A Survey on User Interaction with Linked Data

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Abstract. Since the beginning of the Semantic Web and the coining of the term Linked Data in 2006, more than one thousand datasets with over sixteen thousand links have been published to the Linked Open Data Cloud. This rising interest is fuelled by the benefits that semantically annotated and machine-readable information can have in many systems. Alongside this growth we also observe a rise in humans creating and consuming Linked Data, and the opportunity to study and develop guidelines for tackling the new user interaction problems that arise with it. To gather information on the current solutions for modelling user interaction for these applications, we conducted a study surveying the interaction techniques provided in the state of the art of Linked Data tools and applications developed for users with no experience with Semantic Web technologies. The 18 tools reviewed are described and compared according to the interaction features provided, techniques used for visualising one instance and a set of instances, search solutions implemented, and the evaluation methods used to evaluate the proposed interaction solutions. From this review, we can conclude that researchers have started to deviate from more traditional visualisation techniques, like graph visualisations, when developing for lay users. This shows a current effort in developing Semantic Web tools to be used by lay users and motivates the documentation and formalisation of the solutions encountered in the studied tools.

Keywords: Linked Data · Semantic Web · Visualisation · User Interaction.

1 Introduction

With the rise of interest in Linked Data in the recent years, we start to see more applications and platforms using this data modelling paradigm. This interest is fuelled by the benefits that semantically annotated and machine-readable information can have in many systems, like search engines and recommendation systems. However, most times Linked Data is still perceived as data that will only be created and consumed by machines and robots, and not by humans as well. As a result, guidelines and common practices for designing user interaction and to tackle the new problems that occur with developing Linked Data systems for lay users are lacking.

With this survey we aim to research and study the interaction solutions provided in the state of the art tools developed for inexperienced users to interact with Linked Data. This study is focused on works explicitly targeted at users with no previous knowledge of Semantic Web technologies. The goal is to gather information on the commonly used techniques for interacting with and visualising Linked Data for this subset of users. This study covers five types of interaction with content, analysing works that allow users to browse, search, visualise, create and edit Linked Data.

Section 2 presents related works that analyse and classify visualisation tools for Linked Data. Section 3 describes the methodology conducted to perform this literature review and the criteria followed for including or excluding works. Section 4, 5, and 6 will present a brief description about each work reviewed, by categorising them in full-featured tools, browsers and exploratory tools, and models and frameworks, respectively. Section 7 classifies the reviewed works according to their visualisation techniques, interaction actions, implemented search solutions, and conducted evaluation of the user interface. In Section 8, the main results reported in this study are described, and future work is outlined.

2 Related Work

Several works have been published aiming to study and analyse Linked Data visualisation tools. Some surveying all the visualisation tools found in the literature [3, 5, 23, 8], others focusing on more specific subsets of Linked Data tools like Linked Data consumption tools [18], ontology visualisation tools [17], and Linked Data exploration systems [20]. An overview of the works presented in this section can be consulted in Table 1.

In "Approaches to Visualising Linked Data: A Survey" [5] the authors start out by describing the key requirements that visualisations approaches for Linked Data must follow to be accessible to non-domain and non-technical users. It is defended that clear and coherent visualisation of Linked Data is essential to the use of the Semantic Web by everyone. In this survey the existing approaches to visualised Linked Data are reviewed and analysed according to the requirements for interactive visualisation outlined before and that the authors believe will lead to intuitive knowledge discovery for all users.

Similar to the previous work, in "Exploration and Visualization in the Web of Big Linked Data: A Survey of the State of the Art and Challenges Ahead" [3] the authors outline the prerequisites and challenges that should be followed by exploration and visualisation systems, and review the solutions developed by the Semantic Web community and analyse their alignment to the requirements. With this work the focus is the Web of Big Linked Data, and no requirements are outlined to ensure these systems are accessible and usable by users with no previous experience.

Another work surveying the state of the art of Linked Data visualisation tools is "Empirical evaluation of Linked Data Visualization Tools" [8]. In this work the authors formalised a set of goals that the tools must fulfil in order to "provide clear and convincing visualisations" and "encourage user comprehension". Each tool is then evaluated according to these goals to determine which ones can be used successfully by any Linked Data consumers.

