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Network of Ontologies– A Systematic Mapping Study and Challenges Comparison *

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Abstract. Background: Network of ontologies is the pairwise match of a set of ontologies, which became recently relevant due to its applicability in different domains, such as cultural evolution. However, the challenges faced in this area are not completely known and understood, neither are their relations to ontology matching counterpart problems . Aims: The goal of this paper is to identify challenges and applications of a network of ontologies and compare them to the 8 existing challenges of ontology matching (SHVAIKO and EUZENAT, 2013). Research questions are: (i) Which are the challenges for a Network of Ontologies? (ii) What are the applications of a Network of Ontologies? Method: We defined and executed a systematic mapping review protocol. A specialist on systematic mapping review and ontology research evaluated protocol and results. Results: Out of the 67 relevant studies, 10 addressed the research questions. All of them presented challenges, but only four presented applications. Conclusions: We identified four new challenges and related them with the eight challenges presented in (SHVAIKO and EUZENAT, 2013).

Keywords: Ontology, Ontology Alignment, Network of Ontologies, Systematic Mapping Study.

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1 Introduction

After years of research and work on the Ontology field, different ontologies for describing the same domain of discourse were developed, either from scratch or based on existing ones. In both cases, the ontologies are biased towards attending requirements for particular applications, such as data translation or query answering (LENZERINI, 2002). To deal with a number of distinct ontologies for the same domain, various Ontology matchings systems were developed towards improving the process of aligning two ontologies in a pairwise manner. The field of Ontology Matching evolved significantly; yet, some challenges still remain, as highlighted in (SHVAIKO and EUZENAT, 2013). For instance, the user involvement challenge is focused in how to use specialist knowledge to improve matching.

With the advances on matching techniques, a network structure naturally arose, composed by the set of discovered alignments and their respective ontologies. As the whole network structure grows, the maintenance effort to keep applications running may become costly. The network environment brings new tasks that were not necessary when we were dealing with single or pairs of ontologies. Query translators may have to discover the best (fast or reliable) way to cross ontologies and alignments or when an alignment update causes an inconsistency, a broken path is created and repair options must be presented to an administrator that will choose the better one. So to explore the network of ontologies problems, and try to understand the relation with the matching problems, we did a systematic mapping study and compared the challenges we have found with the challenges presented in (SHVAIKO and EUZENAT, 2013).

The paper is structured as follows: technical background about network of ontologies and ontology matching challenges in section 2, systematic mapping planning in section 3, systematic mapping results in section 4 and final considerations in section 5.

2 Background

Ontology is an explicit specification of a conceptualization (GRUBER, 2011) and a set of representational primitives with which to model a domain of knowledge or discourse (GRUBER, et al, 2008). Many enterprises produced their own ontologies in order to precisely describe knowledge related with their business domains, probably towards integrating their systems, translating queries or supporting a semantic web environment. The same enterprises needed a way to map the concepts among their own systems and systems belonging to partners, suppliers and customers (LENZERINI, 2002). This process is called ontology matching, which aims to discover and express correspondences between entities from different ontologies (MEILICKE, 2011),(SHVAIKO and EUZENAT, 2013). The set of all correspondences discovered between two ontologies is called an alignment. Indeed, alignments are subject to structural constraints, that have to be obeyed to keep their consistency (LAMBRINI and ACHILLES, 2015). Thus, the ontology matching (pairwise) problem - and its challenges - may change or even new challenges may arise as these structures become more complex, as in a network of ontologies.

2.1 Network of Ontologies

We need to understand network of ontologies to better perceive challenges about them. Network of ontologies is a set of ontologies with a set of alignments between these ontologies (EUZENAT, 2011), or a set of theories linked by different kind of relations (EUZENAT, 2015). In (LAMBRINI and ACHILLES, 2015) a network of aligned ontologies is defined as a dynamic distributed system with whose components (e.g. ontologies) are interacting and interoperating among them (LAMBRINI and ACHILLES, 2015). This distributed system and the semantics involved may be of one of three types: a single domain encompassed by the network; independent domains where the network helps one ontology to complement the others; each ontology has its own domain but respecting the network knowledge (ZIMMERMANN, et al, 2006).

