Ontologies Supporting Research-related Information Foraging Using Knowledge Graphs: Literature Survey and Holistic Model Mapping

Viet Bach Nguyen[1 [0000−0003−2709−3297]], Vojtěch Svátek[1 [0000−0002−2256−2982]], Gollam Rabby[1 [0000−0002−1212−0101]], and Oscar Corcho[2 [0000−0002−9260−0753]]

[1] University of Economics, Prague, Czech Republic
{nguv03,svatek,rabg00}@vse.cz
[2] Ontology Engineering Group, Universidad Politécnica de Madrid, Spain
ocorcho@fi.upm.es

Abstract. We carried out a literature survey on ontologies dealing with the scholarly and research domains, with focus on modeling the knowledge graphs that would support information foraging by researchers within the different roles they fulfill during their career. In the state of the art we identified 43 relevant ontologies, of which 34 were found sufficiently documented to be reusable. At the same time, based on the analysis of extensive CVs and activity logs of two senior researchers, we formulated a structured set of competency questions that could be answered through information foraging on the web, and created a high-level conceptual model indicating the data structures that would provide answers to these questions in a holistic knowledge graph. We then studied the retrieved ontologies and mapped them on the entities and relationships from our conceptual model. We identified many overlaps between the ontologies, as well as a few missing features. Preliminary proposals for dealing with some of the overlaps and gaps were formulated.

Keywords: scholarly ontology · literature survey · competency question · knowledge graph · information foraging

1 Introduction

On a daily basis, researchers find themselves in situations when they need to acquire information from resources on the Web. The nature of such information needs differs based on the specific academic role of the researcher at the given moment, such as that of a paper writer, event organizer, scientific evaluator, advisor of other researchers, or project coordinator. Yet, many of these needs revolve around a small set of generic entity types and their relationships on which information is sought, such as people, institutions, publications, scientific venues, projects, topics, problems, arguments, or research artifacts. This common basis is relatively generic across research fields and makes it possible to proceed from textual search to the exploitation of structured databases on the web. Further, the rise of RDF-based knowledge graphs (KGs) may help overcome the rigidity of traditional database schemas; information from independent resources could nowadays be integrated and searched with less overhead. Yet, academic KGs spanning over many different entity types are still scarce; most published RDF datasets are only restricted to a few of these entity types, e.g., publications and their authors, paper citations, or projects and the institutions involved. Researchers who look for research-related information thus still have to either deal with multiple databases or delve into unstructured textual search. If holistic academic KGs are to be developed to address such needs in an integrated manner, it is important to understand the currently available 'eco-system' of reusable, well documented ontologies that could underlie such KGs, and point out the overlaps and gaps in this system. While the existence of overlaps implies the need of some decision support in the choice among the overlapping ontologies, the gaps, in turn, ask for the development of new ontologies.

Many papers published in the last two decades contained some surveys of existing scholarly ontologies, whether standalone or in comparison with a newly introduced model. We are however unaware of either a survey or a comprehensive ontology aiming to cover the concepts referenced by the *daily activities* of an (especially, senior) researcher. For such activities, a researcher takes on multiple 'hats' (roles), including such that directly relate to research – for example, not just to undergraduate education or to the general course of a working contract valid for any position and organization. Most previous papers and models restrict the analyzed activities to 'doing research' proper (methods, experiments, tools, etc.) and/or to attributes of research publications. This is the case, e.g., for the previous standalone survey by Ruiz & Corcho [22], focused on modeling scientific documents. Similarly, the recent requirements analysis for an Open Research KG by Brack et al. [3] is confined to the 'literature-oriented' tasks of scientists. Even the Scholarly Ontology [20], which comprehensively covers 'scholarly practices' (using thorough modeling with the help of foundational ontologies) including entities such as projects, courses, or information resources, focuses on a use case related to scientific activities tied to experiments and paper writing.

In this paper we aim not only at updating the previous scholarly/research ontology surveys by covering some newly developed models, but, in particular, at aligning them with a systematic analysis of information needs triggered by *different research-related roles* played by researchers. The information needs are expressed using *high-level competency questions*, giving rise to entity type paths from which a *holistic conceptual graph* was eventually built. Entities and relationships from the graph were approximately (manually, in a lightweight manner) *matched* with those of the surveyed ontologies, thus providing insights into what is covered and what is not, as well as where the overlaps are the strongest.

The main content of this paper is structured in the following way. Section 2 describes the process of literature search through which the relevant ontologies were identified and selected. Section 3 explains how the competency questions were formulated and the corresponding high-level model constructed. Section 4 presents the alignment between the model and the surveyed ontologies. Last, section 5 wraps up and outlines the directions for future research.

