

An Extensible Framework to Validate and Build Dataset Profiles

Ahmad Assaf^{1,2}, Aline Senart² and Raphaël Troncy¹

¹ EURECOM, Sophia Antipolis, France. <firstName.lastName@eurecom.fr>

² SAP Labs France. <firstName.lastName@sap.com>

Abstract. Linked Open Data (LOD) has emerged as one of the largest collections of interlinked datasets on the web. In order to benefit from this mine of data, one needs to access to descriptive information about each dataset (or metadata). Such metadata information is currently very limited to a few data portals where they are usually provided manually, thus being often incomplete and inconsistent in terms of quality. To address this issue, we propose a scalable automatic approach for extracting, validating, correcting and generating descriptive linked dataset profiles. This approach applies several techniques in order to check the validity of the metadata provided and to generate descriptive and statistical information for a particular dataset or for an entire data portal. We target CKAN powered data portals and validate our framework on the Linked Open Data (LOD) cloud. The results demonstrate that the general state of LOD cloud needs more attention as most of the datasets suffer from bad quality metadata lacking some informative metrics needed to facilitate dataset search. The noisiest metadata values were access information such as licensing information, resource descriptions as well as resource reachability problems.

Keywords: Linked Data, Dataset Profile, Metadata, Data Quality

1 Introduction

From 12 datasets cataloged in 2007, the Linked Open Data cloud has grown to nearly 1000 datasets containing more than 82 billion triples³ [5]. Data is being published by both the public and private sectors and covers a diverse set of domains from life sciences to media or government data. The Linked Open Data cloud is potentially a gold mine for organizations and individuals who are trying to leverage external data sources in order to produce more informed business decisions [11]. This success lies in the cooperation between data publishers and consumers. Consumers are empowered to find, share and combine information in their applications easily. However, the heterogeneous nature of data sources reflects directly on the data quality as these sources often contain inconsistent as well as misinterpreted and incomplete metadata information. Considering the significant variation in size, the languages used and the freshness of the data,

³ <http://datahub.io/dataset?tags=lod>

one realizes that finding useful datasets without prior knowledge is increasingly complicated. This can be clearly noticed in the LOD Cloud where few datasets such as DBPedia [6], Freebase [10] and YAGO [37] are favored over less popular datasets that may include domain specific knowledge more suitable for the tasks at hand. For example, for the task of building context-aware recommender systems in an academic digital library over LOD cloud, popular datasets like Semantic Web Dog Food⁴, DBLP⁵ or Yovisto⁶ can be favored over lesser known but more specific datasets like VIAF⁷ which links authority files of 20 national libraries, list of subject headings for public libraries in Spain⁸ or the French dissertation search engine⁹.

The main entry point for discovering and identifying datasets is either through public data portals such as DataHub¹⁰ and Europe's Public Data¹¹ or private search engines such as Quandl¹² and Engima¹³. Private portals harness manually curated data from various sources and expose them to users either freely or through paid plans. The data available is of higher quality but lesser quantity compared to what is available in public portals. Similarly, in some public data portals, administrators manually review datasets information, validate, correct and attach suitable metadata information. This information is mainly in the form of predefined tags such as *media*, *geography*, *life sciences* for organization and clustering purposes. However, the diversity of those datasets makes it harder to classify them in a fixed number of predefined tags that can be subjectively assigned without capturing the essence and breadth of the dataset [30]. Furthermore, the increasing number of datasets available makes the metadata review and curation process unsustainable even when outsourced to communities.

Data profiling is the process of creating descriptive information and collect statistics about that data. It is a cardinal activity when facing an unfamiliar dataset [1]. It helps in assessing the importance of the dataset, in improving users' ability to search and reuse part of the dataset and in detecting irregularities to improve its quality. Data profiling includes typically several tasks:

- **Metadata profiling:** Provides general information on the dataset (dataset description, release and update dates), legal information (license information, openness), practical information (access points, data dumps), etc.
- **Statistical profiling:** Provides statistical information about data types and patterns in the dataset, i.e., properties distribution, number of entities and RDF triples, etc.