"Interacting with Linked Data: A Survey from the SIGCHI Perspective" [23] is focused on studying the current interaction and visualisation approaches for Linked Data. This survey reviews Human-Computer Interaction (HCI) works on Linked Data and analyses them according to the following aspects: the end-users, the context, the design contributions, and how is the research validated. The authors highlight that there is little research supporting human end-users in querying, browsing, and visualising Linked Data, and that the ones that exist rarely include validation methods or theoretical conclusions.

In "Ontology Visualization Methods - A Survey" [17] a more specific set of Linked Data tools is analysed, specifically tools for visualising ontologies. A set of requirements is previously defined for this type of visualisation tools and the reviewed approaches were analysed according to it. The surveying tools were also categorised according to the different characteristics of the presentation, interaction techniques, functionalities supported, and visualisation dimensions. Another two surveys focused on smaller sets of Linked Data tools are a "Survey of Tools for Linked Data Consumption" [18] and "Survey of Linked Data based exploration systems" [20] where tools for Linked Data consumption and Linked Data exploration and search tools are reviewed, respectively.

Some of the previously mentioned works are focused on defining requirements that Linked Data visualisation tools must follow to be accessible to non-technical and lay users, and then reviewing all the state of the art approaches according to those requirements. However, none set their goal as surveying the state of the art of Linked Data visualisation tools and applications targeted at inexperienced users. With this survey on user interaction with Linked Data, we set out to analyse and review the Linked Data applications and visualisation tools developed with inexperienced users in mind to find their most commonly used visualisation techniques, interaction features, and search approaches. Instead of focusing on evaluating and determining which tools from the set of published solutions could be used by lay-users, we aim to find the most used visualisation and interaction techniques and the evaluation methods in the subset of tools explicitly designed for inexperienced users.

Table 1. Overview of the related works.

Work	Year	Description
Katifori et al. [17]	2007	Survey of ontology visualisation methods, and the evaluation of their features and characteristics according to a previously defined set of requirements.
Dadzie and Rowe [5]	2011	Survey of Linked Data visualisation tools, and their evaluation according to key requirements that tools must follow to be accessible by lay users.
Marie and Gandon [20]	2014	Survey of Linked Data based exploration systems.
Bikakis and Sellis [3]	2016	Survey of systems developed in the context of the Web of Linked Data, and their evaluation according to requirements for modern exploration and visualisation systems.
Klímek et al. [18]	2019	Survey of tools for Linked Data consumption, and their evaluation based on their usability by non-technical and non-domain experts.
Santo et al. [23]	2020	Survey of the Human-Computer Interaction contributions for the Linked Data research field.
Desimoni and Po [8]	2020	Survey of the current approaches for visualising and exploring Linked Data, and their evaluation according to a set of goals that allow tools to provide clear and comprehensible visualisations.

3 Methodology

Visualisation tools play a big part in studying user interaction with Linked Data. Even tough by definition visualisation tools are developed to offer its users features to explore the data to identify patterns, infer correlations, and causalities [3]; many tools featured in LD visualisation studies [21, 8] are in fact developed not only for people with previous experience with LD. The works featured in this literature review are tools and applications developed for inexperienced users and intended for navigating, searching, authoring, and visualising data, as opposed to analytical pattern and statistics extraction.

To conduct this literature review, we started out by defining 4 survey research questions by which we will guide our research. We aim to acquire knowledge about what visualisation techniques are commonly used to display Linked Data, what actions can the users perform in the applications, what are the most reoccurring search solutions, and information about the conducted evaluations. To answer these issues we defined the following survey research questions:

SRQ1: Which interaction actions can the user perform?
SRQ2: What visualisation techniques are commonly used?
SRQ3: Which search solutions are provided?
SRQ4: How is the user interface evaluated?

Next, we established inclusion and exclusion criteria to filter the works to be reviewed. We included works considered as LD visualisation tools, applications, or models to aid the development of user interfaces for LD applications; and works targeted at users with no previous knowledge of Semantic Web technologies. We excluded works not written in English and focused on tools for the extraction of statistics and analytical patterns from data.

Finally, we entered the following search query, `[("linked data" OR "semantic web") interaction]`, in several scientific databases, specifically Google Scholar[5], ResearchGate[6], and ACM Digital Library[7], and selected works according to the previously described criteria. Additionally, we collected works by recursively analysing for each article the citations from it and the citations to it.

In the end, 18 works were selected, which are presented in chronological order in the next three sections, each one corresponding to one category of works: Section 4 with full-featured tools, Section 5 with search and exploratory tools, Section 6 with models and frameworks. A list of the 18 works can be consulted in Table 2.

