We provide an interactive interface where the user can test and debug SPARQL queries or import predefined queries, which they may modify at will.

Transform. Data transformation occurs in three moments: at the definition of the SPARQL query, which determines the information to be retrieved from the SPARQL endpoint; at the transformation engine, where the SPARQL results sets are cleaned and trans-

formed into a suitable data model for the visualization; and when the user filters the input dataset in one view to explore it in another, which requires reshaping the data to fit the visualization technique.
Visual Mapping. Visual mapping occurs in three ways: by transforming the SPARQL results set in a suitable format for visualization, by mapping the data variables to the visual variables of each technique, and by allowing users to tune certain variables, e.g., by defining colors to represent them.
Rendering. This is handled by MGExplorer (Cava, 2017), a visualization interface to explore multidimensional network data.
Interaction. Via the MGExplorer interface, we provide selection operations that enable the user to subset the input data to be explored via different visualization techniques, which present complementary views to the data.

4.1 Data Model

The data model corresponds to a custom graph model defined through a SPARQL query, which uses arbitrary query patterns on RDF graphs to generate the edges `?s ?p ?o` of the graph one wants to visualize, where `?s` and `?o` represent the nodes of the graph and `?p` corresponds to labeled edges between them. Listing 4 illustrates an example SPARQL query supported by LDViz. In this example query `?s` and `?o` will be bound to actors and `?p` to films. The result of this SPARQL query will be used to build a visualization of the social network of actors co-starring in films. In addition to these three variables, the data model allows three other reserved variables that serve to describe the edges (`?p`) of the output graph visualization: `?type`, `?label`, and `?date`. Variable `?type` can be used to type the edges of the output graph (e.g., in a graph where films connect actors, films can be "typed" or classified by their genre). Due to human's perceptual and cognitive limits towards visualizations, only a certain number of graphic elements can be drawn on the screen. Thus, we allow the variable `?type` to be bound to only four different values describing the edges. If the variable `?type` is bound to more than four distinct values in the SPARQL query result, the system automatically determines the three more relevant ones based on the number of bindings and considers the remaining values as the "Other" category. The `?label` variable is intended to provide a description of edges in natural language (e.g., the value of `rdfs:label` properties describing resources). Finally, the `?date` variable is used to provide a visual representation of the distribution of edges over time (e.g., if edges are films, it could correspond to the release year).

4.2 SPARQL Query Management Interface

The query management interface (Fig. 2) allows users to test and debug SPARQL queries or import predefined ones, which they can edit or clone according to their needs. The interface expects an address for the SPARQL endpoint of the targeted RDF dataset, a name for the SPARQL query (optional), and the query code itself. Note that the user can retrieve data from more than one endpoint by leveraging the full strength of the SPARQL language, including the SERVICE clause – depending on the SPARQL implementation available at the queried SPARQL endpoint. Action buttons at the bottom (Fig. 2d) allow to visualize the SPARQL query results using MGExplorer or export them as a JSON file.

