Survey of linked data based exploration systems

Nicolas Marie, Fabien Gandon

Survey of linked data based exploration systems

Nicolas Marie[1,2] and Fabien Gandon[1]

[1] WIMMICS, INRIA Sophia-Antipolis, Sophia Antipolis, France
[2] Alcatel-Lucent Bell Labs, Nozay, France
{firstname.lastname}@inria.fr

Abstract. Linked datasets now constitute a valuable background knowledge for supporting exploration and discovery objectives through browsers, recommenders and exploratory search systems in particular. Today there is a need to look at the achievements and tendencies in this rapidly developing field in order to better orient the future research works. In this paper we propose a survey of such systems from the earliest semantic browsers to more recent and innovative ones.

1 Introduction

[19] stressed the need for efficient exploratory search systems (ESS) i.e. systems optimized for investigation and learning tasks. Linked data [3] and DBpedia [18] respectively correspond to an approach for publishing and linking data on the web and its application to data extracted from Wikipedia[3]. The semantic search community [28] enlightened the possibilities brought by semantics incorporation in search systems, their capability to support advanced search experiences and to solve complex information needs. Today major initiatives in the field of semantic search emerge from important web players[4].

The amount and heterogeneity of the contributions in the field of linked data based exploration is growing. There is a need to look at the achievements and tendencies in order to orient the future research works. We propose the following diagram in order to structure the reflection, see Figure 1. The *exploratory search tasks characteristics* on the left are summarized from [30]. We derived from these characteristics a list of *desired effects of the systems* and linked them to the widespread features implemented in the existing applications.

To the best of our knowledge no previous survey specifically dedicated to linked data based exploration and discovery systems exist. We review (1) the linked data browsers, (2) the linked-data based recommenders, (3) the linked data based exploratory search systems.

[3] http://www.wikipedia.org/
[4] e.g. http://www.bing.com/blogs/site_blogs/b/search/archive/2013/03/21/satorii.aspx

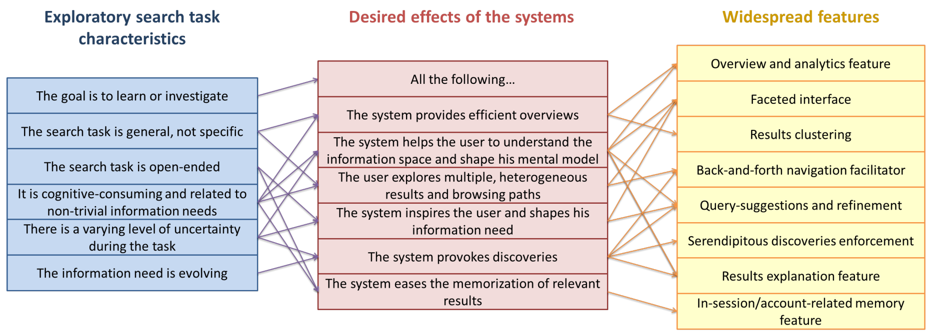

Fig. 1. Relation between exploratory search tasks characteristics and widespread systems features

2 Linked data browsers

The first generation of tools designed to explore linked data was semantic browsers. At their beginning semantic browsers gave a very simple view of the data in graph form or were strongly inspired by the web pages browsing. More recently innovative browsing paradigm were proposed. In this section we review textual, visual, faceted and more singular browsers.

2.1 Text-based browsers

A plethora of semantic text-based browsers exists. We propose a selection of some of the most cited in the literature to give an idea of the functionalities this class of browsers proposes. A more complete survey is available in [7]. **Noadster** [26] is an early (2005) and generic RDF browser that performs a property-based clustering on the data. The properties-based clusters are used to structure the results: frequent properties appear higher in the results-tree. **Disco**[5] (2007) is a simple server-side browser that render the RDF data in columns of property-value pairs associated to the currently browsed resource (object) in a table. **Marbles**[6] (2007) formats the RDF triples using the Fresnel vocabulary [7]. Marbles retrieves additional data about the browsed resources from semantic index, search and review systems. Colored bubbles (the *"marbles"*) help the users to identify the sources of provenance of the data retrieved.