2 Literature survey methodology and results

The first step of our survey was to obtain a list of candidate ontologies that could potentially include entities related to researcher information needs and its context. Given the fact that most ontologies and relevant projects are reported in papers, a major source to be searched were high-coverage bibliographic/citation databases, of which we considered *Scopus*,[3] *Web of Science*[4] and *Google* Scholar.[5] Additionally, we also directly asked the generic *Google search engine*, to also cater for ontologies not accompanied with a paper for some reason. The different resources are complemenary. While the (top) Google/Scholar search should lead to popular resources with many inlinks/citations, the traditional bibliographic databases primarily return respectful academic publications (even those with lower citation response) and can be searched using more sophisticated means, thus reducing the amount of noice for the subsequent manual scan of results. While there are, obviously, a number of other possible databases to consider (such as DBLP, or the IEEE/ACM libraries), we assumed that sufficient coverage can already be obtained via the four we chose. Finally, for directly retrieving ontologies, an obvious choice was the *Linked Open Vocabularies* (LOV) portal[6]

Using Google as the initial baseline, we searched for the most obvious phrases only, to keep the precision acceptable: *scholar/ly ontology*, *academic ontology*, *research/er ontology*, and *bibliography/ic ontology*. For each Google query, we examined the first 10 pages of results, which consisted in a mix of publications, projects, and actual ontology documentations. Overall we identified, this way, a total of 9 relevant ontologies.

We then used the Google Scholar search engine with the same search terms. Google Scholar returned, in all cases, publications, from which we collected 5 further relevant ontologies.

Next, we used the Scopus bibliographic database. The advantage of searching in a specialized database was the higher degree of relevance To make a better use of the search tools provided by Scopus, we used our search terms to search for papers by titles and keywords, while limiting the scope to the Computer Science and Engineering fields. The following snippet represents our Scopus search query, which we used for searching in the title; analogous queries were applied on the abstract and keywords:

```
TITLE ((academic OR scholarly OR researcher OR bibliography)
    AND  ontology) AND (SUBJAREA("COMP") OR  SUBJAREA("ENGI"))
```

The search in the titles (TITLE) yielded 57 results, the search in abstracts (ABS) yielded 2829 results, and the search in keywords (KEY) yielded 279 results, all sorted by relevance. In the case of abstract-related results, we browsed

[3] https://www.scopus.com/
[4] https://webofknowledge.com
[5] https://scholar.google.com/
[6] https://lov.linkeddata.es/

the first 10 pages (approx. 100 results). Among these results, we found a total of 22 additional ontologies.

Our last bibliographic database of choice was the Web of Science. First, we searched for each term one by one. The term *scholarly ontology* yielded 32 results, the term *academic ontology* yielded 87 results, the term *researcher ontology* yielded 182 results (all with the refinement to the 'article' document type and to the 'computer science and information systems' category). Next, we used a query equivalent to the one used on Scopus, for searching in the title (and, analogously, in the topic) as follows:

```
TI = ((academic OR scholarly OR researcher OR bibliography)
    AND ontology) AND SU = (Computer Science OR Engineering)
```

This query returned 22 results for the title filter (TI) and 423 results for the topic (TS) filter. Among these results, we found 2 additional ontologies.

Aside the keyword-based search, we also benefited from the availability of *citation links* in Google Scholar, Scopus and Web of Science. We followed some promising incoming citation links to the papers on ontologies found so far. Using this technique, we identified 3 further ontologies.

For each ontology found through a paper reporting on it, we as much information as possible, including its metadata, source code and full texts of the referencing papers (when available).

Last, we directly searched for ontologies on the LOV portal. We found a considerable amount of relevant resources using the keywords *research*, *academic*, *scholar* and *bibliography*, of which most had already been covered by the previous bibliographic database or Google results. However, two new relevant ontologies were still found this way.

We then used the LOV results as a referencing resource to find related literature that described them (and possibly escaped the previous literature search), projects that used them, as well as to complete the missing information such as the namespaces and links to the source code.

To facilitate running a similar process in the future, we briefly summarize our literature search protocol for finding state-of-the-art ontology data:

1. determine search engines and relevant online databases,
2. define search criteria for optional filtering which include the top-level field, topic or domain, and keywords including their combinations,
3. execute initial search and iterate through an adequate amount of results,
4. exclude duplicate articles among the initial results,
5. manually include relevant articles based on title, keywords and abstract,
6. since search by keyword can miss some papers, try reverse citation tracking, even if paper is weak (has not been cited many times), forward tracing, reverse tracking of citations, since a later work could include a comparison of such papers,
7. look for ontologies in online specialized catalogs such as LOV.