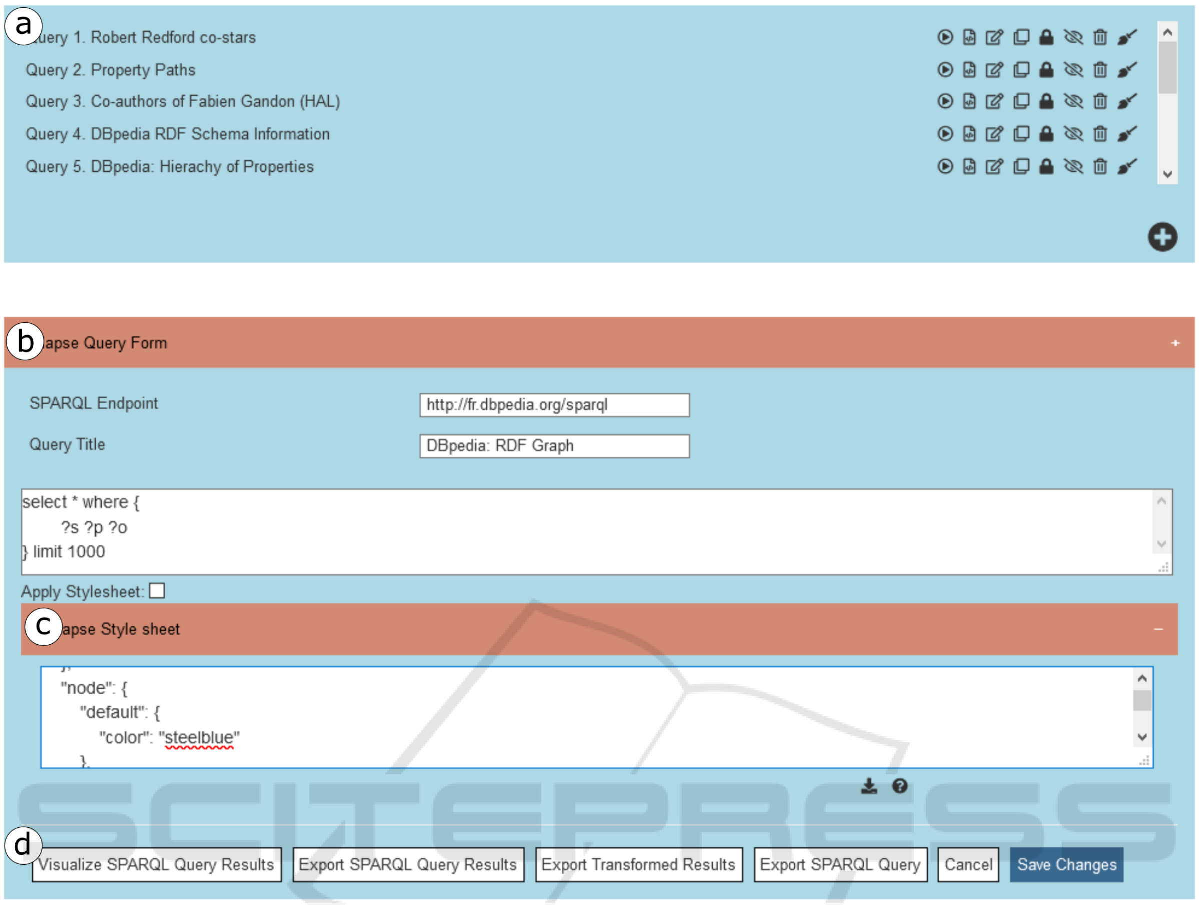
```
(a) {"node": { "fst": {"color": "green"},
"snd": {"color": "orange"} },
"services": { "Corese Browser": { "url":
"http://corese.inria.fr/srv/service/covid?uri="}}}

(b) select * where { ?s ?p ?o
    bind("fst" as ?style1) bind("snd" as ?style2)}
```

Listing 1: Example of (a) GSS and (b) its usage in a SPARQL query.

Each query is associated with a **Graph Style Sheet (GSS)** that can be used to transform the default node-link diagram through a declarative specification of visibility, layout, and styling rules (Pietriga, 2006). For doing so, the user defines the styling rules as classes in a style sheet of reference (JSON format) (e.g., Listing 1a) and bind them to dedicated variables in the SPARQL query (i.e. `?style1` to style `?s`, `?style2` to style `?o`, and `?style` for both). This information is then processed in the transformation engine, which associates the style classes to the visual variables used in the visualization. Moreover, the GSS supports a behavior feature that enables exploring data via an external service (e.g., the Corese browser (Corby et al., 2012), which allows browsing the original repository of open data) as long as an URL is provided (see Listing 1a).

4.3 MGExplorer

In our approach, data visualization is provided via MGExplorer (Menin et al., 2021), a tool that assists the exploration of multidimensional and multivariate graphs. Its main advantage is a flexible exploratory process that combines multiple views to allow comparing (i) two or more different subsets of



Query 1. Robert Redford co-stars
Query 2. Property Paths
Query 3. Co-authors of Fabien Gandon (HAL)
Query 4. DBpedia RDF Schema Information
Query 5. DBpedia: Hierachy of Properties

apse Query Form

SPARQL Endpoint	http://fr.dbpedia.org/sparql
Query Title	DBpedia: RDF Graph

```
select * where {
       ?s ?p ?o
} limit 1000
```

Apply Stylesheet: ☐

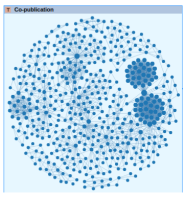
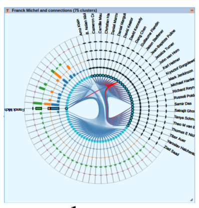
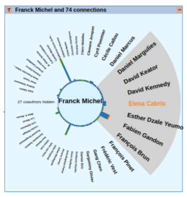
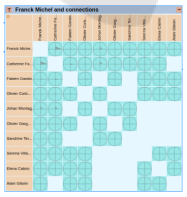
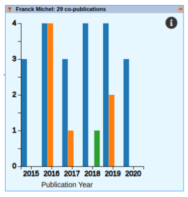
apse Style sheet

```
  "node": {
     "default": {
        "color": "steelblue"
     }
```

Visualize SPARQL Query Results | Export SPARQL Query Results | Export Transformed Results | Export SPARQL Query | Cancel | Save Changes

Figure 2: SPARQL Query Management Interface. (a) Listing of predefined queries. (b) The querying area. (c) The GSS editing area. (d) Control buttons to visualize and export the results.

Table 2: Classification of visualization techniques available in MGExplorer according to the type of analysis they provide.