⁴ <http://datahub.io/dataset/semantic-web-dog-food>

⁵ <http://datahub.io/dataset/dblp>

⁶ <http://datahub.io/dataset/yovisto>

⁷ <http://datahub.io/dataset/viaf>

⁸ <http://datahub.io/dataset/lista-encabezamientos-materia>

⁹ <http://datahub.io/dataset/thesesfr>

¹⁰ <http://datahub.io>

¹¹ <http://publicdata.eu>

¹² <https://quandl.com/>

¹³ <http://enigma.io/>

- **Topical profiling:** Provides descriptive knowledge on the dataset content and structure. This can be in form of tags and categories used to facilitate search and reuse.

In this work, we address the challenges of automatic validation and generation of descriptive datasets profiles. This paper proposes an extensible framework consisting of a processing pipeline that combines techniques for data portals identification, datasets crawling and a set of pluggable modules combining several profiling tasks. The framework validates the provided dataset metadata against an aggregated standard set of information. Metadata fields are automatically corrected when possible, e.g., adding a missing license URL reference. Moreover, a report describing all the issues highlighting those that cannot be automatically fixed is created to be sent by email to the dataset’s maintainer. There exist various statistical and topical profiling tools for both relational and Linked Data. The architecture of the framework allows to easily add them as additional profiling tasks. However, in this paper, we focus on the task of dataset metadata profiling and present our findings by running our framework on the LOD cloud. The results demonstrate that the general state of LOD cloud needs more attention as most of the datasets suffer from bad quality metadata lacking some informative metrics needed to facilitate dataset search. The noisiest metadata are the access information such as licensing information, resource descriptions as well as resource availability problems.

The remainder of the paper is structured as follows. In Section 3, we review relevant related work. In Section 4, we describe our proposed framework’s architecture and components that validate and generate dataset profiles. In Section 5, we present the results when running this tool on the LOD cloud and we summarize the main issues found. Finally, we conclude and outline some future work in Section 6.

2 Motivation

Metadata contain the information needed to effectively understand and use datasets. This information includes the dataset license, provenance, context, structure and accessibility.

3 Related Work

There exists a considerable amount of tools that tackle specific profiling tasks. For example, [2][34] focus on generating statistical dataset information where in [30][20] authors use various techniques to attach additional topical information. However, to the best of our knowledge, this is the first effort towards extensible automatic validation and generation of descriptive dataset profiles. For this paper, we will focus on Linked Data metadata profiling tasks. However, one of the advantages of this framework is the ability to easily configure additional profiling tasks e.g., statistical or topical and accommodate different data types e.g., relational.

Data Catalog Vocabulary (DCAT) [19] and the Vocabulary of Interlinked Datasets (VoID) [15] are concerned with metadata about RDF datasets. There exist several tools aiming at exposing dataset metadata using these vocabularies. In [8] authors generate VoID descriptions limited to a subset of properties that can be automatically deduced from resources within the dataset. However, it still provides data consumers with interesting insights. Quality Assessment of Data Sources (Flemming’s Data Quality Assessment Tool)¹⁴ provides basic metadata assessment as it calculates data quality scores based on manual user input. The user assigns weights to the predefined quality metrics and answer a series of questions regarding the dataset. These include, for example, the use of obsolete classes and properties by defining the number of described entities that are assigned disjoint classes, the usage of stable URIs and whether the publisher provides a mailing list for the dataset. The ODI certificate¹⁵ on the other hand provides a description of the published data quality in plain English. It aspires to act as a mark of approval that helps publishers understand how to publish good open data and users how to use it. It gives publishers the ability to provide assurance and support on their data while encouraging further improvements through an ascending scale. ODI comes as an online and free questionnaire for data publishers focusing on certain characteristics about their data. Although these approaches try to perform metadata profiling, they are either incomplete or manual. In our framework, we propose a more automatized and complete approach.

Metadata profiling: The Project Open Data Dashboard¹⁶ tracks and measures how US government websites implement the Open Data principles to understand the progress and current status of their public data listings. A validator analyzes machine readable files e.g., JSON files for automated metrics like the resolved URLs, HTTP status and content-type. However, deep schema information about the metadata is missing like description, license information or tags. Similarly on the LOD cloud, the Data Hub LOD Validator¹⁷ gives an overview of Linked Data sources cataloged on the Data Hub. It offers a step-by-step validator guidance to check a dataset completeness level for inclusion in the LOD cloud. The results are divided into four different compliance levels from basic to reviewed and included in the LOD cloud. Although it is an excellent tool to monitor LOD compliance, it still lacks the ability to give detailed insights about the completeness of the metadata and overview on the state of the whole LOD cloud group and is very specific to the LOD cloud group rules and regulations.