In all cases the networks started with single ontologies built for several domains, but unfortunately through isolated initiatives, producing a concurrency between them and generating interoperability issues for systems using different ontologies (EUZENAT, SHVAIKO, 2013).

For instance, many ontologies for software engineering (SE) were created for years and if a single ontology could merge all others, probably it would result in an embracing SE ontology. However, merging all ontologies in only one may cause inconsistencies and overlapping concepts (CALERO, et al., 2016). Another approach is to built a new and complete single ontology for SE from the scratch. But according to (SUÁREZ-FIGUEROA, et al, 2012), big and monolithic ontologies create issues for construction and maintenance, thus arising cost problems.

Probably the best action plan is to build a network of ontologies, keeping smaller ontologies separated by subdomains so they can independently evolve (SUÁREZ-FIGUEROA, et al, 2012). However, splitting domains without precise baseline can cause issues handling the ontologies. As ontologies may be compromised with the dependence of the task they should help to solve (EUZENAT, 2015), the creation of a network of ontologies in layers may be used to handle the need for evolution and, also, sharing responsibilities within levels, while keeping control of the semantics in all ontologies belonging to the network.

The creation of a network of ontologies was compared with an engineering concept by (DIAZ, et al, 2011). They differ the situation of using some aligned ontologies to the situation where one creates the whole network from the scratch. On the other way (GÓMEZ-PÉREZ and SUÁREZ-FIGUEROA, 2009) showed that both cases may be used to build a network in their approach to create a methodology to design networks of ontologies called NeOn.

At some point, as with isolated ontologies, an application may need to search and locate the best place to make an alignment between ontologies that belong to a network. These ontologies organized in network have to be maintained with supporting tools that permits, for instance, monitor the network traffic, discover alternatives for unavaiable alignments and set permissions for users and groups. Are these problems equals to the pairwise ontology matching presented in (SHVAIKO and EUZENAT, 2013)?

Thus to better understand which problems may arise, related challenges and how to address the best solutions we formulated the questions presented in section 3. However before addressing the challenges found in our study, we need to review the challenges proposed by Euzenat (SHVAIKO and EUZENAT, 2013) to after check if they remain or not in network context.

2.2 Ontology Matching Challenges

Shvaiko and Euzenat stated many open challenges for research in 2013 in matching techniques (SHVAIKO and EUZENAT, 2013). In order to investigate what was being researched, they made an overview covering matching techniques and related work to help researchers in future works. The paper focuses on three questions: "Is the field still making progress? Is this progress significant enough to pursue further research? If so, what are the particularly promising directions?".

In the present paper, we are interested only on the third question, i.e. the promising direction or what challenges are being faced. Shvaiko and Euzenat classified challenges in eight areas and related each area with research directions, as we present in Table 1 and explain below (SHVAIKO and EUZENAT, 2013):

i. Large-scale matching evaluation is about how to evaluate a matching process when involved ontologies have more than 100000 entities, for instance. Manually checking this process is almost unfeasible, requiring tools to test, measure against benchmarks and a methodology. Best approaches were based in semantic alignment, correlation between matchers and standardization of metrics to promote a real tool comparison and the authors proposed research in measurement and methodologies (SHVAIKO and EUZENAT, 2013).

ii. Efficiency of matching techniques is about resources' consumption when a matching is running, besides the quality aspect of matching tools. The following directions may be useful to help efficiency: parallelization of matching tasks, e.g., cluster computing; distribution of matching tasks over peers with available computational resources; approximation of matching results, which over time become better, i.e., more complete; modularization of ontologies, yielding smaller more targeted matching tasks; optimization of existing and empirically proved to-be-useful matching methods (SHVAIKO and EUZENAT, 2013).

iii. Matching with background knowledge is about ontologies with some context information besides the formal specification when they are built. Hence, a problem is how to glue additional artifacts to help matching systems. Some of them may have valuable information and improve results, but the maintenance of used resources, as a tool configuration, is a relevant issue. So investments in reuse and query of knowledge are suggested (SHVAIKO and EUZENAT, 2013).