Node-link Diagram	ClusterVis	IRIS	GlyphMatrix	Bar chart	Listing
					
network	clusters	pairwise		distribution	listing

data through a particular perspective generated by a particular view, and (ii) multiple perspectives of the same subset of data using several views. The views can be dragged, allowing the user to rearrange the visualization space in meaningful ways to the task at hand. They are connected via line segments to represent their dependencies and enable retracing the exploration path.

The bootstrapping process of MGExplorer consists in displaying a node-link diagram of the relationships within the dataset and a history panel, which are both interactive and visible throughout the whole exploration process. Other views can be created, and the history panel is progressively completed with provenance information that indicates the dependencies between views in a hierarchical representation, which allows for prompt recovering of the multiple analytical paths that emerge from a particular view. Further, users can hide any of the currently displayed views, which they may revisit later using the history panel, thus cleaning the display area in a way that help them to focus on what is relevant to the task at hand. The input data is the reference data for selection operations throughout the whole exploratory process. The system supports data and view selection, allowing users to specify subsets of interest from the whole input graph and suitable views to explore them. Upon the element selection, the system filters the input dataset accordingly, and the resulting subset undergoes a process that transforms and maps it to the chosen visualization technique. An exploration history records information regarding the selection operation, the data subset, the chosen view, and the transformed data.

Table 2 summarizes the set of visualization techniques available in MGExplorer. The **Node-link** diagram shows nodes as items and edges between them as relationships. This diagram is used to provide an overview of any network defined within the dataset according to some criteria (e.g., keywords, co-publications, etc.).

The **ClusterVis** (Cava et al., 2017) technique depicts clusters according to some relationship among data items. It has a multi-ring layout, where the innermost ring is formed by the data items (represented by circles), and the remaining rings display the data attributes (represented by rectangles). The items belonging to the same cluster are connected via curved lines.

The **IRIS** technique allows isolating a data item of interest (at the center) and showing all other data items with which it has a specific relationship in a circular view (Cava et al., 2014). The data attributes of the pairwise relationships are encoded by the height and color of a bar placed between the item of interest and each related item. The user can place any item in the field of view center by clicking on it, switching the focus of the IRIS.

The **GlyphMatrix** (Cava and Freitas, 2013) technique is based on a matrix where rows and columns represent data items in a cluster, and the cells contain glyphs encoding attributes that describe a pairwise relationship. The default glyph is a star-plot-like shape, with a variable number of axes used to encode values of selected data attributes. By pointing a glyph in the matrix, it is possible to enlarge the glyph to see the data attributes' details.

The **Bar Chart** technique shows the distribution of data attributes' value for an item or set of items. For example, in one of our use case scenarios, the x-axis encodes temporal information, while the y-axis encodes the counting of co-publications. The data is displayed as a single bar per time period or multiple colored bars to represent categorical information of attributes.

The **Listing** technique lists the items that form the relationship between two or more nodes in the graph. Each item of the list is linked to a descriptive web page in the dataset, where the user can obtain more information about it.

4.4 Transformation Engine

The transformation engine of LDViz consists of a converter module from SPARQL JSON results to the MGExplorer data model and a set of algorithms (i.e., mappers) that process subsets of data defined during the exploratory process via visual querying operations and map the resulting data to a particular visualization technique, also interactively chosen by the user.

From SPARQL Results to MGExplorer Data Model. The system receives the SPARQL JSON results set, which undergoes a transformation process to extract an attributed graph, encoded in the JSON format, that will serve as input data to MGExplorer. Besides identifying the mandatory and optional variables from the dataset, the process also derives indicators to describe the relationship between each pair of nodes, such as the total count of items and the count of items per type, when this information is provided.

MGExplorer Mappers. Every selection operation triggers a transformation process that filters and transforms the data and maps it to the selected visualization technique via: the *ClusterViz mapper*, which extracts clusters of nodes grouped according to the existing links among them, e.g., in a co-authorship network, the algorithm detects groups of authors co-authoring the same publication(s); the *IRIS mapper*, which extracts pairwise relationships between the selected node and the other nodes in the subset; the *GlyphMatrix mapper*, which extracts pairwise relationships by analyzing every possible combination of pairs of nodes within the subset; the *Bar chart mapper*, which extracts the distribution of items in the subset according to a particular attribute (e.g., date); and the *Listing mapper*, which extracts the list of links in the graph and their descriptive information (if provided). Regardless of the resulting relationship type, every mapper keeps information on the count and type of items per relationship.