2.2 Visualization-based browsers

Visualization-based browsers lower the users' cognitive load and help them overcoming the data complexity by relying on their natural visual ability. For a

[5] http://wifo5-03.informatik.uni-mannheim.de/bizer/ng4j/disco/
[6] http://wiki.dbpedia.org/Marbles
[7] http://www.w3.org/2005/04/fresnel-info/

complete survey the reader may refer to [6]. **RDF Gravity**[8] (2004) is a RDF and OWL visualization tool [8]. It offers filtering, search functionalities and allows the users to reposition the nodes for better visualization. The resources are displayed in different colors according to their RDF types for a more comprehensive layout. **Tabulator**[9] (2005) [2] is a generic RDF browser that displays the data through a tree-view. By clicking the hierarchically displayed trees the users browse through increasing levels of details. **DBpedia Mobile**[10] (2008) is a location-aware mobile web application [1]. It displays the geolocated DBpedia resources surrounding the users (or elsewhere) on a map by using *geo:lat* and *geo:long* properties. Filtering and context-aware strategies are used to minimize the amount of displayed triples. **LENA**[11] (2008) offers a mechanism to build Fresnel-based visualization templates using SPARQL queries [16]. The objective is to propose specific views that correspond to users in respect to their interests and expertise.

2.3 Faceted browsers

A faceted search system *"presents users with key-value metadata that is used for query refinement"* [17]. Each time a constraint (a facet value) is applied the results are filtered, the available facets and facets' values are updated. **Longwell**[12] (2005) is a web application for browsing and searching large RDF datasets. Longwell offers a faceted filtering mechanism. The facets and their values are heuristically derived from the dataset. These heuristics can be pre-configured by the users. MuseumFinland[13] (2005) is a faceted semantic browser that was implemented on the top of a Finnish art-collections RDF knowledge base [13]. Preview counts showing the amount of results per facets help the users in their manipulation. **mSpace** (2005) uses the facets dependencies as a support for browsing [31]. The facets are organized horizontally e.g. *era, composer, place* in the domain of classical music. The order is not neutral and constitutes a hierarchy where the left-most column is the top level. The value(s) applied in each facet constrain(s) the displayed values of the facets on *the right*. The users can change the orders of facets, swap, delete and add new ones. **/facet** (2006) automatically set up faceted browsing over a heterogeneous linked dataset where manual configurations are too fastidious or unfeasible [11]. The facets and their hierarchical dependencies are generated with the help of the ontological knowledge e.g. the RDFS classes and their associated properties. Such facets generation has the advantage to be applicable on every linked database. **Humboldt** (2008) is a faceted browser that helps the users to explore a local RDF graph [15]. Contrary to the majority of semantic web faceted browsers Humboldt proposes facets corresponding to classes, for example *Person* appears instead of *directed, stars in,*

[8] http://semweb.salzburgresearch.at/apps/rdf-gravity
[9] http://dig.csail.mit.edu/2005/ajar/ajaw/tab
[10] http://beckr.org/DBpediaMobile
[11] http://isweb.uni-koblenz.de/Research/lena
[12] http://simile.mit.edu/wiki/Longwell_User_Guide
[13] http://www.museosuomi.fi/

was awarded for, etc.. Proposing class-based facets simplifies the interface by decreasing their amount. More details about the relations are given on demand.