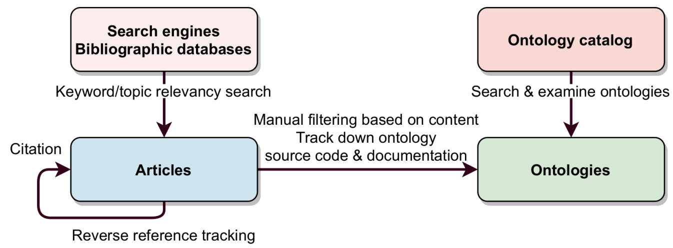

Fig. 1. Procedure for retrieving ontology related resources.

In Figure 1, we provide an overview of this literature survey procedure.

The result of our survey was a comprehensive table of metadata related to the ontologies. However, there were still some incomplete records due to unavailable or missing information. Content-level analysis also revealed some ontologies that were likely irrelevant for practical information search, e.g., an 'Ontology for describing academic mental state'. From the totality of 43 ontologies found, we thus eventually chose 34 for which 1) we deemed the availability of source code and/or metadata sufficient for effective reuse, and 2) the ontology content was indeed relevant to researcher information needs. Table 1 shows the final list of ontologies[7] used in our subsequent analysis.

3 Roles, competency questions and conceptual model

As mentioned, our starting point for examining the required coverage for scholarly knowledge graphs were the researcher needs associated with their research-related activities. Our approach is thus more 'human-centric', compared to 'data-centric' approaches to scholarly KG requirement analysis, which primarily look at what is already available in structured databases and KGs.

We started with identifying the *roles* fulfilled by researchers and entailing information foraging from external sources. For this purpose, the two senior co-authors (VS and OC) went through their comprehensive CVs and/or daily activity log, and distilled from the activities and achievements a set of distinct roles. The following roles (partially grouped, for brevity) have been identified:

- Researcher (general) - researching and publishing
- Leader of a research group (or of a more formal unit such as a Department)
- Advisor (of PhD students, or generally, more junior colleagues)
- Event organizer / Volume editor / Journal board member
- Evaluator of publications, researchers, organizations/groups, projects, and funding programs
- Research project proposer / manager
- Industry transfer mediator / recruiter.

[7] Some acronyms in this table are unofficial, e.g. OAD or RPO, and are only introduced for convenient referencing within this research.

Acronym	**Name**	
SO	Scholarly Ontology	[20]
OLOUD	Ontology for Linked Open University Data	[8]
VIVO	VIVO-ISF Ontology	[2]
CCSO	Curriculum, Course, and Syllabus Ontology	[14]
AIISO	Academic Institution Internal Structure Ontology	[13]
FRAPO	Funding, Research Administration and Projects Ontology	[26]
ORKG	Open Research Knowledge Graph	[15]
ESO & EAO	Education Standards & Education Application Ontology	[21]
SEDE	Ontology for Scholarly Event Description	[11]
OAD	Ontology for Academic Department	[33]
AcademIS	AcademIS Ontology	[32]
CSO	The Computer Sciene Ontology	[24]
BIBO	The Bibliographic Ontology	[6]
FOAF-Academic	FOAF-Academic Ontology	[13]
SemSur	Semantic Survey Ontology	[7]
RO	Research Object Ontology	[1]
SWRC	Semantic Web for Research Communities	[30]
ABET	Ontology for Academic Program Accreditation	[23]
RPO	Researcher Profile Ontology for the Academic Environment	[4]
CERIF	Common European Research Information Format Ontology	[12]
FaBiO	FRBR-aligned Bibliographic Ontology	[17]
CiTO	Citation Typing Ontology	[17]
BiRO	Bibliographic Reference Ontology	[10]
C4O	Citation Counting and Context Characterisation Ontology	[16]
DoCO	Document Components Ontology	[5]
PSO	Publishing Status Ontology	[19]
PRO	Publishing Roles Ontology	[19]
PWO	Publishing Workflow Ontology	[9]
SCoRO	Scholarly Contributions and Roles Ontology	[27]
DataCite	DataCite Ontology	[28]
BiDO	Bibliometric Data Ontology	[31]
FiveStars	Five Stars of Online Research Articles Ontology	[29]
FR	FAIR* Reviews Ontology	[25]
OCO	OpenCitations Ontology	[18]

Table 1: Research-related ontologies

For each researcher role, we formulated several verbal *competency questions* (CQs) and equipped them with *paths* of high-level concepts and relationships whose instantiations should provide answers to the questions in a hypothetical KG. An example of path is `RESEARCHER - ORGANIZATION - EVENT`. This way, we created a set of paths from which we then constructed a holistic, highly abstract *conceptual model* presented in Figure 3. We also gathered the terms in these paths into a separate collection. These terms were later put into a logical hierarchy, as shown in Figure 2. To reduce the complexity of the conceptual model, we only show ten top-level terms in it. In Table 2 we showcase several chosen CQs and associated paths. (To demonstrate the wider scope of the conceptual model, we omit the roles of 'general' researcher and publication writer, as these have been the main focus of most previous initiatives surveying scholarly ontologies/KGs. They are however also part of our complete CQ set.)