5 USE CASE SCENARIOS

In this section, we demonstrate the flexibility of LDViz to accommodate and represent different aspects of an RDF dataset via three case studies exploring (1) the interactive visualization of an RDF graph and its ontology, (2) the interactive visualization of RDF

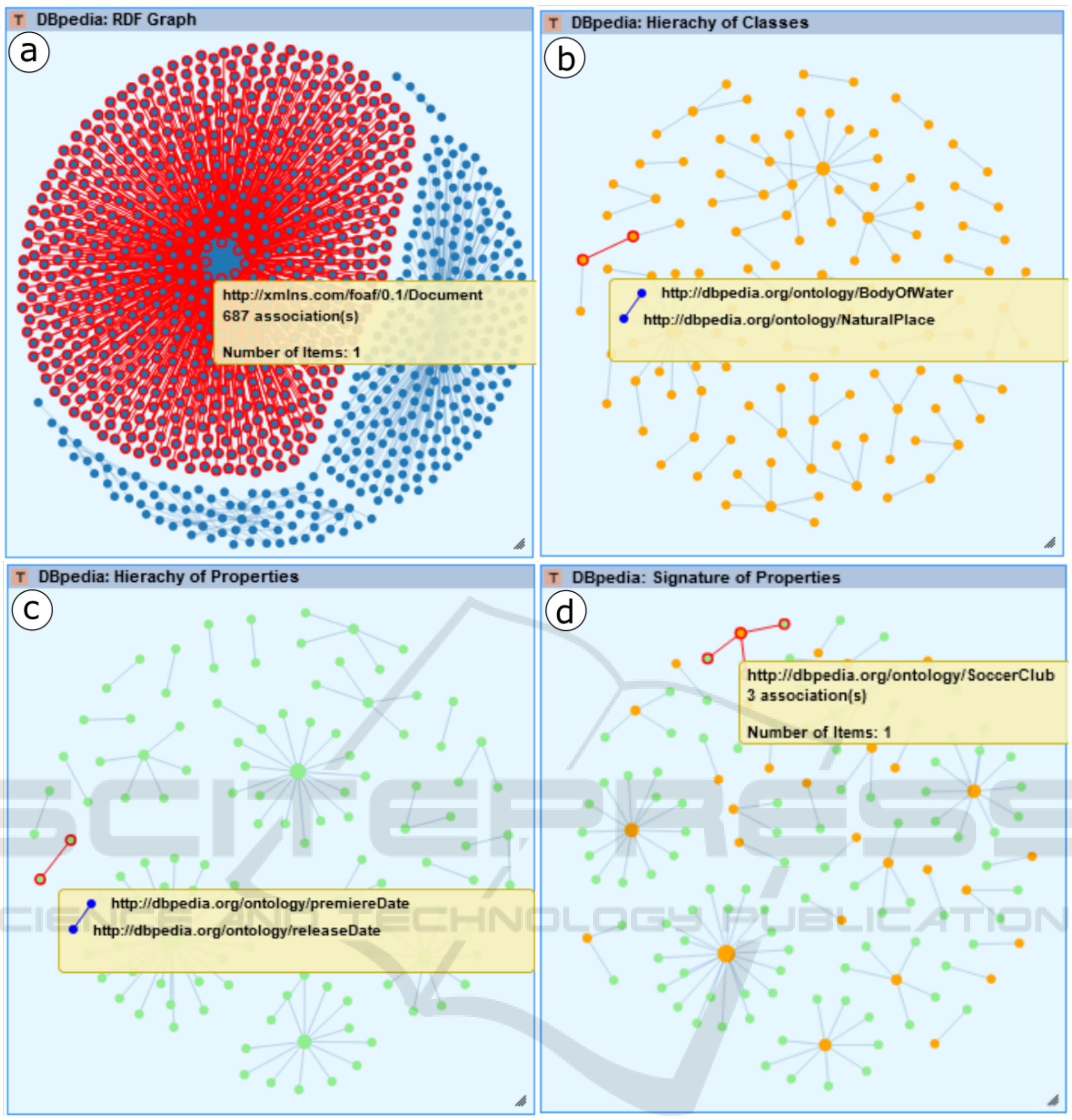

DBpedia: RDF Graph
a
http://xmlns.com/foaf/0.1/Document
687 association(s)
Number of Items: 1
DBpedia: Hierachy of Classes
b
http://dbpedia.org/ontology/BodyOfWater
http://dbpedia.org/ontology/NaturalPlace
DBpedia: Hierachy of Properties
c
http://dbpedia.org/ontology/premiereDate
http://dbpedia.org/ontology/releaseDate
DBpedia: Signature of Properties
d
http://dbpedia.org/ontology/SoccerClub
3 association(s)
Number of Items: 1

Figure 3: Node-link diagrams representing an extract of DBpedia's (a) RDF graph, (b) class hierarchy, (c) property hierarchy, and (d) signatures of properties linking classes (orange) and properties (light green).

graph summarizations, and (3) visual mining of RDF graphs. Further, we show the generality of LD-Viz by illustrating those case studies on two distinct SPARQL endpoints giving access to the DBpedia FR dataset[1], which gathers about 400 million triples describing the content generated in the Wikipedia project, and the *HAL* dataset[2], which gathers scientific publications from the HAL open archive, a storage of scholarly documents from all academic fields.

