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Article

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LOD for Library Science: Benefits of Applying Linked Open Data in the Digital Library Setting

Retrospects and Research Topics

Atif Latif · Ansgar Scherp · Klaus Tochtermann

Abstract Linked Open Data (LOD) has gained widespread adoption by large industries as well as non-profit organizations and governmental organizations. One of the early adopters of LOD technologies are libraries. Since the “early years”, libraries have been key use case and innovation driver for LOD and significantly contributed to the adoption of semantic technologies. The first part of this paper presents selected success stories of current activities in the Linked Data Library community. In a nutshell, these studies include i) a conceptualization of the Linked Data Value chain, ii) a case study for consumption of Linked Data in a digital journal environment, and iii) an approach to publish metadata on the Semantic Web from an Open Access repository. These stories reveal a strong relationship between LOD in libraries and research topics addressed in traditional fields of computer science such as artificial intelligence, databases, and knowledge discovery. Thus, in the second part of this paper we systematically review the relation of LOD in digital libraries from a computer science perspective. We discuss current LOD research topics such as data integration and schema integration, distributed data management, and others. These challenges have been discussed with computer scientists at a German national database meetup as well as with librarians from ZBW - Leibniz Information Center for Economics and at international librarians meetup.

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1 Introduction

Digital Libraries are facing up to the challenge of providing access to the huge amounts of data which is hidden, inaccessible, and stored in the data silos since a long period of time. With key developments of web technologies in promoting easy access to heterogeneous data, it is getting more relevant for digital libraries to find optimal ways for the publishing of well gardened metadata which will subsequently permit library collections to be discovered, linked and accessed by related libraries in a sustainable manner. On the other hand, Linked Open Data [10] provides the best practices in publishing and sharing of information by use of semantic technologies and gives access to a large amount of heterogeneous data which presents exciting opportunities for the application development like: applications on seem-less data integration which in particular aggregate information from multiple data-sources to provide a coherent data view. Interestingly, Linked Data guidelines [1] can help digital libraries to get rid of data silos by publishing their dataset as structured data; and they can bring a lot of value to the libraries. However, for Linked Data to get recognition within library community, it is critical to highlight the Linked Data application value with the help of developed system case studies.

1 In the first part of this paper, we will retrospect
2 on systems and technologies we have developed and
3 applied to put up the strong case of Linked Data use
4 age in the library community. The scientific impact of
5 these systems and technologies has been published in
6 various research conferences and journals. The major
7 work covers the following three success stories which
8 are extensively explained in Section 2 of the paper:
9 (i) We developed a model to identify the implicit actors
10 which are involved in the Linked Data generation
11 process [18]. This work led us to better conceptualize
12 the dynamics within the Linked Data value generation
13 cycle and how it may impact Linked Data uptake at various
14 levels, e. g., organizational and commercial. (ii) In
15 order to understand Linked Data consumption we developed
16 the "Keyword to URI" technique to retrieve the user
17 queried keyword information from the Linked
18 Data cloud¹ by successfully hiding the complexities of
19 semantic querying [15]. (iii) After understanding the
20 basic mechanics of Linked Data and its links to digital
21 libraries, in our third story we describe how we
22 published our open access repository metadata as linked
23 data² and started developing systems helping us to connect
24 to other digital libraries [17].

25 Following the presentation of the three selected success
26 stories, the paper will discuss general research topics
27 where computer scientists, particularly in the traditional
28 fields of artificial intelligence, databases, and knowledge
29 discovery, can contribute to library sciences. We identify
30 six research topics that surprisingly are well known in the
31 above mentioned fields but where library sciences, in
32 particular in the context of Linked Open Data, brings
33 in a new shed of light and poses interesting research
34 challenges. The research topics are put into the context
35 of the three success stories. In addition, they have been
36 discussed in large groups of researchers and practitioners,
37 both within the computer science community as well as the
38 library science community.

39 The remainder of the paper is structured as follows:
40 In Section 2, we present the success stories and explain
41 how these studies are related to digital libraries and
42 what are their contributions. Section 3 describes in detail
43 the general research topics which arise when dealing with
44 LOD in digital libraries. We stress how these challenges
45 of LOD in digital libraries overlap with research

46 topics in traditional computer science fields, before we
47 conclude the paper.