2.4 Others browsing paradigms

The following browsers propose innovative and singular interaction paradigms implemented over linked data sources. **Parallax** (2009) aims to overtake the classic *one resource at a time* interaction paradigm [12]. The authors of Parallax introduce the *"set-based browsing"* paradigm that allows to browse several links at the same time: from a set of entities to another set of entities e.g. all the US presidents to their children. Along the exploration the users can apply filters on the currently displayed data. A browsing history helps the users to edit their previous interactions. **RelFinder**[14] (2009) is a web application that displays the paths existing between two resources of interest in a graph form [10]. The path identification remains at the instances level and do not traverse *rdf:type* properties. Identifying such paths can be very cognitive and time consuming by *manual* browsing. **gFacet** (2010) is a prototype combining graph-based visualization and faceted filtering techniques [9]. The facets are represented in the form of nodes in a graph, the arcs represent their dependencies (e.g. *birthPlace* links the facets *Person* and *Place*). When the users select a filtering value in a facet it recomputes the values in the others facets as well as in the results set. **Visor** (2011) is a semantic web browser that implements the *"multi-pivoting browsing"* paradigm [25]. Visor allows multi-directional exploration by following several properties at a time. The users first select one or several classes thanks to a keyword-search functionality. The selected classes and the properties which connect them are displayed in a graph form. The majority of interactions occurs at the schema level (e.g. adding, removing classes). The instances are only shown on demand.

3 Recommenders

Several research works have shown the great potential of linked data and especially DBpedia to compute semantic similarities. Such similarity measures are mainly used by recommenders. At the beginning domain-constrained approaches were researched (first subsection). More recently more complex recommendations were investigated (second subsection). The domain-specific approaches target a single sub-ensemble of a dataset for which they are optimized e.g. DBpedia actors, directors and movies and related properties. They can be constrained to a single type e.g. movies recommendations starting from a movie. Recently Bing, Google and Yahoo deployed their own entities' recommendation approach. If an entity is recognized in the users' query these search engines display structured data about it in a knowledge panel. The Google (2012) and Bing (2013) methods are unpublished. Yahoo partially revealed the functioning of its SPARK recommender (2013) which is based on heterogeneous features extraction (e.g. co-ocurrence, type) and a stochastic gradient boosted decision tree, [4].

[14] http://www.visualdataweb.org/relfinder.php

3.1 Domain-specific recommenders

The **Linked Data Semantic Distance** (LDSD, 2010) is based on direct and indirect paths counting between a pair of resources [23]. It was applied on the music domain for computing similarities between all the *Bands* and *Musical Artists* instances contained in DBpedia. The LDSD results were successfully evaluated against the LastFM[15] recommendations. The **DBpedia Ranker** (2010) proposes a similarity measure which is a combination of several weights including external services (search engine correlations measure with Google, Yahoo, Bing and Delicous[16]), one link analysis measure based on the existence of a relation between the resources (no links, a link in one direction, two links in both directions) as well as a literal (label) based analysis. It was implemented over DBpedia resources belonging to the ICT domain. **MORE**[17] (2010) is a DBpedia-based movie recommender [21]. It is based on a semantic adaptation of the vector space model. The more features two resources share the more similar they are. They can be linked through direct properties (e.g. *"subsequentWork"*), be the subject of triples having the same property and object (*"starring" "Robert de Niro"*) or be the objects of two RDF triples having the same property and subject. The users can ask explanations about the recommendations by requesting the shared properties between the queried movie and the results.

3.2 Cross-domains recommenders

The recommenders previously described are focused on a specific domain and/or limited to a specific type of items. This constraint is motivated by performance and recommendations quality concerns. This can be considered as a severe limitation in the linked data context. Indeed the richness of the linked data datasets offers an unprecedented ground for computing complex similarities metrics. **Fernandez and al.** (2011) proposed a framework to compute recommendations in a defined domain starting from instances that belong to another domain e.g. music starting from places [14]. The instances belonging to the 2 domains are linked in an acyclic graph. This acyclic graph is composed of a set of classes and properties that are selected by an expert. Finally a weighted traversal algorithm is performed over this graph to generate the recommendations. The evaluations showed very encouraging results and confirmed the potential of DBpedia for cross-domains/types recommendations. [27] proposed the **hyProximity** algorithm (2011), designed to support industrial problem solving. A valuable approach in open innovation is to identify topics that are lateral to a given problem in order to find innovative solution coming from another domain. The goal of the hyProximity algorithm is to identify hidden and unexpected associations between industrial topics. A set of DBpedia entities is first extracted from the

[15] www.lastfm.com
[16] https://delicious.com/
[17] http://apps.facebook.com/new-more/

targeted industrial problem description. Then the hyProximity algorithm traverses the DBpedia graph and finds laterals topics (and consequently associated experts) that might propose an innovative solution.