Use Case 1: Exploring RDF Graphs and Their Ontologies.
When working with the Semantic Web, a recurrent task is to inspect the RDF graph and its ontology for learning its content. In this use case, we consider exploration tasks where the user wants to (1) display the RDF graph with no particular goal in mind and (2) get an idea of the ontology used in the RDF graph. Thus, we generate four visualizations with the SPARQL queries in Listing 2, which, although they are applied to DBpedia, are generic enough to retrieve information from any SPARQL endpoint.

Fig. 3a depicts the node-link diagram representing the 1000 first statements in the DBpedia graph,

[1]SPARQL endpoint: http://fr.dbpedia.org/sparql

[2]SPARQL endpoint: http://sparql.archives-ouvertes.fr/sparql.

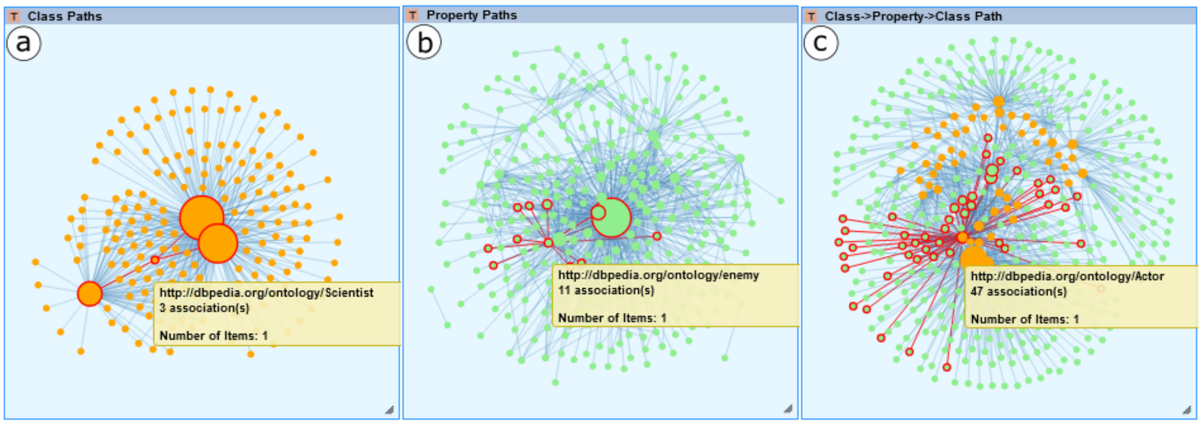


Figure 4: Node-link diagrams representing DBpedia's (a) class paths, (b) property paths, and (c) paths of type class → property → class.

where we can hover over the nodes to inspect related resources. Fig. 3b-d depicts the node-link diagrams representing the three typically explored aspects of an ontology: the class hierarchy, the property hierarchy, and the signatures of properties that connect properties to classes. Users can hover over the nodes to inspect and navigate within hierarchies and explore properties signatures by hovering over nodes that represent either properties to inspect their signature or classes to identify all the properties to whose signatures the selected class belongs, e.g., `dbo:SoccerClub` is related to three properties. Besides allowing users to define nodes and relationships in meaningful ways for their exploration purposes, GSS can be used to assign meaningful visual elements to certain variables. For example, in Fig 3d, we use color to distinguish property (light green) and class nodes (orange), easing visual search and understanding of relationships between nodes of different types.

```
(a) select * where { ?s ?p ?o }

(b) select * where { ?s ?p ?o
    filter(?p = rdfs:subClassOf) }

(c) select * where { ?s ?p ?o
    filter(?p = rdfs:subPropertyOf) }

(d) select * where { ?s ?p ?o
    filter(?p = rdfs:domain || ?p = rdfs:range)
    bind("fst" as ?style1) bind("snd" as ?style2)}
```

Listing 2: SPARQL queries used in Use Case 1 to retrieve an extract of DBpedia's (a) RDF graph, (b) class hierarchy, (c) property hierarchy, and (d) signature of properties.

Use Case 2: Exploring RDF Graph Summarizations.

An RDF graph with millions of triples will generate a huge and cluttered node-link diagram. Structural RDF graph summarization addresses this issue by providing indices or summaries of RDF graphs to aggregate the triples in meaningful ways. Here we consider the visualization of (i) existing paths between classes of resources in an RDF graph, (ii) existing property paths between the resources of the graph, or (iii) paths showing the resource between classes and properties. The resolution of these tasks is possible via three visualizations generated with the SPARQL queries in Listing 3. The resulting node-link diagrams (Fig. 4) show classes or properties instead of resources of the RDF graph.

```
prefix ldv: <http://ldv.fr/path/>
(a) select distinct ?s ?p ?o
    where { ?a ?p ?b . ?a a ?s . ?b a ?o }

(b) select distinct ?s (ldv: as ?p) ?o where {
    ?x ?s ?y . ?y ?o ?z . filter (?s != ?o)}

(c) select distinct ?s (ldv: as ?p) ?o where {
    {?a ?b ?c. ?a a ?s . bind (?b as ?o)} UNION
    {?a ?b ?c. ?c a ?s . bind (?b as ?o)}}
```