Although the above mentioned tools are able to provide various types of information about a dataset, there exists no approach that is extensible to combine further information coming from various profiling tools.

Statistical profiling: Calculating statistical information on datasets is vital to applications dealing with query optimization and answering, data cleansing,

¹⁴ <http://linkeddata.informatik.hu-berlin.de/LDSrcAss/datenquelle.php>

¹⁵ <https://certificates.theodi.org/>

¹⁶ <http://labs.data.gov/dashboard/>

¹⁷ <http://validator.lod-cloud.net/>

schema induction and data mining [26] [23] [30]. Semantic sitemaps [14] and RDFStats [31] were one of the first to deal with RDF data statistics and summaries. ExpLOD [28] creates statistics on the interlinking between datasets based on `owl:sameAs` links. In [1] the author introduces a tool that induces the actual schema of the data and gather corresponding statistics accordingly. LODStats [4] is a stream-based approach that calculates more general dataset statistics. ProLOD++ [2] is a Web-based tool that allows LOD analysis via automatically computed hierarchical clustering [9]. Aether [34] generates VoID statistical descriptions of RDF datasets. It also provides a Web interface to view and compare VoID descriptions. LODOP [21] is a MapReduce framework to compute, optimize and benchmark dataset profiles. The main target for this framework is to optimize the runtime costs for Linked Data profiling. In [27] authors calculate certain statistical information for the purpose of observing the dynamic changes in datasets.

Topical Profiling: Topical and categorical information facilitates dataset search and reuse. Topical profiling focuses on content-wise analysis at the instances and ontological levels. GERBIL [39] is a general entity annotation framework that provides machine processable output allowing efficient querying. In addition, there exist several entity annotation tools and frameworks [13] but none of those systems are designed specifically for dataset annotation. In [22], authors created a semantic portal to manually annotate and publish metadata about both LOD and non-RDF datasets. In [30], authors automatically assigned Freebase domains to extracted instance labels of some of the LOD Cloud datasets. The goal was to provide automatic domain identification, thus enabling improving datasets clustering and categorization. In [7], authors extracted dataset topics by exploiting the graph structure and ontological information, thus removing the dependency on textual labels. In [20] authors generate VoID and VoL descriptions via a processing pipeline that extracts dataset topic models ranked on graphical models of selected DBpedia categories.

Dataset Search: Dataset search can be done without relying on attached metadata (tags and categories). For example, there exist several approaches to create LOD indexes. In [3], authors used VoID descriptions to optimize query processing by determining relevant query-able datasets. In [25], authors created an approximate index structure (QTree) and an algorithm for answering conjunctive queries over Linked Data. SchemEX [29] is a stream-based approach leveraging type and property information of RDF instances to create schema-level indexes.

Semantic search engines like Sindice [17], Swoogle [18] and Watson [16] help in entities lookup but are not designed specifically for dataset search. In [35], authors utilized the sig.ma index [38] to identify appropriate data sources for interlinking. Dataset search and discovery is currently done via data portals that rely on attached metadata to provide dataset search features as they run a Solr index on the metadata schemas. Having missing or inconsistent information will affect the search results quality.

4 Profiling Data Portals

In this section, we provide an overview of the processing steps for validating and generating dataset profiles. Figure 1 shows the main steps which are the following: (i) data portal identification; (ii) metadata extraction; (iii) instance and resource extraction; (iv) profile validation (v) profile and report generation.

Our framework is built as a Command Line Interface (CLI) application using Node.js. Instructions on installing and running the framework are available on its public Github repository¹⁸. Related functions are encapsulated into modules that can be easily plugged in/out the processing pipeline. The various steps are explained in detail below.