4 Linked data based exploratory search systems

Exploratory search systems are the most advanced systems in the field of linked data based exploration. They all propose a variety of functionalities dedicated to exploration purposes. There are two main currents in the literature in terms of processing and interaction model. The first one is to allow the users to produce views on the graph through rich operators (first subsection). The second approach consists in applying algorithms that leverage the semantics in order to select and rank a small amount of data that are presented to the users (second subsection). In the second case the graph is not displayed as it is, computed meaningful relations (similarity, relatedness) are shown instead.

4.1 View-based exploratory search systems

Aemoo[18] (2012) is an exploratory search system based on Encyclopedic Knowledge Pattern[19] (EKP) [22]. EKP are knowledge patterns that define the typical classes used to describe entities of a certain class. For instance *"airport"*, *"aircraft"*, *"military conflict"* or *"weapon"* are part of the *"aircraft"* EKP. They were built by using a DBpedia graph analysis. Aemoo presents the resource explored direct neighborhood filtered with its class' EKP in the form of a graph. It also proposes a *"curiosity"* function which displays the resource of interest neighborhood through an inverted EKP filtering. This function aims to reveal surprising knowledge. Aemoo also provides explanations by showing the cross-references in Wikipedia pages between the topic of interest and the results. **Linked Jazz**[20] (2013) aims to reveal the network of the social and professional relations within the American jazz community [24]. The objective is to capture the relations semantics in RDF from jazz people interviews' transcripts. The method used to reach this goal is a combination of automated processing and crowd-sourced curation. The dataset obtained can be explored through a graph visualization web application. It gives an overview of the jazz community network and supports more focused explorations e.g. individual connections, shared connections, dynamic network creation by manual selections.

4.2 Algorithm-based exploratory search systems

Yovisto[21] (2009) is an academic videos search engine that provides a linked data based exploratory search feature [29]. The exploratory search feature retrieves

[18] http://wit.istc.cnr.it/aemoo
[19] http://www.ontologydesignpatterns.org/ekp/
[20] http://linkedjazz.org/
[21] http://www.yovisto.com/

topics suggestions that are semantically related to the users' query. When the user enters a query Yovisto retrieves a set of semantically interrelated suggestions. These suggestions are computed over DBpedia by using a property ranking process based on a set of heuristics. **Semantic Wonder Cloud** (SWOC, 2010)[22] is based on the DBpedia Ranker [21]. First the users select a starting topic by using the DBpedia lookup[23] (rapid resource selection by typing). Then SWOC surrounds it by its 10 most similar concepts in a graph form. SWOC exposes associations that does not exist in the original dataset. The second system based on the DBpedia Ranker is **Lookup Explore Discover** (LED, 2010)[24] [21]. The users first enter a topic of interest using a DBpedia lookup. Then LED suggests semantically similar query-resources that are presented in the form of a tags cloud. Thanks to them the users can refine the query and easily explore an unknown domain. Once the query is composed, LED retrieves an aggregation of results coming from several major search engines (Google, Yahoo, Bing) as well as a news feed and a microblogging service. The **Seevl**[25] musical discovery platform (2012) uses the LDSD measure to retrieve artist recommendations. The users can also browse through the properties-values associated to an artist in order to explore and discover other artists e.g. its musical genres, collaborations. Shared-properties based explanations are available. **Discovery Hub**[26] (2013) implements a linked data exploration framework based on a semantic-sensitive traversal algorithm coupled to a live graph sampling technique [20]. Discovery Hub offers faceted browsing and multiple results explanations features. Several advanced query modes are supported by the framework including the specification of facets of interest and disinterest about the topic explored and the injection of randomness during the data processing to retrieve more surprising results. **inWalk**[27] (2014) is a web application for high level linked data exploration [5]. It allows the users to interact with a graph of clusters named *inCloud*. An inCloud is a set of linked data based clusters, computed according to a manually declared list of properties. The clusters are related each others by a semantic proximity link. The current inWalk web application is implemented on a Freebase subset related to athletes and celebrities. InWalk aims to give an high-level overview on a domain and to ease its appropriation by the users.