2 Success Stories

48 In this section, we present the success stories of LOD in
49 digital libraries in detail. In general, these stories will
50 depict the varying needs of digital libraries with respect
51 to information supply and will summarize how maturation
52 of Linked Data technologies and systems have happened
53 to counter these needs. Moreover, with the help of
54 established system case studies, this section will also
55 categorically highlight the major benefits which digital
56 libraries can harness by applying the Linked Data
57 technologies.

2.1 Linked Data Value Chain

58 Since its inception, the Linked Data project has been
59 facilitating the transformation of publicly available Open
60 Data to Linked Data. Still by now the vast majority
61 of data is being generated by research communities
62 and commercial uptake of Linked Data is catching
63 up. From a corporate and business perspective it is
64 very important to conceptualize the Linked Data
65 generation cycle. We introduce the Linked Data Value
66 Chain as a lightweight model for business engineers
67 to support the conceptualization of successful business
68 cases [18]. Thereby, we identified three main concepts
69 as illustrated in Figure 1: Different Entities acting
70 in different roles (i. e., *Raw Data Provider*, *Linked Data
71 Provider*, *Linked Data Application Provider* and *End
72 Users*), both consuming and providing different Types
73 of Data (i. e., *Raw Data*, *Linked Data*, and *Human
74 Readable Data*).

75 We established that the assignment of roles to these
76 entities, the combination and involvement of roles, the
77 data selected as well as the data transformation process
78 may hold inherent risks. Moreover, we proposed two
79 main areas where pitfalls may arise and grouped them
80 into *Role-Related Pitfalls* and *Data-Related Pitfalls*.
81 In a nutshell, Role-Related Pitfalls are either related
82 to individual roles or to the interaction of different
83 roles, e. g., usage rights, privacy policies, data
84 availability, and role incentives. Whereas Data-Related
85 Pitfalls are either related to the data itself or the
86 data transformation process, e. g., data quality and
87 trust, data

88 ¹ <http://lod-cloud.net/>

89 ² <http://linkeddata.econstor.eu/beta/>

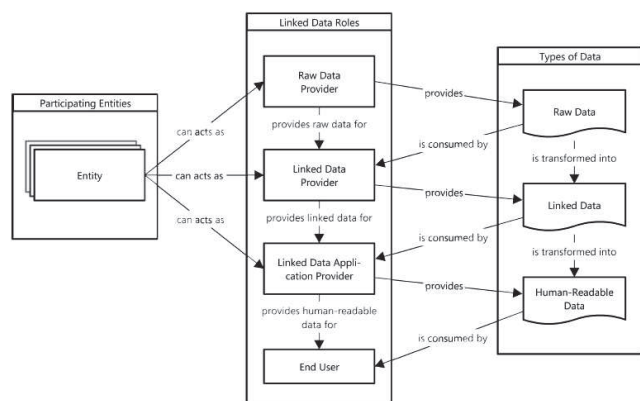


Fig. 1 Linked Data Value Chain (adopted from [18])

provenance, transparent data transformation and inter-linking.

For demonstration purpose, we applied the Linked Data Value Chain to an existing business case from the BBC³ (a pioneer adopting to Linked Data technologies) and highlighted the potential pitfalls along the way. Overall, the Linked Data Value Chain helped to identify and categorize potential pitfalls which have to be considered by business engineers and furthermore, has led us in establishing the ways to a clear understanding of the complete Linked Data generation cycle. This model is easily mappable to other disciplines, e. g., digital libraries, life sciences, and media. It will help in better planning for Linked Data publishing along with clear indication of potential research challenges which may arise during data conversion and data interlinking as covered in Section 3.

2.2 Author Profiles

This study was conducted to highlight the added value which can be drawn by consuming Linked Data for a real world application, i. e., a profiling systems in digital journal environment. In this study, we pointed out the challenges of author name recognition and disambiguation, which we faced during processing of person related information [15]. A profiling system tends to find information about persons on some individual particulars i.e. expertise, influence in social media, and the number of publications. For instance, a well connected digital journal can play a vital role in creating opportunities for collaborations between organizations,

³ <http://bbc.co.uk>

institutions, and persons. However, finding correct information about authors (author profiles) is crucial to increase the overall visibility, efficiency, and unprecedented success of a digital journal.