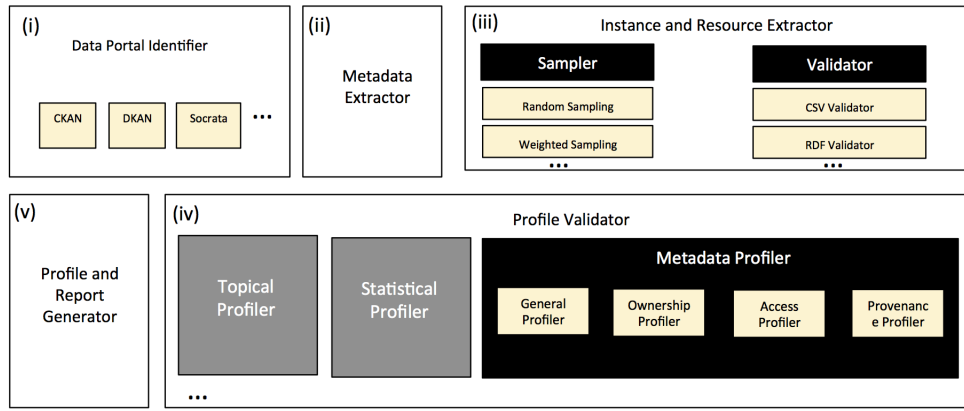


Fig. 1: Processing pipeline for validating and generating dataset profiles

4.1 Data Portal Identification

Data portals can be considered as data access points providing tools to facilitate data publishing, sharing, searching and visualization. CKAN¹⁹ is the world's leading open-source data portal platform powering websites like the DataHub, Europe's Public Data and the U.S Government's open data. Modeled on CKAN, DKAN²⁰ is a standalone Drupal distribution that is used in various public data portals as well. Socrata²¹ helps public sector organizations improve data-driven decision making by providing a set of solutions including an open data portal. In

¹⁸ <https://github.com/ahmadassaf/opendata-checker>

¹⁹ <http://ckan.org>

²⁰ <http://drupal.org/project/dkan>

²¹ <http://www.socrata.com>

addition to these tradition data portals, there is a set of tools that allow exposing data directly as RESTful APIs like Datatank²² and Database-to-API²³.

Identifying the software powering data portals is a vital first step to understand the API calls structure. Web scraping is a technique for extracting data from Web pages. We rely on several scraping techniques in the identification process which includes a combination of the following:

- **URL inspection:** Check the existence of certain URL patterns. Various CKAN based portals are hosted on subdomains of the <http://ckan.net>. For example, CKAN Brazil (<http://br.ckan.net>).
- **Meta tags inspection:** The `<meta>` tag provides metadata about the HTML document. They are used to specify page description, keywords, author, etc. Inspecting the `content` attribute can indicate the type of the data portal. We use CSS selectors to check the existence of these meta tags. An example of a query selector is `meta[content*="ckan"]` (all meta tags with the attribute content containing the string *CKAN*). This selector can identify CKAN portals whereas the `meta[content*="Drupal"]` can identify DKAN portals.
- **Document Object Model (DOM) inspection:** Similar to the meta tags inspection, we check the existence of certain DOM elements or properties. For example, CKAN powered portals will have DOM elements with class names like `ckan-icon` or `ckan-footer-logo`. A CSS selector like `.ckan-icon` will be able to check if a DOM element with the class name `ckan-icon` exists. The list of elements and properties to inspect is stored in a separate configurable object for each portal. This allows the addition and removal of elements as deemed necessary.

The identification process for each portal can be easily customized by overriding the default function. Moreover, adding or removing steps from the identification process can be easily configured.

After those preliminary checks, we query one of the portal's API endpoints. For example, DataHub is identified as CKAN, so we will query the API endpoint on http://datahub.io/api/action/package_list. A successful request will list the names of the site's datasets, whereas a failing request will signal a possible failure of the identification process.

4.2 Metadata Extraction

Data portals expose a set of information about each dataset as metadata. The model used varies across portals. However, a standard model should contain information about the dataset's title, description, maintainer email, update and creation date, etc. We divided the metadata information into the following:

General information: General information about the dataset. e.g., title, description, ID, etc. This general information is manually filled by the dataset

²² <http://thedataatank.com>

²³ <https://github.com/project-open-data/db-to-api>

owner. In addition to that, tags and group information is required for classification and enhancing dataset discoverability. This information can be entered manually or inferred modules plugged into the topical profiler.

Access information: Information about accessing and using the dataset. This includes the dataset URL, license information i.e., license title and URL and information about the dataset’s resources. Each resource has as well a set of attached metadata e.g., resource name, URL, format, size, etc.

Ownership information: Information about the ownership of the dataset. e.g., organization details, maintainer details, author, etc. The existence of this information is important to identify the authority on which the generated report and the newly corrected profile will be sent to.