5 Discussion

5.1 Evolution over time

The Figure 2 shows the evolution of the research in terms of linked data based exploration systems. **During the first development phase of the semantic**

[22] http://sisinflab.poliba.it/semantic-wonder-cloud/index/
[23] http://wiki.dbpedia.org/Lookup
[24] http://sisinflab.poliba.it/led/
[25] http://play.seevl.fm/
[26] http://discoveryhub.co
[27] http://islab.di.unimi.it/inwalk

web (2001 - 2007) several types of browsing paradigms were investigated. Text-based browsers inspired by the *classic* web browsing experience appeared. In their simplest form they allowed to navigate one resource-at-a-time using resources outgoing relations. During this period visual (graph) and faceted browsers were also investigated. The small size and the relative homogeneity of the available datasets were favorable to such approaches. **In 2007 the Linked Open Data initiative renewed the research**. The quality, size and coverage of generic datasets like DBpedia and Freebase opened the door to innovative processing and interactions models. New browsing paradigms like set-based, multi-pivoting and hierarchical faceting ones were investigated. **An important shift in the research started with new forms of linked data based algorithms**. The objective was to compute and expose computed links instead of showing the graph as it is. Such algorithms leverage the semantics to select and rank a small amount of data that are then explored by the users. In a first time the computation of linked data based recommendations brought very encouraging results. The similarity computation was domain-constrained at the beginning (MORE, LDSD, DBpedia Ranker). Then cross-domain (Fernandez and al.) and lateral (hyProximity) approaches were researched. **Some of these recommenders constituted the basis of linked data based exploratory search search systems**. The DBpedia Ranker was notably integrated in SWOC and LED. Later the LDSD measure was implemented for computing the Seevl recommendations. Several *from-scratch* exploratory search system, associated data processing and interactions models were developed. Recently (2012 - 2013) the 3 major search engines deployed their entity-recommendation solutions, confirming the potential of such approaches for mainstream services.

Fig. 2. Systems timeline

5.2 Achievements and opportunities

The table 3 gives an overview of the most advanced systems for exploration and discovery on linked data i.e. innovative semantic browsers, recommender systems and exploratory search systems. As the human factor is crucial for exploration tasks we only considered the systems having a user interface in this