Building on the LOD initiative, we have developed a proof of concept application CAF-SIAL (Concept Aggregation Framework for Structuring Informational Aspects of Linked Open Data)⁴. It can discover and present informational aspects of persons from Linked Data. CAF-SIAL identifies a person’s relevant information from DBpedia⁵ by employing a set of heuristics, which is extracted by applying a “Keyword to URI” technique [16]. This extracted information is further filtered and integrated with the help of a Concept Aggregation Framework [19] which subsequently is presented as a profile.

To showcase the application utility in the library setting, it was further extended to establish the links between authors of the digital journal with relevant semantic resources from LOD, i. e., DBpedia and DBLP⁶. The underlying approach of this application was able to identify, disambiguate, retrieve and structure relevant information about an author from these data sets. As a final output, the system constructed a comprehensive aspect-oriented author’s profile and was helpful in giving insights of authors biography (personal and professional information) and lists his published works. This system was further implemented and integrated with the “Links into Future” feature of the Journal of Universal Computer Science (J.UCS)⁷. For instance, the profile of an author Gio Wiederhold who has published a paper in J.UCS can be viewed by following this link: <http://goo.gl/tJFtgI>.

From our point of view these kinds of systems can be easily re-produced in the broader scholarly communication domain, i. e., open access repositories and subject portals. Moreover, the corpus of search can be further extended to integrated authority files like the Integrated Authority File of the German National Library (GND)⁸ and Virtual International Authority File (VIAF)⁹ for more and complete results. In general, authority files comprise controlled keywords and descriptors, which are assigned to a publication during the cataloging process. It’s goal is to further simplifying

⁴ <http://cafsial.lod-mania.com>

⁵ <http://www.dbpedia.org/>

⁶ <http://dblp.13s.de/d2r/>

⁷ <http://www.jucs.org/>

⁸ <http://www.dnb.de/EN/gnd>

⁹ <https://viaf.org/>

the search and retrieval process. In contrast, a name authority file is an authority file for persons.

2.3 Linked Data Publishing - EconStor

In last few years, Open Access repositories have contributed heavily towards the success of Open Data and have become one of the most prominent types of library applications. These repositories are systems for collecting, publishing, disseminating, and archiving digital scientific content. With respect to Open Access publishing, repositories nowadays serve as platforms for acquiring and disseminating scientific content, which before had been almost exclusively released by commercial publishers. Citing the importance of Open Access repositories to today's digital libraries and to provide metadata of scientific working papers from the repository in a machine readable fashion, we published our Open Access repository EconStor¹⁰ as Linked Data [17]. EconStor is the Open Access server of ZBW - the German National Library of Economics and provides a platform for publishing working papers in economics. EconStor currently provides access to working papers from approximately 100 institutions as well as full text access to more than 80,000 full text papers.

In this study, we provided both conceptual and practical insight into the process of converting a legacy relational dataset to machine understandable semantic statements, a.k.a. 'triplication', and provided an overview of the D2RQ framework¹¹ that can be used for this purpose. Publishing of EconStor repository data as Linked Data is illustrated with with help of the system architecture as depicted in Figure 2. In a first step, repository data as a relational database was acquired. In a second step, major resources within the repository, i. e., communities, collections, and items (publications and authors) were mapped into a D2R Server mapping file by re-using popular vocabularies, i.e., Dublin Core (DC)¹², Friend of a Friend (FOAF)¹³, and Semantic Web Conference Ontology (SWC)¹⁴. In the last step, repository data was transformed by using the D2R

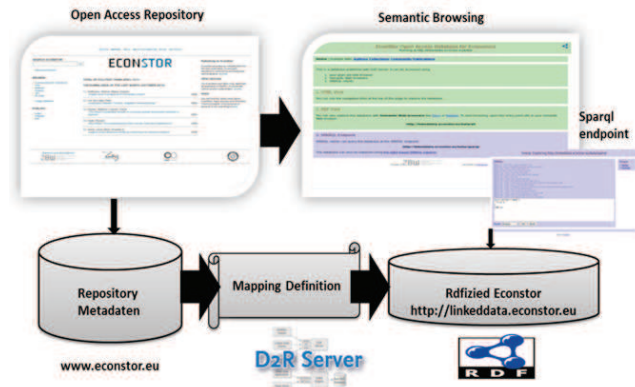


Fig. 2 System Architecture of EconStor Publishing as Linked Data (adopted from [17])

Server and made available as Linked Data along with a SPARQL endpoint for querying¹⁵.