Provenance information: Temporal and historical information on the dataset and its resources. For example, creation and update dates, version information, version, etc. Most of this information can be automatically filled and tracked.

Building a standard metadata model is not the scope of this paper, and since we focus on CKAN-based portals, we validate the extracted metadata against the CKAN standard model²⁴.

After identifying the underlying portal software, we perform iterative queries to the API in order to fetch datasets metadata and persist them in a file-based cache system. Depending on the portal software we can issue specific extraction jobs. For example, in CKAN based portals, we are able to crawl and extract the metadata of a specific dataset, all the datasets in a specific group e.g., LOD Cloud or all the datasets in the portal.

4.3 Instance and Resource Extraction

From the extracted metadata we are able to identify all the resources associated with that dataset. They can have various types like a SPARQL endpoint, API, file, visualization, etc. However, before extracting the resource instance(s) we perform the following steps:

- **Resource metadata validation and enrichment:** Check the resource attached metadata values. Similar to the dataset metadata, each resource should include information about its mimetype, name, description, format, valid de-referenceable URL, size, type and provenance. The validation process issue an HTTP request to the resource and automatically fills up various missing information when possible, like the mimetype and size by extracting them from the HTTP response header. However, missing fields like name and description that needs manual input are marked as missing and will appear in the generated summary report.
- **Format validation:** Validate specific resource formats against a linter or a validator. For example, node-csv²⁵ for CSV files and n3²⁶ to validate N3 and Turtle RDF serializations.

²⁴ http://demo.ckan.org/api/3/action/package_show?id=adur_district_spending

²⁵ <https://github.com/wdavidw/node-csv>

²⁶ <https://github.com/RubenVerborgh/N3.js>

Considering that certain datasets contain large amounts of resources and the limited computation power of some machines on which the framework might run on, a sampler module is introduced to execute various sample-based strategies detailed in [20] where they were found to generate accurate results even with comparably small sample size of 10%.

4.4 Profile Validation

A dataset profile should include descriptive information about the data examined. In our framework, we have identified three main categories of profiling information. However, the extensibility of our framework allows for additional profiling techniques to be plugged in easily i.e., a quality profiling module reflecting the dataset quality. In this paper, we focus on the task of metadata profiling.

Metadata validation process identifies missing information and the ability to automatically correct them. Each set of metadata (general, access, ownership and provenance) is validated and corrected automatically when possible. Each profiler task has a set of metadata fields to check against. The validation process check if each field is defined and if the value assigned is valid.

There exist a bunch of special validation steps for various fields. For example, for ownership information where the maintainer email has to be defined, the validator checks if the email field is an actual valid email address. A similar process is done to URLs whenever found. However, we also issue an HTTP HEAD request in order to check if that URL is reachable or not. For the dataset resources, we use the `content-header` information when the request is successful in order to extract, compare and correct further metadata values like `mimetype` and `content size`.

Despite the legal issues surrounding Linked Data licenses [36], it is still considered a gold mine for organizations who are trying to leverage external data sources in order to produce more informed business decisions [11]. In [32] the authors see the potential economic effect unfolding in education, transportation, consumer products, electricity, oil and gas, health care and consumer finance. They estimate the potential annual value enabled by Open Data in these domains to be 3 trillion US Dollars across seven domains. As a result, validating license related information is vital. However, from our experiments, we found out that datasets' license information is noisy. The license names if found are not standardized. For example, Creative Commons CCZero can be also CC0 or CCZero. Moreover, the license URI if found and if de-referenceable can point to different reference knowledge bases e.g., <http://opendefinition.org>. To overcome this issue, we have manually created a mapping file standardizing the set of possible license names and the reference knowledge base²⁷. In addition, we have also used the open source and knowledge license information²⁸ to normalize the license information and add extra metadata like the domain, maintainer and open data conformance.

²⁷ <https://github.com/ahmadassaf/opendata-checker/blob/master/util/licenseMappings.json>

²⁸ <https://github.com/okfn/licenses>

```

{
  "license_id" : ["ODC-PDDL-1.0"],
  "disambiguations" : ["Open Data Commons Public Domain Dedication and License (PDDL)"]
},
{
  "license_id" : ["CC-BY-SA-4.0", "CC-BY-SA-3.0"],
  "disambiguations" : ["cc-by-sa", "CC BY-SA", "Creative Commons Attribution Share-Alike"]
}

```

Listing 1.1: License mapping file sample

4.5 Profile and Report Generation

The validation process highlights the missing information and presents them in a human readable report. The report can be automatically sent to the dataset maintainer email if exists in the metadata.