The hierarchy in Figure 2 shows six of the top-level concepts, further broken down to subtypes. The scope and purpose of each concept are as follows:

- The *Topic* concept may refer to research areas, research problems, methods etc.; namely, to anything that can be referred to as the subject of publications, of activities by research projects, research groups, funding programs, events, etc. Even 'tangible' assets used for research, including software and datasets, may be considered as a research topic in this context.
- The *Event* concept refers to scientific events such as conferences or seminars, and relates, e.g, to the on what kind of events can an organization organize or and which researchers have been involved in it through their publications.
- The *Assessment* concept refers to various evaluations of the quality of organizations, researchers, research projects, research publications (i.e. peer- or professional reviewing) and publication venues. The quality can be represented by metrics, rankings, certifications, textual reviews, etc.
- The *Organization* concept is a parent concept to the types of organizations or working units that a researcher might be engaged in; some types of organizations can also offer funding programs and support the research projects of researchers, or be the recipients of the academic know-how. We identified 6 subtypes as follows: *NGO*, *Foundation*, *Academic Institution*, *Research Group*, *Company*, *Government Body*. The important concept of *Research Spin-off* is a special type of *Company*.
- The *Publication* concept has 5 subtypes, which distinguish between different publication purposes and publishing formats. For example, an *Edited Collection* can be a book, proceedings, a journal special issue, or any other thematically coherent collection of individual publications, typically with a preface or editorial (its writing is a part of authoring this kind of publication). An *Outreach Publication*'s purpose is to connect science with the society. It can be a magazine article, a press release, etc.
- The *Publication Venue* concept refers to different parts of types of publication venues can researchers submit their manuscripts to.

Research Group Leader / Advisor CQ	
What positions (in projects, or general) in other organizations may attract junior researchers as an alternative to working in my group?	• Topic - Project - Organization • Topic - Position - Organization
Research Event Organizer / Volume Editor / Journal Board Member CQ	
Who should I invite as keynote speaker or reviewer (based on thematic relevance, research quality, and history of engagement in this or similar events)?	• Topic - Publication - Researcher - Assessment • Topic - Researcher - Assessment • Publication Venue - Publication - Researcher - Assessment
Evaluator of publications CQ	
What has been researched / written on the topic this publication deals with?	• Publication - Topic - Publication • Publication - Topic - Project
What has the author previously published on this topic? What is the overlap with the current paper?	• Publication - Researcher - Publication - Topic
How does the paper comply with the standard criteria of scientific writing? What argument is used by an author or a reviewer in a publication/review?	• Publication - Assessment • Publication - Review - Argument
Evaluator of researchers CQ	
How important are the venues where the researcher publishes?	• Researcher - Publication Venue - Assessment
How much technology transfer activity (to industry) does a researcher do?	• Researcher - Organization
Evaluator of projects CQ	
How topical are the goals of the project, in terms of problems addressed? Do people often write on these problems? Are they encouraged by funding programs?	• Project - Goal/Problem - Publication - Researcher • Project - Goal/Problem - Program
Project proposer CQ	
What are the preferred topics of the program/call? What are the topical problems in the field?	• Program - Topic - Problem
Who has experience with previous projects in the chosen program?	• Program - Project - Researcher
What partners should be invited for such a kind of project, based on the problem addressed?	• Problem - Publication - Researcher - Organization • Problem - Method - Researcher - Organization
What is the usual budget of projects in this program?	• Program - Project
Industry transfer promotor CQ	
Which company or other organization is active in the given field, as a potential transfer target?	• Project - Topic - Organization

Table 2: Examples of high-level competency questions and entity type paths

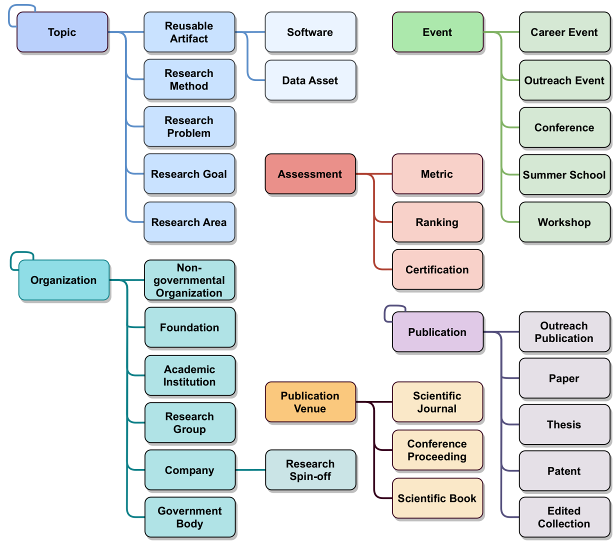

Fig. 2. Natural concept hierarchy

All mentioned relationships in the previous descriptions of top-level concepts are captured in Figure 3. In this model, there are 3 other top-level concepts that do not have a further breakdown. We describe them as follows:

- A *Researcher* can, e.g., be a member of organizations and can contribute to research projects and publications. The researcher also has access to other concepts such as *Event* and *Publication Venue*.
- The *Position* concept is used to describe possible positions or roles of a researcher within an organization.
- The *Funding Program* concept models a source of funding for research projects, possibly assigned across multiple calls.
- A *Project* may be proposed and solved by researchers (in some positions) or organizations, supported by funding programs, and associated with publications.

Note that the paths are not disambiguated, and in many cases may correspond to semantically different kinds of relationships, e.g., Researchers may provide assessments on something, but can also be assessed by other researchers.

4 Mapping the ontologies to the holistic model

Our high-level conceptual model consists of concepts and relationships that hold between them. It can be broken down into individual elements and fragments of concepts. This is needed to map existing ontologies onto the model and to identify their coverage. For this reason, we created a spreadsheet listing concepts, their subtypes and entity-relationship paths in the first column. Then, for

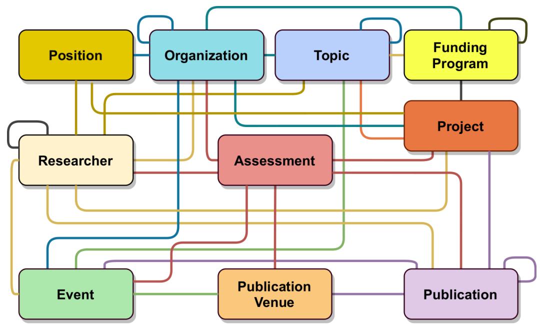

Fig. 3. High-level relationship model

each examined ontology, we noted down which concept is (at least, partially) covered by which entities in those ontologies. The detailed (manual) steps can be approximately described in the form of an algorithm:

Algorithm 1: Ontology coverage

Result: Coverage table
input : Latest versions of ontologies
output: Entities
foreach *Ontology* **do**
  if *Ontology documentation exists* **then**
    Check documentation;
    if *Ontology documentation has descriptive figures* **then**
      Use entities in figures;
    else
      Use entities listed in documentation;
  else if *Ontology source code exists* **then**
    Use entities described in source code;
  else if *Paper has entity descriptions* **then**
    Use entities described in the paper;
end
foreach *Entity* **do**
  Keep only classes, their instances, object properties and datatype properties within the ontology namespace;
end
input : Model elements
input : Entities
output: Coverage records
foreach *Entity* **do**
  If it is a property then also check its domain and range;
  When in doubt, check the comments, definition or description;
  Record the matching entities in the column of the ontology;
end

In Table 3, we show a fragment of our coverage table results. Numerical values in row **Terms covered** indicate how many concepts or relationship paths in the model are covered by the given ontology. Numeric values in column **C** indicate how many ontologies have positive coverage for the given term from the model. Positive coverage means that an ontology concept corresponds to the naming and/or context of a term in our model, providing a similar or same semantics. In many cases, the coverage was not apparent and some manual approximation had to be made. For example, in this table, the model term *Research Group* was considered to be covered by *Group* in the Scholarly Ontology despite its specificity. Other cases include relationships being covered by classes, such as *Researcher – Position* vs. *vivo:contributionRole*. The full coverage table of 73 model concepts and 34 ontologies can be found in our research repository, which also contains the set of CQs and other relevant resources.[8]

	C	**SO**	**OLOUD**	**VIVO core**	...
Terms covered		**15**	6	34	...
Position	**12**	:ActorRole	:Role	:Position, :Faculty Position	...
Position – Project	**5**	:ActorRole		:contributingRole	...
Org	**10**		:Organization	:ResearchOrganization	...
NGO	**0**				...
Foundation	**1**			:Foundation	...
Academic Institution	**8**			:Faculty, :Institute	...
Research Group	**3**	:Group			...
Company, Spin-off	**1**			:Company, :Private Company	...
Government Body	**1**			:GovernmentAgency	...
Org – Assessment	**2**				...
Org – Org	**2**				...
Org – Position	**4**		:roleAt, :role		...
Org – Topic	**1**			:hasResearchArea	...
Org – Event	**1**				...
Org – Project	**6**	:ActorRole		:supportedBy, :sponsoredBy	...
Org – Fund Prog	**4**			:FundingOrganization	...
Topic	**7**	:Topic	:Specialization		...
Reuseable Artifact	**9**	:Tool, :Information-Resource		:Dataset	...
Research Method	**8**	:Method, :Assertion		:CaseStudy	...
Research Problem	**4**	:Proposition, :ResearchQuestion			...
Research Goal	**5**	:Assertion, :Goal			...
Research Area	**6**	:Discipline		:hasResearchArea, :subjectAreaOf, :researchAreaOf	...
Topic – Topic	**4**	:hasPart, :Step			...
...	...	...	...	...	...