4 Full-featured tools

In this section we describe the works that present platforms and applications for Linked Data that are focused on providing the user with a complete experience. These tools

[5] https://scholar.google.com
[6] https://www.researchgate.net
[7] https://dl.acm.org

provide ways for the users to explore and navigate the dataset, perform search queries, visualise individuals or groups of resources, and, in some cases create and edit data.

CS AKTiveSpace (CAS) [10] is a platform developed to take advantage of the semantic and distributed content collected related to Computer Science research in the United Kingdom. This application was developed, in part, to test the applicability to any domain of the mSpace model [9], described later in Section 6. Due to being based on mSpace, CAS user interface allows a semantic exploration of the domain tailored to its unique attributes. Users can explore the dataset by filtering down the instances by research area and location. An overview of the main instances, in this case researchers, is displayed to the user using a map, where they can select a specific area. When a researcher is selected, detailed information is also displayed in a simple textual format.

MuseumFinland [15] is a semantic portal for publishing heterogeneous museum collections in the Semantic Web. This application provides its users with several features, such as a global view of the collections, a content-based information retrieval system, and semantically linked and browsable content. Regarding the search features, MuseumFinland is equipped with a multi-faceted search system, that organises the resources in categories, as well as a simple keyword-based and geographical search. When selecting an instance in a result list, the user is redirected to a global view of that instance, composed of the instance image, metadata, and a set of hyperlinks to semantically related instances.

Ontowiki [1] is a Semantic Web tool developed for facilitating the visual representation and creation of a knowledge base for end users. This tool is focused on social collaboration aspects, and so it presents features such as change tracking, comments and discussions forums, rating and popularity metrics, and analysis of the users activity. To visualise a single instance, Ontowiki provides its users with an instance view that combines all of the properties and presents information about similar instances and incoming links. Regarding the search features provided, Ontowiki allows for facet-based browsing and a semantically enhanced full-text search. To author and edit the data, an inline edit mode is present in all information resulting from statements, following the "What You See Is What You Get" approach. The users can quickly edit or add statements by clicking a small edit or add button next to the information.

DBin [24] is a tool for contributing and exploring the Semantic Web by exchanging data in P2P channels. DBin is a tool that allows users to browse data of different domains, and each domain is equipped with predefined settings for visualising, querying and annotating the data with the help of "community configurable user interfaces", called Brainlets. A Brainlet defines which classes and relations between items are featured in DBin's tree layout navigator. This allows for the organisation of the information displayed to be targeted at the needs and common tasks of a certain domain. To aid inexperienced users to query the data, a Brainlet provides predefined common and useful queries to the domain, these are entitled as "precooked queries". Finally, to author and share the data, Brainlet lets its creator define custom domain dependent annotation templates, simple or more complex, and keep track of the annotations authors.

OKM Knowledge Management (OKM) [7] is a Linked Data authoring tool developed to analyse and test how lay users can interact with Linked Data systems. OKM is based on a traditional user interface with "resource-centric" pages, where each resource

has its own page with information and related resources. The users can follow these object properties to navigate the whole dataset. On top of this interface, the authors implemented some atypical features that were studied and analysed in order to assess their benefits to inexperienced users. One of the features was the inclusion of roles and templates. Instead of presenting a possibly exhaustive list of all the properties of a resource, the authors defend that a role must be defined for each class of the domain, where the most relevant information is displayed first. When adding a resource to the system the user must also assign one or more roles to it. Additionally, a template is provided so that all relevant information for that role is filled by the user. To evaluate the impact of these features, user experiments were conducted with participants with no previous knowledge of Linked Data.

The development of RDF Surveyor [26] was motivated by the lack of simple and intuitive solutions for user interfaces capable of being used by lay users to explore RDF data. The tool was developed to provide mechanisms to explore RDF datasets that hide the complex details of this kind of data. RDF Surveyor allows its users to navigate and explore the dataset, visualise an instance and search using a facet-based approach and a keyword-based approach. In the page of an instance the class types, data properties and related individuals are displayed, when applicable a picture and a map view are also provided.

5 Browsers and exploratory tools

Here we present browser and exploratory tools, meaning Linked Data tools and applications that are focused on providing the user with ways to navigate the datasets, or perform specific search tasks. Most tools presented next offer both navigation and search features, as well as, visualisation features.