In addition to the generated report, the enhanced profiles are represented in JSON using the CKAN data model and are publicly available²⁹.

Data portal administrators need an overall knowledge of the portal datasets and their properties. Our framework has the ability to generate numerous reports of all the datasets by passing formatted queries. There are two main sets of aggregation tasks that can be run:

- **Aggregating meta-field values:** Passing a string that corresponds to a valid field in the metadata. The field can be flat like `license_title` (aggregates all the license titles used in the portal or in a specific group) or nested like `resource>resource_type` (aggregates all the resources types for all the datasets). Such reports are important to have an overview of the possible values used for each metadata field.
- **Aggregating key:object meta-field values:** Passing two meta-field values separated by a colon : e.g., `resources>resource_type:resources>name`. These reports are important as you can aggregate the information needed when also having the set of values associated to it printed.

For example, the meta-field value query `resource>resource_type` run against the LODCloud group will result in an array containing `[file, api, documentation...]` values. These are all the resource types used to describe all the datasets of the group. However, to be able to know also what are the datasets containing resources corresponding to each type, we issue a key:object meta-field query `resource>resource_type:name`. The result will be a JSON object having the `resource_type` as the key and an array of corresponding datasets titles that has a resource of that type.

Metadata Report
group information is missing. Check organization information as they can be mixed sometimes
organization_image_url field exists but there is no value defined

²⁹ <https://github.com/ahmadassaf/opendata-checker/tree/master/results>

Tag Statistics	
There is a total of: 21 [undefined] vocabulary_id fields 100.00%	
License Report	
License information has been normalized !	
Resource Statistics	
There is a total of: 10 [missing] url-type fields 100.00%	
There is a total of: 9 [missing] created fields 90.00%	
There is a total of: 10 [undefined] cache_last_updated fields 100.00%	
There is a total of: 10 [undefined] webstore_last_updated fields 100.00%	
There is a total of: 10 [undefined] size fields 100.00%	
There is a total of: 10 [undefined] hash fields 100.00%	
There is a total of: 10 [undefined] mimetype_inner fields 100.00%	
There is a total of: 7 [undefined] mimetype fields 70.00%	
There is a total of: 10 [undefined] cache_url fields 100.00%	
There is a total of: 6 [undefined] name fields 60.00%	
There is a total of: 9 [undefined] webstore_url fields 90.00%	
There is a total of: 9 [undefined] last_modified fields 90.00%	
There is one [undefined] format field 10.00%	
Resource Connectivity Issues	
There are 2 connectivity issues with the following URLs:	
- http://dbpedia.org/void/Dataset	
Un-Reachable URLs Types	
There are: 1 unreachable URLs of type [file]	

Listing 1.2: Excerpt of the DBpedia validation report

5 Experiments and Evaluation

6 Conclusion and Future Work

In this paper, we proposed a scalable automatic approach for extracting, validating, correcting and generating descriptive linked dataset profiles. This approach applies several techniques in order to check the validity of the metadata provided and to generate descriptive and statistical information for a particular dataset or for an entire data portal. Based on our experiments running the tool on the LOD cloud, we discovered that the general state of the datasets needs attention as most of them lack informative access information and their resources suffer low availability. These two metrics are of high importance for enterprises looking to integrate and use external linked data.

It has been noticed that the issues surrounding metadata quality affect directly dataset search as data portals rely on such information to power their search index. We noted the need for tools that are able to identify various issues in this metadata and correct them automatically. We found out that 32.25% of all the metadata information can be automatically fixed, on which 50% of

them can be directly fixed by our framework. The rest are mainly provenance information that requires special treatment.

As part of our future work, we plan to introduce workflows that will be able to correct the rest of the metadata either automatically or through intuitive manually-driven interfaces. We also plan to integrate statistical and topical profilers to be able to generate full comprehensive profiles. We also intend to suggest a ranked standard metadata model that will help generate more accurate and scored metadata quality profiles. We also plan to run this tool on various CKAN based data portals, schedule periodic reports to monitor the evolvement of datasets metadata. Finally, at some stage, we plan to extend this tool for other data portal types like DKAN and Socrata.