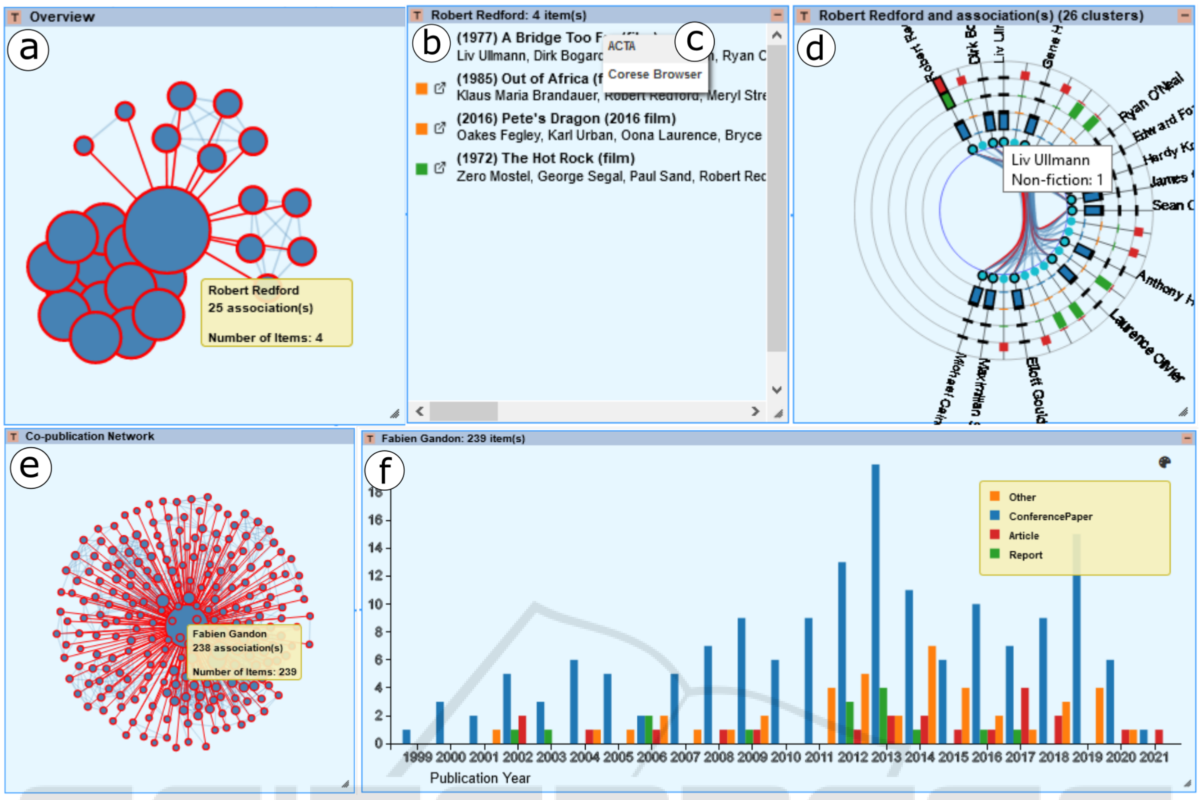
Listing 3: SPARQL queries used in Use Case 2 to retrieve (a) class paths, (b) property paths, and (c) paths of type class → property → class.

Use Case 3: Visual Mining of RDF Graphs.

```
prefix dbo: <http://dbpedia.org/ontology/>
prefix dbp: <http://dbpedia.org/property/>
select ∗ where { ?x rdfs:label ”Robert Redford”@en .
   ?p dbo:starring ?x, ?a1, ?a2; rdfs:label ?label;
      dbp:released ?date ; dbp:genre ?type .
   ?a1 rdfs:label ?s . ?a2 rdfs:label ?o .
   filter (?a1 != ?a2) }
```

Listing 4: SPARQL query to retrieve Robert Redford's co-stars from DBpedia

Here we show how LDViz enables RDF graph mining for exploring data describing a phenomenon of interest: network relationship of people. Listing 4 shows



(1977) A Bridge Too F
Liv Ullmann, Dirk Bogarc
(1985) Out of Africa (f
Klaus Maria Brandauer,
(2016) Pete's Dragon (2016 film)
Oakes Fegley, Karl Urban, Oona Laurence, Bryce
(1972) The Hot Rock (film)
Zero Mostel, George Segal, Paul Sand, Robert Rec

Figure 5: Visualizations used in Use Case 3 to explore Robert Redford's co-stars (a-d) and Fabien Gandon's co-authors (e-f).