QuizRDF [6] is a search engine proposed in 2004, to combine the advantages of free-text search with the advantages of browsing and searching for RDF metadata. The authors of this work defend that a typical user usually benefits more from starting with a single node or resource and exploring the remainder of the dataset from there; as opposed to starting with a general overview of the dataset. In order to do this, QuizRDF provides its users with an initial keyword search query, of ideally one or two terms, and a resulting ordered list of the results. Then, the users can further specify the search by selecting only the instances of a certain class, or the instances with a certain range of values for a given property. All the hyperlinks of properties relating the current class to others, or the super classes are clickable allowing the user to continue browsing and exploring the dataset.

Piggy Bank [14] is a browser extension developed to provide users with ways of using Semantic Web content while exploring and browsing the web. The main feature of this tool is that it allows users to extract information from web pages and transform it into RDF data. Piggy Bank also allows the user to visualise, browse and search for the data that they have saved. Upon saving a retrieved item, considered as a RDF resource that belongs to a class, has property values, and other retrieved resources, the user can assign tags and keywords to it. The items of each tag are then organised in collections, and faceted-search can be performed using them.

Tabulator [2] is a RDF browser developed for both inexperienced and experienced users to interact with the Semantic Web, and post and refine RDF data. Tabulator's main goal was to provide a generic Linked Data browser, that at the same time lets users benefit from user interface tools commonly encountered in domain specific applications. Similarly to other works, Tabulator allows the users to semantically browse the web of data, following the links between different resources. These resources are displayed in a tree view, where nodes can be expanded to obtain more information about them. Tabulator also allows the users to query for resources by providing values to different fields. The results can be visualised in different ways, with a table, timeline, map, or calendar view. In either mode, searching or exploring, when a resource is selected, the user is directed to a page with an outline view of the resource featuring more detailed information about it.

TreePlus [19] is a tool for visualising graphs that can be applied to several domains and different types of graphs, like the ones resulting from Linked Data datasets. This tool presents the graph to the users in a tree layout, allowing them to interactively explore it by starting with a single node and incrementally expanding it. The main goals while developing TreePlus were to keep the relationship labels readable and the tree layout as steady as possible. TreePlus offers its users features like a preview of the adjacent nodes, zooming and panning, simple keyword search and browsing and sorting options. The tests conducted concluded that TreePlus performed better in most of the tasks and that its benefits increase with the density of the graphs.

Ozone Browser [4] is a tool to make use of the semantics embedded in web documents in order to improve the experience of the users while browsing the web. The Ozone Browser is a graphical overlay that provides contextual knowledge of the hyperlinks in a web document. Regarding its user interface, Ozone Browser dynamically generates different views according to the domain of the RDF data presented. The default visualisation is composed of the RDF triples and related entities, if geographical data is available a map view is presented.

RelFinder [13] takes on a different approach than other browsing focused Linked Data tools. RelFinder's goal is to extract a graph that covers all the relationships between two predefined objects, and present it to the user. To this very simple graph visualisation, some interactive features were implemented to reduce the number of nodes and relations displayed. To start using this tool the user must select the two main objects using a basic keyword search, then the tool displays the graph connecting these two options. To filter the displayed relationships and nodes, users can select a subset according to their length or the classes they belong to, allowing them to better cater the visualisation to their interests and needs. Finally, if a node is selected in the graph, a simple visualisation of the instance information is displayed.

The approach for visual SPARQL queries based on filter/flow graphs [11] was developed for users with no knowledge or experience with RDF data to be able to create complex queries and obtain in-depth knowledge. This approach is composed of filters on the data or object properties of the data, that are connected as a graph. These filters include restrictions on ordinal values and strings, or resource identifiers. This tool underwent a qualitative user evaluation to assess the users ability to comprehend and compose SPARQL queries. While the results show that most users were able to quickly

complete the tasks, half of the participants already had previous basic knowledge of Semantic Web technologies. With these results we cannot be sure the tool is suited for users with no experience with Linked Data.

PepeSearch [25] is a Linked Data tool for searching semantic datasets, targeted at mainstream users, and thus requires no understanding or previous experience with Semantic Web data formats. PepeSearch provides its users with searching and instance visualisation features. Similar to other works, Pepesearch also allows its users to use a multi-faceted search, where they can apply different constraints to the data and object properties of all the classes in the dataset. The results are presented in a table with the values of all properties, and when an instance is selected the user is redirected to a page dedicated to that instance. In this page the data and object properties of the instance are displayed and the user can follow the links to the pages of the related instances.