References

1. Data profiling for semantic web data. In *Web Information Systems and Mining*. Springer Berlin Heidelberg, 2012.
2. Z. Abedjan, T. Gruetze, A. Jentzsch, and F. Naumann. Profiling and mining rdf data with prolod++. In *Data Engineering (ICDE), 2014 IEEE 30th International Conference on*, 2014.
3. K. Alexander, R. Cyganiak, M. Hausenblas, and J. Zhao. Describing linked datasets - on the design and usage of void, the 'vocabulary of interlinked datasets'. In *WWW 2009 Workshop: Linked Data on the Web (LDOW2009)*.
4. S. Auer, J. Demter, M. Martin, and J. Lehmann. LODStats - an Extensible Framework for High-performance Dataset Analytics. In *18th International Conference on Knowledge Engineering and Knowledge Management (EKAW)*, pages 353–362, Galway, Ireland, 2012.
5. C. Bizer, T. Heath, and T. Berners-Lee. Linked Data - The Story So Far. *International Journal on Semantic Web and Information Systems*, 2009.
6. C. Bizer, J. Lehmann, G. Kobilarov, S. Auer, C. Becker, R. Cyganiak, and S. Hellmann. Dbpedia - a crystallization point for the web of data. *Web Semant.*, 2009.
7. C. Böhm, G. Kasneci, and F. Naumann. Latent topics in graph-structured data. In *Proceedings of the 21st ACM International Conference on Information and Knowledge Management*, 2012.
8. C. Böhm, J. Lorey, and F. Naumann. Creating void descriptions for web-scale data. *Web Semant.*, 2011.
9. C. Böhm, F. Naumann, Z. Abedjan, D. Fenz, T. Gruetze, D. Hefenbrock, M. Pohl, and D. Sonnabend. Profiling linked open data with prolod. In *Data Engineering Workshops (ICDEW), 2010 IEEE 26th International Conference on*, 2010.
10. K. Bollacker, C. Evans, P. Paritosh, T. Sturge, and J. Taylor. Freebase: A collaboratively created graph database for structuring human knowledge. In *Proceedings of the 2008 ACM SIGMOD International Conference on Management of Data*, SIGMOD '08, 2008.
11. D. Boyd and K. Crawford. Six provocations for big data. *A Decade in Internet Time: Symposium on the Dynamics of the Internet and Society*, 2011.
12. M. Brümmer, C. Baron, I. Ermilov, M. Freudenberg, D. Kontokostas, and S. Hellmann. DataID: Towards semantically rich metadata for complex datasets. In *Proceedings of the 10th International Conference on Semantic Systems*, 2014.