the query used to retrieve the network of Robert Redford's from DBpedia, including the name of actors (?s, ?o) that appear in a movie (?p) with Robert Redford, and a description of movies with the title (?label), release date (?date), and genre (?type). We found 278 results, creating a network of 26 nodes (actors) and 124 links (movies) shown in Fig. 5a. We see that Redford has 25 co-stars across four movies where details are available at the Listing view (Fig. 5b). The resources can be explored using the Corese browser (Fig. 5c) or any other service enabled in the GSS. The ClusterVis view (Fig. 5d) all Redford's co-stars grouped by movies.

```
prefix  dc:<http://purl.org/dc/terms/>
prefix  foaf:<http://xmlns.com/foaf/0.1/>
prefix  hsc:<http://data.archives-ouvertes.fr/schema/>
select * where { ?p dc:creator ?x, ?x1, ?x2 ;
     dc:type ?type ; dc:title ?label ; dc:issued ?date .
     ?x hsc:person ?a . ?a foaf:name "Fabien Gandon".
     ?x1 hsc:person ?a1 . ?a1 foaf:name ?s .
     ?x2 hsc:person ?a2 . ?a2 foaf:name ?o .
     filter(?x1 != ?x2) }
```

Listing 5: SPARQL query to retrieve Fabien Gandon's co-authors from HAL.

We use the SPARQL query in Listing 5 to retrieve the co-authorship network of Fabien Gandon from HAL, which results in 4680 triples. The corresponding graph contains 237 nodes (authors) and 1160 links (publications), which we visualize via the node-link diagram in Fig. 5d. We observe that Fabien Gandon has 238 co-authors via 239 publications. We further explore their temporal distribution using the bar chart (Fig. 5e), where we can observe that the most publications occurred between 2012 and 2014. The chart also displays the publications' types (i.e., conference paper, article, report, other), showing that he mostly published conference papers.

6 DISCUSSION AND CONCLUSIONS

In this paper, we presented and discussed the implications of designing a generic visualization pipeline for exploring LOD datasets. The proposed pipeline covers different means of accessing LOD datasets; it addresses various issues regarding data enrichment, filtering, and reshaping. It supports diverse visualization layouts (i.e., one or multiple view systems) and interactive operations that enable dynamic addition, replacement and/or modification of the input dataset, visualization techniques, and visual mapping. We implemented the pipeline as a generic tool, LDViz, for exploring and understanding the Semantic Web of LOD. It provides access to any SPARQL endpoint by allowing users to perform searches with SPARQL queries and visualize the results via multiple visualization techniques. We developed LDViz using web technologies and made it available at (omitted for blind review), ensuring accessibility by anyone.

LDViz allows the definition of custom subsets of RDF data via SPARQL queries, which enables different ways of data exploration, such as: (i) inspecting and debugging the RDF graph and its ontology, (ii) exploring smaller RDF datasets via summarization to enable task resolution more efficiently by extracting meaningful information from data, and (iii) exploring graph mining result sets. When creating SPARQL queries, a great deal of time and effort is spent in testing and debugging to ensure that the resulting data is sufficient to accomplish the task at hand. Thus, we provide a query management interface where users can test and debug their queries, and import predefined queries, which they may use as templates to create new queries, simplifying the querying process. Furthermore, LDViz includes an interface where users without SPARQL knowledge can explore the result sets of predefined queries. We also provide a visualization interface to expert users in Semantic Web whose goal is to inspect or discover RDF/LOD datasets, and users of a given application domain whose goal is to analyze the data for supporting decision-making processes. For the purpose of strengthening the exploration capabilities, future work includes the implementation of a system of follow-up queries that allows one to import new data on-the-fly into the exploration process by either using predefined queries or creating new suitable queries.

We support exploration search via the MGExplorer, a visualization tool for progressively exploring multidimensional network data via multiple complementary views. Users can select subsets of data through visual queries and display the results in a separate view that shows a different perspective to the data. The multiple views can be hidden, revisited, and arranged in the display area in meaningful ways to support efficient data exploration while reducing cognitive overhead and clutter-related problems. While our use cases showed the support of different exploratory tasks, most data on the Web represent real-world phenomena, which are intrinsically spatio-temporal. Thus, future work includes expanding the visualization techniques and interaction tools to represent geospatial data.

The use case scenarios represent the resolution of well-known use cases for RDF visualization, which demonstrated the utility and feasibility of LDViz. However, user-based evaluations are essential and should be performed to determine the usability and suitability of the approach. Thus, future work includes developing user-based evaluations to investigate the usability of LDViz to assist the resolution of these and other use cases by expert users in Semantic Web, as well as to assist decision-making processes via visual mining of RDF graphs, involving expert users in diverse application domains.

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REFERENCES

Antoniazzi, F. and Viola, F. (2018). RDF graph visualization tools: A survey. In *2018 23rd Conference of Open Innovations Association (FRUCT)*, pages 25–36. IEEE.

Anutariya, C. and Dangol, R. (2018). Vizlod: Schema extraction and visualization of linked open data. In *2018 15th International Joint Conference on Computer Science and Software Engineering (JCSSE)*, pages 1–6. IEEE.