One important outcome of this effort was that a repository's content can be straightforwardly published as Linked Open Data. Another result was the ability to link to valuable external datasets which enabled a repository's data to become more contextualized and 'meaningful'. Below, we discuss the envisioned goals which we have achieved after publishing the EconStor Open Access repository as Linked Data¹⁶:

- Published scientific working papers into the Semantic Web and thereby supported the publishing process and dissemination of current research results in Economics.
- Successfully opened up content from typical repository systems like DSpace for the Semantic Web and integrated it into the mainstream of Linked Data by data publishing.
- Created new possibilities for querying distributed research information over the EconStor dataset in form of SPARQL queries. For example, a query can be "Show me all articles on 'Financial Crisis', which have been published by European research institutes after 2012".
- The publishing of EconStor as Linked Data has created the potential for the development of mashup applications which can curate data from different relevant Linked Data stores.

From both practical and software engineering points of view, this study describes an approach towards pub-

¹⁰ <http://econstor.eu>

¹¹ <http://d2rq.org/>

¹² <http://purl.org/dc/terms/>

¹³ <http://xmlns.com/foaf/0.1/>

¹⁴ <http://data.semanticweb.org/ns/swc/ontology#>

¹⁵ <http://linkeddata.econstor.eu/beta/snorql/>

¹⁶ <http://linkeddata.econstor.eu/beta/>

lishing a repository's content as Linked Open Data. This can be of great interest to librarians, repository managers, and software developers who work for libraries.

3 Research Topics of LOD in Library Sciences

Motivated by the success stories of Linked Open Data in library sciences documented above, the authors set back and thought about what are the general research topics for computer science when dealing with LOD in digital libraries. Following the Linked Data value data chain described in Section 2.1, there emerged six research topics for LOD in library sciences. Interestingly, all these topics refer to challenges in traditional areas of computer science such as artificial intelligence, databases, and knowledge discovery.

In summary, the six research questions are: First, regarding the conversion of "raw" data such as semi-structured metadata of scientific publications (author names, titles, publishers provided as strings), we consider the research topic of *Entity Resolution*. This topic was addressed, e. g., by the success story of author profiles described in Section 2.2. Second, related with entity resolution is the topic of *Schema Matching*. Third, regarding the enhancement of content, we find the topic of *Automated Indexing*. Unlike indexing in the database community, the topic of automated indexing in this context refers to the machine learning task of multi-label classification such as assigning a set of descriptors obtained from a thesaurus to a scientific publication. Fourth, while predominantly the task of automated indexing in library sciences is applied to text content, e. g., PDF documents, it is increasingly also important to automatically *Indexing Non-textual Content* such as social media and audio-visual material. Fifth, referring to the phase of consumption in the Linked Data value data chain outlined in Section 2.1, we find the challenges of *Distributed Data Management* that targets to retrieve and aggregate different information such as bibliographic records from various data sources. Finally, when merging data from different sources, such as query results but also results from automated indexing services, it is essential to track the provenance of the data to show the users where certain information comes from and to demonstrate its trustworthiness.

This list of research topics was discussed with the computer science community in form of an invited talk

at a meet-up of the German database community¹⁷. In addition, the topics were also discussed in a 90 minutes session with about 50 domain experts in the broader context of library sciences during an interactive presentation at ZBW in August 2014. Finally, the topics were also presented and discussed in a talk at the 104th German National library meetup on May 26th, 2015.¹⁸ Below, we briefly describe and discuss the nature of the different research topics along the structure outlined above. In particular, we highlight the role of Linked Open Data that brings in a new shed of light and poses interesting research questions to computer science.