6 Models and Frameworks

In this section, we feature works that present formalised interaction models created for, or adapted to Linked Data environments. Additionally, we present software frameworks to develop user interfaces and model user interaction for semantic platforms.

The mSpace model [9] is an interaction model that can be used for interactions with Semantic Web applications. This model provides developers and designers with an intuitive and effective user interface that accommodates alternatives to the commonly used keyword search. Initially, the mSpace model was not developed for Semantic Web applications, but motivated by the lack of research in user interaction with Linked Data, the authors decided on the formalisation of mSpace as an interaction model for the Semantic Web. mSpace is focused on facilitating the interaction with Semantic Web data to perform user-determined exploration of a certain domain. The default visualisation of this model is a multi-column table view, where data classes are ordered from left to right. The users can then browse through the data selecting an instance in each column. By selecting sequentially one instance from each column, the instances are filtered according to their relations, this browsing mechanism allows the users to chose their path while navigating the domain. Additionally, to better accommodate the user interests, the classes presented in the table can be rearranged, or substituted by others. To complement the browsing approach, mSpace provides users with a detailed view for the last selected instance, that displays contextual information about it.

Haystack [22] is a platform to facilitate the development of Linked Data applications, that allow lay users to create, manipulate, and visualise RDF data. Haystack focuses on providing developers and designers with user interface components that were designed specially to handle the heterogeneity of RDF data and contribute to a good user experience. Haystack allows designers to specify different types of views, differing in size and location, for every type of resource in the domain. Additionally, developers can also add customisable operations tailored to a resource, available in the view displayed to the user. This tool provides users with a keyword-based search, a simple textual visualisation of each resource, and mechanisms to author, edit, and annotate the resources. Finally, users can semantically explore the domain by following the links of the related resources.

Table 2. Overview of the interaction actions provided by the works reviewed.

	Exploration/ Navigation	Search	Author/ Edit	Visualisation
Full-featured tools				
CS AKTiveSpace (2004) [10]	✓			✓
MuseumFinland (2005) [15]	✓	✓		✓
Ontowiki (2006) [1]		✓	✓	✓
DBin (2006) [24]	✓	✓	✓	✓
OKM (2010) [7]	✓	✓	✓	✓
RDF Surveyor (2019) [26]	✓	✓		✓
Search and exploratory tools				
QuizRDF (2004) [6]	✓	✓		✓
Piggy Bank (2005) [14]	✓	✓		✓
Tabulator (2006) [2]	✓	✓		✓
TreePlus (2006) [19]	✓	✓		
Ozone Browser (2009) [4]	✓			✓
RelFinder (2009) [13]	✓	✓		✓
Filter/Flow (2014) [11]		✓		
PepeSearch (2016) [25]		✓		✓
Models and frameworks				
mSpace (2003) [9]	✓			✓
Haystack (2003) [22]	✓	✓	✓	✓
Information Workbench (2011) [12]	✓	✓	✓	✓
Sampo-UI (2020) [16]	✓	✓		✓

The Information Workbench [12] is a platform that supports the whole development process of developing a Linked Data application. Here, we will be focused on reviewing the options and chosen solutions for the user interface design. Firstly, the platform supports the implementation of basic a keyword search, as well as graph pattern search and faceted search. The Information Workbench provides the developers with a wide range of different visualisation widgets to accommodate the highly heterogeneity of Linked Data datasets. For a set of instances or resources views like maps, lists, timelines, and graphs are provided. For a single instance information can be consulted in a generic textual view, tabular view, or graph view, where only the neighbourhood of the instance selected is displayed. In all these visualisation options the user can semantically browse the dataset by clicking in the related instances hyperlinks. Additionally to searching, visualising and browsing the data, users are provided with simple widgets to edit and annotate the presented data.

Sampo-UI [16] is a software framework for developing customisable and responsive user interfaces for semantic portals. The authors started out by outlining the requirements for the user interfaces for Semantic Web applications, based on their experience in developing these semantic portals. The first requirement presented is providing the user with a variety of different ways of exploring the data, for this the authors highlight some search paradigms: free-text search, faceted search, geospatial search, and temporal search. Another requirement is providing the users with different views of the search results, in the form of tables, lists, geospatial, or temporal visualisations. The final requirement outlined is that the user interface should support semantic browsing, meaning semantic links should allow the users to browse through the dataset, from one instance's page to another. These instance pages are described as a landing page for an

[7] http://conference-explorer.fluidops.net/

Table 3. Overview of the visualisation techniques used in the reviewed works.