System	**Parallax**	**Relfinder**	**gFacet**	**Yovisto**	**MORE**	**SWOC**	**LED**	**Visor**	**Aemoo**	**Google K. Panel**	**Yahoo SPARK**	**Bing Snapshot**	**Seevl**	**Discovery Hub**	**inWalk**	**Linked jazz**
Type	Set-based browser	Visualization tool	Hierarchical faceted	Video ES platform	Recommender	ESS	ESS	Multi-pivoting browsers	ESS	Recom-mender	Recom-mender	Recom-mender	ESS	ESS	ESS	ESS
Year	2009	2009	2010	2010	2010	2010	2010	2011	2012	2012	2012	2012	2012	2012	2013	2013
Context	Research	Research	Research	Research	Research	Research	Research	Research	Research	Industry	Industry	Industry	Research	Research	Research	Research
IR																
Query-paradigm	Keyword search	Multiple lookups	Multiple lookups	Keyword search	Lookup(s)	Lookup(s)	Keyword search	Manual facets selection	Lookup	Keyword search	Keyword search	Keyword search	Lookup	Lookup	Lookup	Manual selection
Matching	String-match	Direct match (lookup)	Direct match (lookup)	String-match	Direct match (lookup)	Direct match (lookup)	String-match	Selection	Direct match (lookup)	Entity recognition	Entity recognition	Entity recognition	Direct match (lookup)	Direct match (lookup)	Direct match (lookup)	Selection
Data	Freebase subset	DBpedia, Linked MDB, LOD,	Dbpedia	DB	DBpedia subset	SWOC	DBpedia subset	DBpedia	DBpedia	Google KG	Yahoo KG	Bing Satori	Dbpedia subset	DBpedias	Freebase subset	Linked jazz KB
Type and/or domain specific	No	No	No	No	Type and domain constrained	Domain constrained	Domain constrained	No	No	No	No	No	Types and domain constrained	No	Domain constrained	No
Main data processing	/	Iterative paths identification	/	Set of heuristics	sSVM	DBpedia Ranker	DBpedia Ranker	/	EKP-based filtering	Undisclosed	Stochastic gradient decision tree	Undisclosed	LDSD	Spreading activation adaptation	Semantic clustering	/
HCI																
Principal layout	List	Graph	Graph of facets	Query suggestions	List	Graph	Tags cloud	Graph	Graph	List	List	List	List	List	Graph	Graph
Overviews and analytics	Resources set visualization	Paths between the seeds	Graph	No	No	No	No	Spreadsheet builder	No	(Caroussel)	No	No	No	Large pictures board	Clusters' graph	Graph
Faceted interface	Yes	No	Yes	Yes	No	No	No	Yes	No	No	No	No	Yes	Yes	No	No
Results clustering	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No
Back-and-forth navigation facilitator	In-session history	No	No	Yes	No	In-session history	In-session history	No	In-session history	In-session history	No	No	No	In-session history	In-session history	No
Query suggestion	No	No	No	Yes	No	No	Yes	No	No	Yes	Yes	Yes	No	No	No	No
Results explanations	No	Properties labels	Facets dependencies	No	Common properties	No	No	No	Wiki cross-references	No	No	No	Common properties	Multiple	No	Textual
Memory-features	In-session history	No	No	No	No	In-session history	In-session history	No	In-session history	In-session history	No	No	No	In-session h., collections	In-session history	No

Fig. 3. Summary of the systems according to their main information retrieval and human-computer interaction aspects.

table. We comment the table below, reusing the *desired effects of the systems* listing proposed in the introduction.

The system provides efficient overviews: The majority of systems do not implement specific over-viewing features. Some layout like the Discovery Hub (pictures board) or Linked jazz ones (whole graph visualization) are helpful but not sufficient. Several applications are specifically built to favor the understanding of the data space by adopting a *schema first, instances second* design (Visor, InWalk). However these approaches might be confusing for the lay users. In order to mitigating this problem we see an opportunity in exposing both schema and instances information at the same time in order to obtain a good tradeoff between information richness and intuitiveness.

The system helps the user to understand the information space and to shape his mental model: faceted interfaces, used by 5 systems out of 14, constitute a powerful approach for understanding the domain explored as they expose explicitly its important dimensions. At the same time 6 out of 14 systems propose results explanations features which are crucial components to rise the information space understanding. There is an opportunity in investigating new forms of faceted interfaces and explanations e.g. personalized ones which put the information space in perspectives with resources already known by the users.

The user explores multiple, heterogeneous results and browsing paths: concerning the results heterogeneity several systems have shown that it is possible to propose linked data exploratory search systems without targeting a specific type or domain (e.g. Aemoo, Discovery Hub). It is noticeable that 7 out of 14 systems propose in-session memory feature (also known as breadcrumbs). Such features allow the users to easily come back to a previous state. They considerably lower the perceived cost of browsing and consequently encourage the exploration. We see an opportunity in setting up rich interfaces to reduce even more the perceived cost of browsing.