3.1 Entity Resolution

Entity resolution refers to the problem of identifying whether two resources of Linked Open Data refer to the same real world entity. This is a challenging task, as the resources do not have any identity of their own but the semantics is only defined by considering the properties that are used to describe and connect the resources [7]. One approach to deal with the problem is manual alignment as it is conducted in the Linked Open Data project of the German National Library¹⁹. The Integrated Authority File of the German National Library contains among others information about the authors that published in Germany and is connected with DBpedia and others. Here, the challenge is to discriminate famous authors like the former German chancellor Helmut Kohl (available through: <http://d-nb.info/gnd/118564595>) from his namesake who also publishes.

However, manual alignment is very expensive and not possible when merging large datasets. For example, in the context of library sciences there are data sources providing information about persons of sizes ranging from 364,000 in DBpedia, 1,797,911 in the German National Library Authority File, 3,800,000 in the Library of Congress, and 10 million in the Virtual International Authority File²⁰ (VIAF) [23]. VIAF combines multiple name authority files of different national libraries. However, a particular problem here is that en-

¹⁷ "Databases meets LOD", Frühjahrstreffen der GI Fachgruppe Datenbanken, March 20-21, 2014, Brunswick, Germany. URL: <http://www.ifis.cs.tu-bs.de/node/2911>

¹⁸ 104. Bibliothekartag, May 26-29, 2015, Nuremberg, Germany, URL: <http://www.bibliothekartag2015.de/>

¹⁹ <http://www.d-nb.de/>

²⁰ <https://viaf.org/>

tity resolution over name, co-authors, title, and venue is often not sufficient [11].

3.2 Schema Matching

Ontology matching [3] or more general schema matching [26] is similar to the challenge of entity resolution and refers to the question of data integration. The goal of Linked Open Data is to define and publish vocabularies that become self-descriptive by referring to definitions of concepts and properties of other existing vocabularies. However, the integration of different vocabularies and thus the data they describe is far from trivial, even for databases with similar schemata [26]. For example, the property `foaf:name` of the famous Friend-of-a-Friend (FOAF) vocabulary²¹ is quite similar to `vcard:family-name` of the vCard ontology²². However, the `foaf:name` property is more general and can take more than just the surname as in the case of the `vcard:family-name` property.

While schema integration is desired to improve library services, at the same time the library science community demands a very high quality in schema matching. As a consequence, different works on schema matching in library science have been carried out in the past by manually aligning thesauri. For example, ZBW's thesaurus for economics STW²³ is aligned with other thesauri such as TheSoz²⁴ in social sciences where a couple of thousand manually created mappings were build in 2004 to 2005. For describing the mappings, the relations between keywords are typically represented using the Simple Knowledge Organisation System²⁵ (SKOS) vocabulary. For example, related keywords are expressed using `skos:related`.

Due to the size of the thesauri of usually a couple of thousand or even ten-thousand descriptors plus corresponding synonyms, automated approaches for schema matching are needed. Thus, since 2012 there is a Library Track on ontology matching in the Ontology Alignment Evaluation Initiative²⁶ (OAEI). The OAEI aims to compare different schema matching techniques and

to establish a consensus regarding the evaluation of methods for ontology matching.

3.3 Distributed Data Management

Particular characteristics of Linked Open Data is its highly distributed fashion of publishing and interlinking data on the web. The VIAF is a good example where a couple dozen international organisations collaborate in building a distributed network of library resources, not only traditional records (i. e., publications) but also persons and organisations. A central data storage and search over this data is neither a desired nor a feasible solution. To access the data published in such a highly distributed fashion, technologies for federated querying are needed and index-structures that store information about which data is provided by which source.

In the past, the Semantic Web community has developed various different techniques for distributed querying of Linked Open Data [4,9,8] as well as stream-processing of Linked Open Data for providing a lookup service what data is provided by which source [14,5]. However, so far it is not clear which approach is the most appropriate for accessing the distributed data, e. g., a distributed set of (SPARQL-based) endpoints [4] vs. traversal-based querying of Linked Open Data [9].

In addition, one needs to think about ranking of results in order to accommodate the user expectations when using library search services. Like in web search, users of library search services consider the first hits implicitly more important and relevant than others. To address this challenge, the DFG project LibRank²⁷ at ZBW investigates the integration of journal rankings in the computation of the search result order.