iv. Matcher selection combination and tuning is about how to choose best matchers for each case of matching. Some tools are better than others in specific domains. If one tool can be used in a semiautomatic way to complement another one, probably it will obtain better results. Some directions were proposed using a database execution plan with a decision tree, or using multi-agent techniques, frameworks and machine learning algorithms. To help discover the correct matcher, integrations of matchers and optimization techniques are proposed (SHVAIKO and EUZENAT, 2013).

v. User involvement is about using human expertise to help matchers. In this case, experts may not be available all the time because of costs constraints or the matching process may not be stopped every time to request an expert. Good usability engineering practices must be used to design interfaces to allow a better experience to specialists. thus, challenges are about how to design such interfaces and when to efficiently use the experts efficiently (SHVAIKO and EUZENAT, 2013).

vi. Explanation of matching results is about an extension of user involvement. Showing precise information about alignments found in a matching process on the interface is relevant for decision making. Some advances include score tools to summarize wrong decisions by entity, or to help users to learn with examples as a wizard. Hence usability engineering and standardization may help the progress with the users (SHVAIKO and EUZENAT, 2013).

vii. Social and collaborative matching is about users organized in a group context, who can interact with matchers or data produced by social networks can aid the matching process. Challenges include how to facilitate several users to propose better alignments or correct them, detect bad users, implement voting schemes or surveys to get domain information using the community. Indeed knowing the trust of social information is crucial (SHVAIKO and EUZENAT, 2013).

viii. Alignment management is about providing infrastructure and support to create an environment where engineers and other users can safely manage, store, tune and share their work. This environment can be a background layer to create facilities and services used for matchers. It can be a support toll like an IDE for developers or a middleware offering services. The creation of standards have to be done to become easier the tasks relate to ontology matching and decrease costs of developing and maintaining ontologies (SHVAIKO and EUZENAT, 2013).

Table 1. Ontology Matching Challenges and Research Summarization (SHVAIKO and EUZENAT, 2013)

Challenge	Research Areas
(i) Large-scale matching evaluation	Measurement and methodologies
(ii) Efficiency of matching techniques	Parallelization, distribution, approximation, modularization and optimization.
(iii) Matching with background knowledge	Knowledge querying and reuse
(iv) Matcher selection, combination and tuning	Integration and optimization
(v) User involvement	Usability
(vi) Explanation of matching results	Usability and standardization
(vii) Social and collaborative matching	Trustworthiness
(viii) Alignment management: infrastructure and support	Standardization

3 Systematic Mapping Planning

The goal of a systematic mapping is to produce and evaluate contents about a particular topic, without being biased by the researcher way of work and prior ideas. Another benefit is to permit that other researchers run and verify by themselves the results and reuse the work (KITCHENHAM and CHARTERS, 2007). The context of this systematic mapping is searching papers with challenges and difficulties related to ontology network area.

To support systematic mapping analysis, we defined the research questions in Table 2, which guided data collection. Publication selection was done in three steps. First: search string execution and results cataloguing. Second: titles and abstracts of all the publications selected in the first step were assessed and then filtered in/out according to the inclusion (IC)/exclusion (EC) criteria (shown in Table 3). Third: all publications selected in the second step were finally assessed to verify if they really meet the defined criteria.

Table 2. Research Questions

#	Main Research Question	#	Secondary Research Question
RQ1	Which challenges on network of ontologies have been found in the literature?	RQ 1.1	Which type of challenges may arise in a network of ontologies context (match, repair, large scale, social and collaboration, others) compared with traditional ontology processing?
		RQ 1.2	Are challenges in network of ontologies context the same described in (SHVAIKO and EUZENAT, 2013)?
		RQ 1.3	When and where have the studies been published?
		RQ 1.4	Which research methodologies have been followed?
RQ2	Have network of ontologies been used in industry practical application?	RQ 2.1	In what areas network of ontologies are being applied?

Table 3. Inclusion (IC) and Exclusion (EC) Criteria

IC1	The publication defines, proposes or describes challenges about network of ontologies.
EC1	The publication does not have an abstract, is only an abstract, is not written in English, is only an older version of a new one already included or we could not access the entire publication.
EC3	The publication is not derived from peer reviewed conferences or journals.
EC4	The publication shows usage of a network of ontologies in a domain outside IT.
EC5	The publication is not a book chapter not subject to peer-review (such as not originated from conference papers) or other non-scientific publications (such as whitepapers).