Brunetti, J. M., Auer, S., García, R., Klímek, J., and Nečaskỳ, M. (2013). Formal linked data visualization model. In *Proceedings of International Conference on Information Integration and Web-based Applications & Services*, pages 309–318.

Card, S. K., Mackinlay, J. D., and Shneiderman, B., editors (1999). *Readings in Information Visualization: Using Vision to Think*. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA.

Cava, R. and Freitas, C. D. S. (2013). Glyphs in matrix representation of graphs for displaying soccer games results. In *The 1st Workshop on Sports Data Visualization. IEEE*, volume 13, page 15.

Cava, R., Freitas, C. M., Barboni, E., Palanque, P., and Winckler, M. (2014). Inside-in search: an alternative for performing ancillary search tasks on the web. In *2014 9th Latin American Web Congress*, pages 91–99. IEEE.

Cava, R., Freitas, C. M. D. S., and Winckler, M. (2017). Clustervis: visualizing nodes attributes in multivariate graphs. In *Proceedings of the Symposium on Applied Computing*, pages 174–179.

Cava, R. A. (2017). Heterogeneous approaches for interactive exploration of multivariate networks (ph.d. thesis). http://hdl.handle.net/10183/157522.

Chawuthai, R. and Takeda, H. (2015). Rdf graph visualization by interpreting linked data as knowledge. In *Joint International Semantic Technology Conference*, pages 23–39. Springer.

Corby, O., Gaignard, A., Faron-Zucker, C., and Montagnat, J. (2012). KGRAM Versatile Data Graphs Querying and Inference Engine. In *Proc. IEEE/WIC/ACM International Conference on Web Intelligence*, Macau.

De Vocht, L., Dimou, A., Breuer, J., Van Compernolle, M., Verborgh, R., Mannens, E., Mechant, P., and Van de Walle, R. (2015). A visual exploration workflow as enabler for the exploitation of linked open data. In *IESD'14 Proceedings of the 3rd International Conference on Intelligent Exploration of Semantic Data*, volume 1279, pages 30–41. CER-WS. org.

Deligiannidis, L., Kochut, K. J., and Sheth, A. P. (2007). Rdf data exploration and visualization. In *Proceedings of the ACM first workshop on CyberInfrastructure: information management in eScience*, pages 39–46.

Destandau, M., Appert, C., and Pietriga, E. (2021). S-paths: Set-based visual exploration of linked data driven by semantic paths. *Semantic Web*, 12(1):99–116.

Frasincar, F., Telea, A., and Houben, G.-J. (2006). Adapting graph visualization techniques for the visualization of rdf data. In *Visualizing the semantic web*, pages 154–171. Springer.

Gandon, F. (2018). A Survey of the First 20 Years of Research on Semantic Web and Linked Data. *Revue des Sciences et Technologies de l'Information*.

Graves, A. (2013). Creation of visualizations based on linked data. In *Proceedings of the 3rd International Conference on Web Intelligence, Mining and Semantics*, pages 1–12.

Graziosi, A., Di Iorio, A., Poggi, F., Peroni, S., and Bonini, L. (2018). Customising lod views: a declarative approach. In *Proceedings of the 33rd Annual ACM Symposium on Applied Computing*, pages 2185–2192.

Jacksi, K., Zeebaree, S. R., and Dimililer, N. (2018). Lod explorer: Presenting the web of data. *Int. J. Adv. Comput. Sci. Appl. IJACSA*, 9(1).

Keim, D. A. (2002). Information visualization and visual data mining. *IEEE transactions on Visualization and Computer Graphics*, 8(1):1–8.

Kremen, P., Saeeda, L., and Blasko, M. (2018). Dataset dashboard-a sparql endpoint explorer. In *VOILA@ ISWC*, pages 70–77.

Menin, A., Cava, R., Freitas, C. M. D. S., Corby, O., and Winckler, M. (2021). Towards a Visual Approach for Representing Analytical Provenance in Exploration Processes. In *25th International Conference Information Visualisation*.

Munzner, T. (2014). *Visualization analysis and design*. CRC press.

Peña, O., Aguilera, U., and López-de Ipiña, D. (2016). Exploring lod through metadata extraction and data-driven visualizations. *Program*.

Pietriga, E. (2006). Semantic web data visualization with graph style sheets. In *Proceedings of the 2006 ACM symposium on Software visualization*, pages 177–178.

Skjæveland, M. G. (2012). Sgvizler: A javascript wrapper for easy visualization of sparql result sets. In *Extended Semantic Web Conference*, pages 361–365. Springer.

Telea, A. C. (2014). *Data visualization: principles and practice*. CRC Press.

Thellmann, K., Galkin, M., Orlandi, F., and Auer, S. (2015). Linkdaviz–automatic binding of linked data to visualizations. In *International Semantic Web Conference*, pages 147–162. Springer.