3.4 Automated Indexing

In contrast to the notion of indexing in the database community, indexing in library sciences refers to the task of selecting multiple labels for the classification of documents such as scientific publications. One approach for indexing is the manual labeling of scientific publications that has been conducted by library scientists of ZBW for more than 1.6 million economic documents in the past using the STW. On average, each

²¹ <http://xmlns.com/foaf/spec/>

²² <http://www.w3.org/TR/vcard-rdf/>

²³ <http://zbw.eu/stw/versions/latest/about>

²⁴ <http://lod.gesis.org/pubby/page/thesoz/>

²⁵ <http://www.w3.org/2004/02/skos/>

²⁶ <http://oaei.ontologymatching.org/>

²⁷ <http://www.librank.info/>

1 of the 1.6 million scientific publications has been an-
2 notated with five STW descriptors. Another example
3 is the publication server EconStor (see Section 2.3),
4 which performs auto-completions on author keywords
5 regarding STW and other thesauri. Here, the author
6 confirms a keyword by selecting a suggested STW term,
7 i. e., the keyword is matched with the semantic concept.
8 A particular challenge here is the quality of the pro-
9 vided annotations, which is, unlike the annotations by
10 library scientists, of lower quality and does not neces-
11 sarily refer to a semantic concept from the STW.
12

13 In addition, the tremendously increasing amount
14 of electronically delivered publications per year (com-
15 pared to print publications which remains stable) at
16 the German National Library shows that automated
17 approaches for indexing literature are needed [21]. In
18 the past, automated approaches for the classification of
19 PDFs have been developed. For example, the PETRUS
20 project at the German National Library uses Support
21 Vector Machines to classify documents along 100 classes
22 (so called “Sachgruppen”). However, the automated in-
23 dexing of scientific literature has already been investi-
24 gated by libraries since a long time ago. For example,
25 the DFG-funded project GERHARD in the nineties in-
26 vestigated methods for automatically indexing scientific
27 Web content.
28

29 About 1 million documents were crawled and auto-
30 matically indexed using about 10.000 hierarchically
31 organized concepts from the Universal Decimal Clas-
32 sification (UDC) [22] system. The indexing was per-
33 formed using the UDC in three language (German, En-
34 glish, French). The infrastructure was a single server
35 machine using the Oracle relational database manage-
36 ment system with full-text indices ConText (today: Or-
37 acle Text). At the time being, the GERHARD project
38 of course neither use Semantic Web technologies nor re-
39 fer to data published on the web for the annotations.
40 Despite these early developments, the automated index-
41 ing of scientific literature remains a very active research
42 field until today.
43

44 A promising work towards the automated index-
45 ing of scientific documents using Linked Open Data is
46 developed in a recent ZBW project for multi-labeling
47 scientific documents using the STW. It uses the kNN
48 classifier in combination with entity detection and the
49 HITS algorithm [13] for assessing the importance of
50 STW concepts for a specific document [6]. Experiments
51 over a large corpus of about 62,000 open access docu-
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ments from ZBW’s EconBiz²⁸ literature search portal
showed an average recall of .40 (SD:.32) and an average
precision of .40 (SD:.32), resulting in a F-measure of .39
(SD:.31). By this, the technique outperforms today’s
approaches for multi-labeling such as Maui [20] using
decision trees (average F-measure of .36 on the same
dataset [24]). The solution developed at ZBW is to the
best of our knowledge the by far largest experiment for
automated indexing carried out. In addition, it has the
advantage that it does not require expensive training
phases that are required with approaches like Support
Vector Machines where samples need to be manually
selected in order to train the machine classifier [24].

Please note, although the term “automated index-
ing” denotes that there is no human in the loop, the
above mentioned technique is not designed to be run
without human intervention. In fact, the expertise of
library scientists is needed to constantly monitor the
quality of the automatically suggested descriptors and
adapt the thesauri like the STW to reflect new trends
and topics. Thus, a particular challenge besides the
multi-labeling task itself is the integration and use of
the machine learning results in the context of a real-
world application and the organizational integration.