Table 3: Ontology coverage – table excerpt

The coverage table indicates that even if the roles played by researchers during their career, and the associated CQs, are numerous, the relevant concepts

[8] https://github.com/nvbach91/iga-knerd

and relationships are mostly well covered by available ontologies. Presumably, a proper (but still relatively large) subset of them might be found that would still cover all considered CQs. For such a set of ontologies, the abstract concept-relationship paths could be instantiated by constellations of OWL entities that could become part of *guidelines* for researcher data publishers. Possibly several alternative ontologies can be recommended for the parts of the domain where multiple of them *overlap*; these are, for example, the parts dealing with publications or organizations. More detailed criteria describing these choices in terms of ontology design patterns and their impact should be formulated.

As a likely gap in the existing ontology eco-system, we perceive, for example, the sub-domain of *spin-offs*. (In fact, even beyond the scope of the current survey, we were unable to find any ontology devoted to start-ups in general.) Underdeveloped also seems to be the conceptualization of, e.g., *funding programs* or some forms of *assessment*. In some cases, notions belonging to one 'bag' are dispersed across several ontologies, lacking a unifying super-concept, e.g. a *reusable artifact*.

5 Conclusions and future work

The presented research adds to the current vivid motion around scholarly KGs the perspective of a wider scope of (senior) researcher daily activities as well as that of ontology reuse. The comparison between a model extracted from a collection of researcher information needs and KG competence questions on one side and existing ontologies on the other side reveals that in many areas a huge number of models overlap while some others are nearly untouched.

The presented survey focused on ontologies alone. The most imminent future work then consists in extending the survey, in an integrated manner, to actual KGs as well as to existing thesauri. Although any ontology can be reused in the future, their actual usage in datasets may vary; this represents another dimension that could be added to our analysis. We have been collecting, in parallel, links to scholarly KGs, roughly partitioned according to the concepts from the model presented in this paper.

The research has been partially supported by the VSE IGS project no. 43/2020, "Knowledge Engineering of Researcher Data (KNERD)".

References

1. Belhajjame, K., Zhao, J., Garijo, D., Hettne, K.M., Palma, R., Corcho, Ó., Gómez-Pérez, J.M., Bechhofer, S., Klyne, G., Goble, C.A.: The Research Object Suite of Ontologies: Sharing and Exchanging Research Data and Methods on the Open Web. CoRR **abs/1401.4307** (2014), http://arxiv.org/abs/1401.4307
2. Börner, K., Conlon, M., Corson-Rikert, J., Ding, Y.: VIVO: A Semantic Approach to Scholarly Networking and Discovery. Synthesis Lectures on the Semantic Web, Morgan & Claypool Publishers (2012), https://doi.org/10.2200/S00428ED1V01Y201207WBE002