The system eases the memorization of relevant results: in-session memory features avoid the users to memorize their sequences of browsing, freeing their cognitive resources that can be used for more valuable exploratory sub-tasks e.g. results analysis and comparison. There is a need to develop account-related memory features that can support knowledge acquisition for long-lasting interest. Collaborative approaches (gathering several points of view) and advanced knowledge organization (e.g. mind maps) are relevant axes of development for such functionalities.

The system inspires the user and shapes his information need: there are only two systems which propose query suggestions: LED and Yovisto. To overtake the actual limitation there is a need to propose a query model that is more flexible, expressive and that can open the door to finer assistance in the composition e.g. declaring that some characteristics of an input-resource are important. Today the query-unit remains at resource level. There is a need to propose alternative to this *monolithic* approach for more precise query expressiveness and corresponding assistance.

The system provokes discoveries: by nature all the tools listed in this review provoke discoveries at some point. In this ensemble, two systems go one step further by implementing dedicated strategies to expose unexpected knowledge. Aemoo proposes a curiosity functionality inverting its habitual view on data. The framework implemented by Discovery Hub can inject randomness in its processing to retrieve unusual results. We see an opportunity in personalized discovery approaches using profiles. It seems relevant to adapt the level of evidence/surprise of the results according to the users' prior state of knowledge.

6 Conclusion

In this paper we reviewed the systems designed for linked data exploration. The earliest approaches were inspired by the classic web browsing experience. Visual and faceted browsers over datasets having a limited size were also common. The LOD initiative and the appearance of DBpedia in particular offered new possibilities and challenges in terms of data processing and interactions for linked data based exploration and discovery. Innovative approaches were researched from recommenders to exploratory search systems. Last but not least the users are increasingly familiar with structured data in search through the major search engines. In our opinion the massive use of linked data based exploratory search functionalities and systems will constitute a decisive improvement for the future of web search experience and its outcomes.

References

1. C. Becker and C. Bizer. Dbpedia mobile: A location-enabled linked data browser. *LDOW*, 369, 2008.
2. T. Berners-Lee, Y. Chen, L. Chilton, D. Connolly, R. Dhanaraj, J. Hollenbach, A. Lerer, and D. Sheets. Tabulator: Exploring and analyzing linked data on the semantic web. In *Proceedings of the 3rd International Semantic Web User Interaction Workshop*, volume 2006, 2006.
3. C. Bizer, T. Heath, and T. Berners-Lee. Linked data-the story so far. *International journal on semantic web and information systems*, 5(3):1–22, 2009.
4. R. Blanco, B. B. Cambazoglu, P. Mika, and N. Torzec. Entity recommendations in web search. In *The Semantic Web–ISWC 2013*, pages 33–48. Springer, 2013.
5. S. Castano, A. Ferrara, and S. Montanelli. inwalk: Interactive and thematic walks inside the web of data. In *EDBT*, pages 628–631, 2014.
6. A.-S. Dadzie and M. Rowe. Approaches to visualising linked data: A survey. *Semantic Web*, 2(2):89–124, 2011.
7. A.-S. Dadzie, M. Rowe, and D. Petrelli. Hide the stack: toward usable linked data. In *The Semantic Web: Research and Applications*. Springer, 2011.
8. S. Goyal and R. Westenthaler. Rdf gravity (rdf graph visualization tool). *Salzburg Research, Austria*, 2004.
9. P. Heim, T. Ertl, and J. Ziegler. Facet graphs: Complex semantic querying made easy. In *The Semantic Web: Research and Applications*. Springer, 2010.
10. P. Heim, S. Hellmann, J. Lehmann, S. Lohmann, and T. Stegemann. Relfinder: Revealing relationships in rdf knowledge bases. In *Semantic Multimedia*. 2009.