3.5 Indexing Non-textual Content

Besides textual content such as scientific publications
provided as PDF and websites relevant for being in-
dexed by libraries, there is also a large amount of non-
textual content such as social media and audio-visual
material. Specific challenges here are the mapping of
traditional scientific content with social media but also
with research data, which is addressed by ZBW in the
EU project EEXCESS²⁹. The idea is to automatically
combine structured scientific content (metadata, full-
texts, paragraphs, citations, and others) with informal
and hasty content from social media channels in or-
der to link topics, objects (the textual and non-textual
resources), and the users. Challenges are entity resolu-
tion and indexing over multiple modalities, but also the
cross-media retrieval of content.

In order to address the challenge of multimodal re-
trieval, we developed a novel pipeline for better under-
standing information graphics that are typically con-
tained in scientific publications. The pipeline allows

²⁸ <http://www.econbiz.de/>

²⁹ <http://eexcess.eu/>

for the automated extraction of multi-oriented text elements from information graphics by a novel combination of different methods from data mining and computer vision [2]. This allows for textual search over the information graphics and combining it with the textual content of the scientific publications.

3.6 Data Provenance

The Virtual International Authority File (VIAF) mentioned above aims to facilitate an inter-organizational and cross-border and thus cross-lingual linkage of bibliographic records. The goal is to lower costs and increase utility of library authority files by matching and linking widely-used authority files and making these links available on the Web. However, in such a multi-national setting particular challenges arise:

- How to track data/metadata (re)use?
- How to refer to original data/metadata when library A uses a (part of) record from library B?
- How to assess the trustworthiness of data/metadata incorporated into one's systems?

In order to (partially) address these challenges of provenance, the library sciences community developed in the past sophisticated models for describing library resources. The Functional Requirements for Bibliographic Records (FRBR)³⁰ is a quite powerful model to describe different variants of the same library resource, e. g., different prints and translations of the same book into different languages. Thus, it is not only applicable to books but to any kinds of resources. The concepts of FRBR are incorporated in the new cataloging code Resource Description and Access (RDA)³¹ to describe any kind of content, including online media. RDA also allows to attach provenance information to the different concepts. The data model of Europeana³² foresees the attachment of provenance to the metadata, i. e., who created the metadata record, as well as the provenance of the resource itself, e. g., Leonardo da Vinci as painter of Mona Lisa. A standard for describing the provenance of data on the web is the W3C PROV ontology³³.

However, what is still missing is an approach to reliably verify the provenance of metadata published as

³⁰ <http://www.ifla.org/publications/functional-requirements-for-bibliographic-records>

³¹ <http://www.rda-jsc.org/rda.html>

³² <http://www.europeana.eu/portal/>

³³ <http://www.w3.org/TR/prov-o/>

Linked Open Data on the web. One very promising first approach to track reuse of metadata is the framework for digitally signing graph data developed by Kasten et al. [12]. It allows to sign arbitrary graph data such as Linked Open Data by attaching a digital signature to it and publishing the data together with the signature on the web. This allows to track the provenance of metadata and build a “network of trust”.

In addition, provenance-aware applications are missing that make use of such information. Applications like the semantic search engine Sig.ma [25] were capable of providing support for entity search over Linked Open Data and filtering results based on the provenance. Unfortunately, the project was discontinued. Search engines such as Sig.ma may, prove very valuable in the international setting of searching for relevant (scientific) literature and information (including social media channels) from diverse and distributed sources on the web based on provenance information.

4 Conclusion

Linked Library Data can be seen as innovation driver and libraries as early adopters of Semantic Web technologies. In this paper, we have presented selected success stories of LOD in library sciences. At the same time, we reflected on different topics and challenges that are relevant for computer scientists and that can be well motivated from library sciences.

At ZBW - Leibniz Information Center for Economics, we are addressing these challenges of LOD in library sciences not only from a technological perspective as described by the success stories in Section 2 and the challenges in Section 3, but in an interdisciplinary setting [24]. For example, in the project on automated indexing [6,2] an interdisciplinary team of domain experts collaborates with computer scientists where new research ideas are discussed and reflected from a practitioners' perspective in order to achieve both high-quality research outcomes as well as improved services for ZBW's customers.

Please note, we focused in this article on discussing technological success stories and research topics of LOD in libraries. Out of scope here (but equally important) are data quality management (e. g., for automated indexing), legal aspects of text and data mining, as well as educating data scientists and the job market for LOD in libraries.

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