3. Brack, A., Hoppe, A., Stocker, M., Auer, S., Ewerth, R.: Requirements Analysis for an Open Research Knowledge Graph. CoRR **abs/2005.10334** (2020)
4. Bravo, M., Reyes-Ortiz, J.A., Cruz-Ruiz, I.: Researcher Profile Ontology for Academic Environment. In: Arai, K., Kapoor, S. (eds.) Advances in Computer Vision - Proceedings of the 2019 Computer Vision Conference, CVC 2019, Las Vegas, Nevada, USA, 25-26 April 2019, Volume 1. Advances in Intelligent Systems and Computing, vol. 943, pp. 799–817. Springer (2019), https://doi.org/10.1007/978-3-030-17795-9_60
5. Constantin, A., Peroni, S., Pettifer, S., Shotton, D.M., Vitali, F.: The Document Components Ontology (DoCO). Semantic Web **7**(2), 167–181 (2016), https://doi.org/10.3233/SW-150177
6. D'Arcus, B., Giasson, F.: Bibliographic Ontology Specification, http://bibliontology.com/, [accessed: 10-04-2020]
7. Fathalla, S., Vahdati, S., Auer, S., Lange, C.: SemSur: A Core Ontology for the Semantic Representation of Research Findings. In: Fensel, A., de Boer, V., Pellegrini, T., Kiesling, E., Haslhofer, B., Hollink, L., Schindler, A. (eds.) Proceedings of the 14th International Conference on Semantic Systems, SEMANTICS 2018, Vienna, Austria, September 10-13, 2018. Procedia Computer Science, vol. 137, pp. 151–162. Elsevier (2018), https://doi.org/10.1016/j.procs.2018.09.015
8. Fleiner, R., Szász, B., Micsik, A.: OLOUD - An Ontology for Linked Open University Data. Acta Polytechnica Hungarica **14**, 63–82 (01 2017), https://10.12700/APH.14.4.2017.4.4
9. Gangemi, A., Peroni, S., Shotton, D.M., Vitali, F.: The Publishing Workflow Ontology (PWO). Semantic Web **8**(5), 703–718 (2017), https://doi.org/10.3233/SW-160230
10. Iorio, A.D., Nuzzolese, A.G., Peroni, S., Shotton, D.M., Vitali, F.: Describing Bibliographic References in RDF. In: Castro, A.G., Lange, C., Lord, P.W., Stevens, R. (eds.) Proceedings of the 4th Workshop on Semantic Publishing co-located with the 11th Extended Semantic Web Conference (ESWC 2014), Anissaras, Greece, May 25th, 2014. CEUR Workshop Proceedings, vol. 1155. CEUR-WS.org (2014), http://ceur-ws.org/Vol-1155/paper-05.pdf
11. Jeong, S., Kim, H.: SEDE: An Ontology for Scholarly Event Description. J. Inf. Sci. **36**(2), 209–227 (2010), https://doi.org/10.1177/0165551509358487
12. Jörg, B.: CERIF: The Common European Research Information Format Model. Data Science Journal **9**, CRIS24–CRIS31 (2010), https://doi.org/10.2481/dsj.CRIS4
13. Kalemi, E., Martiri, E.: FOAF-Academic Ontology: A Vocabulary for the Academic Community. In: Xhafa, F., Barolli, L., Köppen, M. (eds.) 2011 Third International Conference on Intelligent Networking and Collaborative Systems (INCoS), Fukuoka, Japan, November 30 - Dec. 2, 2011. pp. 440–445. IEEE Computer Society (2011), https://doi.org/10.1109/INCoS.2011.94
14. Katis, E., Kondylakis, H., Agathangelos, G., Vassilakis, K.: Developing an Ontology for Curriculum and Syllabus. In: Gangemi, A., Gentile, A.L., Nuzzolese, A.G., Rudolph, S., Maleshkova, M., Paulheim, H., Pan, J.Z., Alam, M. (eds.) The Semantic Web: ESWC 2018 Satellite Events - ESWC 2018 Satellite Events, Heraklion, Crete, Greece, June 3-7, 2018, Revised Selected Papers. Lecture Notes in Computer Science, vol. 11155, pp. 55–59. Springer (2018), https://doi.org/10.1007/978-3-319-98192-5_11
15. Oelen, A., Jaradeh, M.Y., Farfar, K.E., Stocker, M., Auer, S.: Comparing Research Contributions in a Scholarly Knowledge Graph. In: Garijo, D., Markovic,

M., Groth, P., Santana-Pérez, I., Belhajjame, K. (eds.) Proceedings of the Third International Workshop on Capturing Scientific Knowledge co-located with the 10th International Conference on Knowledge Capture (K-CAP 2019), Marina del Rey, California , November 19th, 2019. CEUR Workshop Proceedings, vol. 2526, pp. 21–26. CEUR-WS.org (2019), http://ceur-ws.org/Vol-2526/paper3.pdf