	Instance View					Instance Set View				
	Textual	Map	Calendar	Table	Graph	List	Table	Tree	Map	Timeline	Graph
Full-featured tools											
CS AKTiveSpace (2004) [10]	✓					✓	✓		✓		
MuseumFinland (2005) [15]	✓					✓					
Ontowiki (2006) [1]	✓	✓	✓			✓	✓				
DBin (2006) [24]	✓							✓			
OKM (2010) [7]	✓					✓					
RDF Surveyor (2019) [26]	✓	✓				✓					
Search and exploratory tools											
QuizRDF (2004) [6]	✓					✓					
Piggy Bank (2005) [14]	✓					✓	✓				
Tabulator (2006) [2]	✓					✓	✓	✓	✓	✓	
TreePlus (2006) [19]							✓				
Ozone Browser (2009) [4]	✓	✓									
RelFinder (2009) [13]	✓					✓	✓		✓	✓	✓
Filter/Flow (2014) [11]	✓			✓							
PepeSearch (2016) [25]	✓					✓					
Models and frameworks											
mSpace (2003) [9]	✓						✓				
Haystack (2003) [22]	✓					✓					
Information Workbench (2011) [12]	✓			✓	✓	✓	✓		✓	✓	✓
Sampo-UI (2020) [16]	✓					✓	✓		✓	✓	

entity, providing information about its metadata, and internal and external links to other related entities. The development of Sampo-UI was based on these requirements and components to implement these features were developed.

Table 4. Overview of the evaluation methods conducted.

	None	Qualitative	Quantitative
Full-featured tools			
OKM (2010) [7]		Satisfaction Study (71)	User Study (71)
RDF Surveyor (2019) [26]			Usability Study (14)
Search and exploratory tools			
TreePlus (2006) [19]		User Study (28)	
Filter/Flow (2014) [11]		User Study (10)	
PepeSearch (2016) [25]			Usability Study (15)

7 Discussion

To answer the survey research questions previously stated, each reviewed work was classified according to its interaction actions, visualisation techniques, search solutions and user interface evaluation. The information gathered was then systematised in 4 tables and analysed. Regarding SRQ1 we categorised the works according to the main interaction actions provided to the users, summarised in Table 2. These were divided

in 4 categories: (1) exploration/navigation, meaning the users were able to semantically browse the data by following related resources, and without the need to always start a new search task; (2) search, where users can query the system for a single or a group of resources; (3) author/edit, where the users are provided with mechanisms to edit, create, or annotate resources; (4) visualisation, applications where users have access to the visualisation of a single resource or a group of related resources. We can conclude that the majority of works provide ways for users to explore, search and visualise Linked Data, with only a small group of works providing features to author and edit. We can assume the lack of tools for authoring data is due to the fact that most targeted at lay-users are focused on browsing and visualising it, as opposed to focused on users contributing to the dataset. Another reason might be the complexity of designing an interface that motivates the users to input semantically correct RDF data, with no previously knowledge of these technologies. It is also worth mentioning that the two works with no visualisation features [19, 11] are solely focused on the development of a novel approach for lay-users to construct SPARQL queries and exploring graph-based data, respectively.

Table 5. Overview of the search techniques in the reviewed works.

	Facet-based	Keyword-based	Predefined queries	Geographical	Temporal
Full-featured tools					
MuseumFinland (2005) [15]	✓	✓		✓	
Ontowiki (2006) [1]	✓	✓			
DBin (2006) [24]			✓		
OKM (2010) [7]	✓				
RDF Surveyor (2019) [26]	✓	✓			
Search and exploratory tools					
QuizRDF (2004) [6]		✓			
Piggy Bank (2005) [14]	✓				
Tabulato (2006)r [2]			✓		
TreePlus (2006) [19]		✓			
RelFinder (2009) [13]		✓			
Filter/Flow (2014) [11]	✓				
PepeSearch (2016) [25]	✓				
Models and frameworks					
mSpace (2003) [9]	✓				
Haystack (2003) [22]	✓				
Information Workbench (2011) [12]	✓	✓			
Sampo-UI (2020) [16]	✓	✓		✓	✓