13. M. Cornolti, P. Ferragina, and M. Ciaramita. A framework for benchmarking entity-annotation systems. In *Proceedings of the 22Nd International Conference on World Wide Web*, WWW '13, 2013.
14. R. Cyganiak, H. Stenzhorn, R. Delbru, S. Decker, and G. Tummarello. Semantic Sitemaps: Efficient and Flexible Access to Datasets on the Semantic Web. In *5th European Semantic Web Conference (ESWC)*, pages 690–704, Tenerife, Spain, 2008.
15. R. Cyganiak, J. Zhao, M. Hausenblas, and K. Alexander. Describing linked datasets with the VoID vocabulary. Technical report, 2011.
16. M. d'Aquin and E. Motta. Watson, more than a semantic web search engine. *Semant. web*, 2011.
17. R. Delbru, N. Toupikov, and M. Catasta. Hierarchical link analysis for ranking web data. *The Semantic Web: Research and Applications*, 2010.
18. L. Ding, T. Finin, A. Joshi, R. Pan, and R. Cost. Swoogle: A semantic web search and metadatabase engine. *CIKM04*, 2004.
19. J. Erickson and F. Maali. Data catalog vocabulary (DCAT). Technical report, 2014. <http://www.w3.org/TR/2014/REC-vocab-dcat-20140116/>.
20. B. Fetahu, S. Dietze, B. Pereira Nunes, M. Antonio Casanova, D. Taibi, and W. Nejdl. A scalable approach for efficiently generating structured dataset topic profiles. In *The Semantic Web: Trends and Challenges*. Springer International Publishing, 2014.
21. B. Forchhammer, A. Jentzsch, and F. Naumann. LODOP - Multi-Query Optimization for Linked Data Profiling Queries. In *International Workshop on Dataset Profiling and Federated Search for Linked Data (PROFILES)*, Heraklion, Greece, 2014.
22. M. Frosterus, E. Hyvönen, and J. Laitio. DataFinland - A Semantic Portal for Open and Linked Datasets. In *8th Extended Semantic Web Conference (ESWC)*, pages 243–254, 2011.
23. M. Frosterus, E. Hyvönen, and J. Laitio. Creating and publishing semantic metadata about linked and open datasets. In *Linking Government Data*. 2011.
24. M. Frosterus, E. Hyvönen, and J. Laitio. DataFinland - a semantic portal for open and linked datasets. In *ESWC (2)'11*, 2011.
25. A. Harth, K. Hose, M. Karnstedt, A. Polleres, K.-U. Sattler, and J. Umbrich. Data summaries for on-demand queries over linked data. In *Proceedings of the 19th International Conference on World Wide Web*, WWW '10, 2010.
26. A. Jentzsch. Profiling the Web of Data. In *13th International Semantic Web Conference (ISWC), Doctoral Consortium*, Trentino, Italy, 2014.
27. T. Käfer, A. Abdelrahman, J. Umbrich, P. O'Byrne, and A. Hogan. Observing Linked Data Dynamics. In *10th European Semantic Web Conference (ESWC)*, 2013.
28. S. Khatchadourian and M. P. Consens. ExpLOD: Summary-based Exploration of Interlinking and RDF Usage in the Linked Open Data Cloud. In *7th Extended Semantic Web Conference (ESWC)*, pages 272–287, Heraklion, Greece, 2010.
29. M. Konrath, T. Gotttron, S. Staab, and A. Scherp. Schemex - efficient construction of a data catalogue by stream-based indexing of linked data. *Web Semant.*, 2012.
30. S. Lalithsena, P. Hitzler, A. Sheth, and P. Jain. Automatic domain identification for linked open data. In *Web Intelligence (WI) and Intelligent Agent Technologies (IAT), 2013 IEEE/WIC/ACM International Joint Conferences on*, 2013.
31. A. Langegger and W. Woss. RDFStats - An Extensible RDF Statistics Generator and Library. In *20th International Workshop on Database and Expert Systems Application (DEXA)*, pages 79–83, 2009.

32. J. Manyika and E. A. Doshi. Open data: Unlocking innovation and performance with liquid information. Technical report, 2013.
33. P. N. Mendes, M. Jakob, A. García-Silva, and C. Bizer. Dbpedia spotlight: Shedding light on the web of documents. In *Proceedings of the 7th International Conference on Semantic Systems, I-Semantics '11*, 2011.
34. E. Mäkelä. Aether – generating and viewing extended void statistical descriptions of rdf datasets. In *Proceedings of the ESWC 2014 demo track*, Springer-Verlag, 2014.
35. A. Nikolov, M. d'Aquin, and E. Motta. What should i link to? identifying relevant sources and classes for data linking. In *The Semantic Web*, volume 7185 of *Lecture Notes in Computer Science*. Springer Berlin Heidelberg, 2012.
36. K. J. Prateek Jain, Pascal Hitzler and C. Venkatramani. There's no money in linked data. 2013.
37. F. M. Suchanek, G. Kasneci, and G. Weikum. Yago: A core of semantic knowledge. In *Proceedings of the 16th International Conference on World Wide Web*, 2007.
38. G. Tummarello, S. Danielczyk, R. Cyganiak, R. Delbru, M. Catasta, E. P. Federale, and S. Decker. Sig.ma: Live views on the web of data. In *In Proc. WWW-2010*. ACM Press.
39. R. Usbeck, M. Röder, A.-C. Ngonga-Ngomo, C. Baron, A. Both, M. Brümmer, D. Ceccarelli, M. Cornolti, D. Cherix, B. Eickmann, P. Ferragina, C. Lemke, A. Moro, R. Navigli, F. Piccinno, G. Rizzo, H. Sack, R. Speck, R. Troncy, J. Waitelonis, and L. Wesemann. GERBIL – general entity annotation benchmark framework. In *Submitted to the 24th WWW conference*, 2015.