16. Osborne, F., Peroni, S., Motta, E.: Clustering Citation Distributions for Semantic Categorization and Citation Prediction. In: Zhao, J., van Erp, M., Keßler, C., Kauppinen, T., van Ossenbruggen, J., van Hage, W.R. (eds.) Proceedings of the 4th Workshop on Linked Science 2014 - Making Sense Out of Data (LISC2014) co-located with the 13th International Semantic Web Conference (ISWC 2014), Riva del Garda, Italy, October 19, 2014. CEUR Workshop Proceedings, vol. 1282, pp. 24–35. CEUR-WS.org (2014), http://ceur-ws.org/Vol-1282/lisc2014_submission_9.pdf
17. Peroni, S., Shotton, D.M.: FaBiO and CiTO: Ontologies for Describing Bibliographic Resources and Citations. J. Web Semant. **17**, 33–43 (2012), https://doi.org/10.1016/j.websem.2012.08.001
18. Peroni, S., Shotton, D.M.: OpenCitations, an Infrastructure Rrganization for Open Scholarship. Quant. Sci. Stud. **1**(1), 428–444 (2020), https://doi.org/10.1162/qss_a_00023
19. Peroni, S., Shotton, D.M., Vitali, F.: Scholarly Publishing and Linked Data: Describing Roles, Sstatuses, Temporal and Contextual Extents. In: Presutti, V., Pinto, H.S. (eds.) I-SEMANTICS 2012 - 8th International Conference on Semantic Systems, I-SEMANTICS '12, Graz, Austria, September 5-7, 2012. pp. 9–16. ACM (2012), https://doi.org/10.1145/2362499.2362502
20. Pertsas, V., Constantopoulos, P.: Scholarly Ontology: Modeling Scholarly Practices. Int. J. on Digital Libraries **18**(3), 173–190 (2017), https://doi.org/10.1007/s00799-016-0169-3
21. Rashid, S.M., McGuinness, D.L.: Creating and Using an Education Standards Ontology to Improve Education. In: Waterman, K.K. (ed.) Proceedings of the Workshop on Semantic Web for Social Good co-located with 17th International Semantic Web Conference, SW4SG@ISWC 2018, Monterey, California, USA, October 9, 2018., Monterey, California, USA, October 9, 2018. CEUR Workshop Proceedings, vol. 2182. CEUR-WS.org (2018), http://ceur-ws.org/Vol-2182/paper_5.pdf
22. Ruiz-Iniesta, A., Corcho, O.: A Review of Ontologies for Describing Scholarly and Scientific Documents. In: Castro, A.G., Lange, C., Lord, P.W., Stevens, R. (eds.) SePublica. CEUR Workshop Proceedings, vol. 1155. CEUR-WS.org (2014), http://ceur-ws.org/Vol-1155/paper-07.pdf
23. Sabri, J.: Ontology for academic program accreditation. International Journal of Advanced Computer Science and Applications **7** (07 2016), https://10.14569/IJACSA.2016.070717
24. Salatino, A.A., Thanapalasingam, T., Mannocci, A., Osborne, F., Motta, E.: The Computer Science Ontology: A Large-Scale Taxonomy of Research Areas. In: Vrandecic, D., Bontcheva, K., Suárez-Figueroa, M.C., Presutti, V., Celino, I., Sabou, M., Kaffee, L., Simperl, E. (eds.) The Semantic Web - ISWC 2018 - 17th International Semantic Web Conference, Monterey, CA, USA, October 8-12, 2018, Proceedings, Part II. Lecture Notes in Computer Science, vol. 11137, pp. 187–205. Springer (2018), https://doi.org/10.1007/978-3-030-00668-6_12
25. Santana-Pérez, I., Poveda-Villalón, M.: FAIR* Reviews Ontology, http://fairreviews.linkeddata.es/def/core/index.html, [accessed: 13-05-2020]

26. Shotton, D., Peroni, S.: FRAPO, the Funding, Research Administration and Projects Ontology, https://sparontologies.github.io/frapo/current/frapo.html, [accessed: 13-05-2020]
27. Shotton, D., Peroni, S.: SCoRO, the Scholarly Contributions and Roles Ontology, https://sparontologies.github.io/scoro/current/scoro.html, [accessed: 13-05-2020]
28. Shotton, D., Peroni, S., Barton, A.J., Gramsbergen, E., Ashton, J., Jacquemot, M.C.: The DataCite Ontology, https://sparontologies.github.io/datacite/current/datacite.html, [accessed: 13-04-2020]
29. Shotton, D.M.: The Five Stars of Online Journal Articles - a Framework for Article Evaluation. D-Lib Mag. **18**(1/2) (2012), https://doi.org/10.1045/january2012-shotton
30. Sure, Y., Bloehdorn, S., Haase, P., Hartmann, J., Oberle, D.: The SWRC Ontology - Semantic Web for Research Communities. In: Bento, C., Cardoso, A., Dias, G. (eds.) Progress in Artificial Intelligence, 12th Portuguese Conference on Artificial Intelligence, EPIA 2005, Covilhã, Portugal, December 5-8, 2005, Proceedings. Lecture Notes in Computer Science, vol. 3808, pp. 218–231. Springer (2005), https://doi.org/10.1007/11595014_22
31. Tapia-León, M., Santana-Perez, I., Poveda-Villalón, M., Espinoza-Arias, P., Chicaiza, J., Corcho, O.: Extension of the BiDO Ontology to Represent Scientific Production. In: Proceedings of the 2019 8th International Conference on Educational and Information Technology. pp. 166–172 (2019), https://doi.org/10.1145/3318396.3318422
32. Triperina, E., Sgouropoulou, C., Tsolakidis, A.: AcademIS: an ontology for representing academic activity and collaborations within HEIs. In: Ketikidis, P.H., Margaritis, K.G., Vlahavas, I.P., Chatzigeorgiou, A., Eleftherakis, G., Stamelos, I. (eds.) 17th Panhellenic Conference on Informatics, PCI 2013, Thessaloniki, Greece - September 19 - 21, 2013. pp. 264–271. ACM (2013), https://doi.org/10.1145/2491845.2491884
33. Yuan, A.: An Ontology for Academic Department, http://www.cs.toronto.edu/~yuana/researchCenter/yuanaOnto.html, [accessed: 10-04-2020]