To survey the visualisation techniques in the reviewed works, we decided to analyse two different kinds of visualisation, the visualisation of a single instance, and the visualisation of a set of instances. The gathered information to answer SRQ2 is summarised in Table 3. For the single instance visualisation, the most common technique is a textual view of the resource, where the related information, data properties, object properties, and other related resources are listed. However, several works highlight the fact that this approach can quickly make the interface too cluttered and dense, when the dataset used is highly connected and the classes have a large number of properties. To combat this we encountered some approaches using collapsible sections, to hide and show more information upon a user's need. The map and table techniques consist of only dis-

playing the related resources with geographical and date data, respectively. The graph view for a single instance, only used in the Information Workbench model [12], is used to display the neighborhood of related resources, suitable to visualise social networks or family trees. Regarding the visualisation techniques for a set of instances, the most common approaches are lists and tables, the only difference between the two being that a table usually displays some of the instance's attributes, while a list only displays the instance's label. Surprisingly, the least common approach was the graph visualisation, represented in Figure 1, usually deeply connected to the visualisation of Linked Data, due to its natural network format. One explanation for this observation is that all tools are developed to be used by anyone with no previous experience with Linked Data, and graph visualisations, specially when large and highly connected, usually result in usability issues for this kind of users.

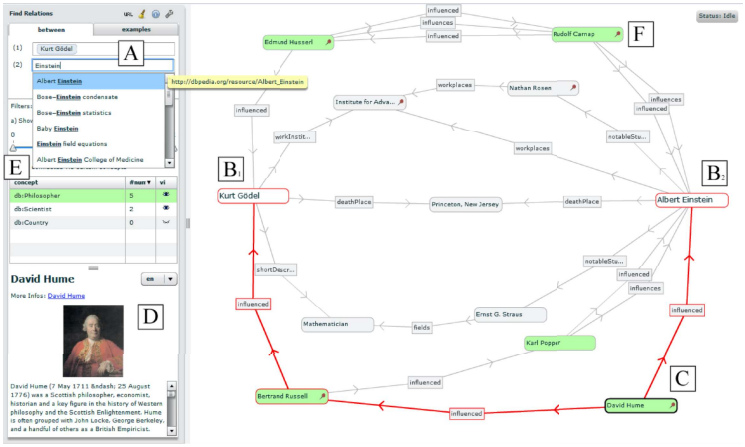

Fig. 1. Example of a graph visualisation in RelFinder [13]

To answer SRQ3 we collected the search solutions available in the subset of works that provided users with features to search for a single or a set of resources. Table 5 summarises the gathered information, and clearly shows that the two most common approaches are faceted-based search and keyword-based search. Tools that offer a faceted-based search allow users to search for resources specifying the class they belong to, data property values, or other related resources. We believe a faceted-based search is the most promising solution for semantic datasets, as it allows users to benefit from the semantic knowledge of the data. However, we find it best used together with the more traditional keyword-based approach, where users can search for resources by matching the entered keywords with the resources' label or other literal attributes.

Finally regarding SRQ4, we categorised the works according to the type of evaluation conducted to validate the user interface, summarised in Table 4. A large majority of around 70% of the works reviewed did not formally test their interfaces, which proves the lack of research and evaluation in user interaction with Linked Data systems.

8 Conclusions and Future Work

In this paper, we reviewed the state of the art Linked Data tools and applications developed for inexperienced users. Our goal was to gather knowledge on common approaches and solutions for user interaction design with Linked Data by analysing which user interaction features, like visualising techniques and search solutions, are more commonly provided in these tools. We can point out some recurring solutions, such as the use of faceted search interfaces and several data visualisation options when consulting a single or a group of resources. Surprisingly, graph-based visualisations, traditionally associated with Linked Data, were the least common approach encountered in the set of works reviewed. Usually, some of these more traditional visualisation and interaction techniques come with usability issues and are not familiar to users with no previous knowledge of Linked Data technologies, especially when associated with large and highly interconnected datasets. While these traditional approaches may negatively impact the use of the web of data by inexperienced users, the alternative visualisation techniques and user interaction approaches that have been developed and studied in the literature show that researchers have started to consider Linked Data as a data modelling paradigm also to be consumed by humans. We outline the future work for this study as the systematic documentation and abstraction of the alternative solutions found with this research, as we consider them necessary to broaden the use of Linked Data and the Semantic Web by lay-users.

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