11. M. Hildebrand, J. van Ossenbruggen, and L. Hardman. /facet: A browser for heterogeneous semantic web repositories. In *The Semantic Web-ISWC 2006*, pages 272–285. Springer, 2006.
12. D. F. Huynh and D. Karger. Parallax and companion: Set-based browsing for the data web. In *WWW Conference. ACM*. Citeseer, 2009.
13. E. Hyvönen, E. Mäkelä, M. Salminen, A. Valo, K. Viljanen, S. Saarela, M. Junnila, and S. Kettula. Museumfinlandfinnish museums on the semantic web. *Web Semantics: Science, Services and Agents on the World Wide Web*, 2005.
14. M. Kaminskas, I. Fernández-Tobías, I. Cantador, and F. Ricci. *Ontology-based identification of music for places*. Springer, 2013.
15. G. Kobilarov and I. Dickinson. Humboldt: Exploring linked data. 2008.
16. J. Koch, T. Franz, and S. Staab. Lena-browsing rdf data more complex than foaf. In *International Semantic Web Conference (Posters & Demos)*, 2008.
17. J. Koren, Y. Zhang, and X. Liu. Personalized interactive faceted search. In *Proceedings of the 17th international conference on World Wide Web*. ACM, 2008.
18. J. Lehmann, R. Isele, M. Jakob, A. Jentzsch, D. Kontokostas, P. N. Mendes, S. Hellmann, M. Morsey, P. van Kleef, S. Auer, et al. Dbpedia-a large-scale, multilingual knowledge base extracted from wikipedia. *Semantic Web Journal*, 2013.
19. G. Marchionini. Exploratory search: from finding to understanding. *Commun. ACM*, 49(4):41–46, Apr. 2006.
20. N. Marie, F. Gandon, M. Ribière, and F. Rodio. Discovery hub: on-the-fly linked data exploratory search. In *Proceedings of the 9th International Conference on Semantic Systems*. ACM, 2013.
21. D. S. E. Mirizzi, Roberto and T. Di Noia. Exploratory search and recommender systems in the semantic web.
22. A. Musetti, A. G. Nuzzolese, F. Draicchio, V. Presutti, E. Blomqvist, A. Gangemi, and P. Ciancarini. Aemoo: Exploratory search based on knowledge patterns over the semantic web. *Semantic Web Challenge*, 2012.
23. A. Passant. Dbrecmusic recommendations using dbpedia. In *The Semantic Web–ISWC 2010*, pages 209–224. Springer, 2010.
24. M. C. Pattuelli, M. Miller, L. Lange, S. Fitzell, and C. Li-Madeo. Crafting linked open data for cultural heritage: Mapping and curation tools for the linked jazz project. *Code4Lib Journal*, (21), 2013.
25. I. O. Popov, M. Schraefel, W. Hall, and N. Shadbolt. Connecting the dots: a multi-pivot approach to data exploration. In *The Semantic Web–ISWC 2011*, pages 553–568. Springer, 2011.
26. L. Rutledge, J. Van Ossenbruggen, and L. Hardman. Making rdf presentable: integrated global and local semantic web browsing. In *Proceedings of the 14th international conference on World Wide Web*, pages 199–206. ACM, 2005.
27. M. Stankovic, W. Breitfuss, and P. Laublet. Linked-data based suggestion of relevant topics. In *Proceedings of the 7th International Conference on Semantic Systems*, pages 49–55. ACM, 2011.
28. T. Tran and P. Mika. A survey of semantic search approaches.
29. J. Waitelonis and H. Sack. Towards exploratory video search using linked data. *Multimedia Tools and Applications*, 59(2):645–672, 2012.
30. R. W. White and R. A. Roth. Exploratory search: Beyond the query-response paradigm. *Synthesis Lectures on Information Concepts, Retrieval, and Services*, 1(1):1–98, 2009.
31. M. Wilson, A. Russell, D. A. Smith, et al. Mspace mobile: A ui gestalt to support on-the-go info-interaction. In *CHI'06 extended abstracts on Human factors in computing systems*, pages 247–250. ACM, 2006.