For establishing the search string, we tested different terms, logical connectors, and combinations among them. We elaborated the following search string: ("Ontology Network" OR "Ontology Networks" OR "Ontologies Networks" OR "Ontologies Network" OR "Ontology alignment network" OR "Networks of Ontologies" OR "Network of Ontology" OR "Network of Ontologies" OR "Networks of Ontology") AND ALL (challenge OR difficult OR pitfall OR pitfalls OR practical OR real OR industry OR experience OR "case study" OR "action research" OR hard OR lack OR "there is no" OR "there are no" OR inconsistency OR mistake OR fail). Scopus (www.scopus.com) search engine was selected due to its reliable and replicable results and due to index most control papers.

4 Systematic Mapping Execution

In June 2017, the search expression was executed on Scopus search engine, returning 67 publications. The second step returned 43 publications. After the third step, 10 remained. We did not filter any venue while executing the search string. All publications returned are properly indexed by Scopus engine. Table 4 presents selected publications. The scope and relevance of subject was evident by the diversity of events where papers were published.

Table 4. Selected papers after complete reading

#	Title, Authors, Publication Year, Source
1	Lambrini, S., Achilles, K. "Composable Relations Induced in Networks of Aligned Ontologies: A Category Theoretic Approach" *Axiomathes* 25.3 pp.285-311 (2015).
2	Euzenat, J. "Revision in networks of ontologies" *Artificial intelligence* v.228 pp.195-216 (2015).
3	Euzenat, J. "First experiments in cultural alignment repair (extended version)" *European Semantic Web Conference*. Springer International Publishing, pp.115-130 (2014).
4	Lambrix, P., and Qiang L. "Debugging the missing is-a structure within taxonomies networked by partial reference alignments" *Data & Knowledge Engineering* vol.86 pp.179-205 (2013).
5	Le Duc, C., Lamolle, M., Zimmermann, A., Curé, O. "DRAOn: A Distributed Reasoner for Aligned Ontologies" *ORE* pp. 81-86 (2013).
6	Rohrer, Edelweis. "Formal specification of ontology networks" *The Semantic Web: Research and Applications* pp.818-822 (2012).
7	Dıaz, Alicia, Regina Motz, and Edelweis Rohrer. "Making ontology relationships explicit in a ontology network." *AMW* v. 749 (2011).
8	Rohrer, Edelweis, Regina Motz, and Alicia Diaz. "Modelling a web site quality-based recommendation system" *International Journal of Web Information Systems* vol.7 n.4 pp. 396-420 (2011).
9	Kutz, Oliver, Immanuel Normann, and Till Mossakowski. "Chinese whispers and connected alignments" *Proceedings of the 5th International Conference on Ontology Matching*. vol.689 pp.25-36 (2010).

10	Ji, Qiu, et al. "RaDON—repair and diagnosis in ontology networks" *The semantic web: research and applications* pp.863-867 (2009).

As a quality assurance procedure, the expert on systematic mappings analyzed all selection steps, as well as the application of inclusion and exclusion criteria. Aiming to dispel doubts and avoid judgments of subjectivity, research questions (both primary and secondary) evolved during study. Protocol described in section 4 already reflects these decisions. We also evaluated the papers presented in table 5 regarding their overall quality and soundness. Although this is partially accomplished by applying exclusion criteria (EC1) that guarantee all papers were peer-reviewed, we also critically read all the papers to assure that proper methodological aspects were applied.

Finally, the decision of whether or not to keep papers in systematic mapping scope in each of selection steps (Tables 2 and 3) and data collection from papers was evaluated. After this step, data collected was summarized. Challenges were evaluated considering their explanations, names and paper goals. Most papers do not clearly summarize those challenges using one or two words, only describing in detail, so we had to analyze each approach and synthesize. Similar-purpose approaches were consolidated into the same challenge.

4.1 Results

From the 10 papers resulting from the systematic mapping, we identified 4 new challenges specifically related to network of ontologies. We considered each challenge as opportunities for future works. The applications found using network of ontologies were related to the following domains: health, semantic web and recommendation systems, but semantic web is a kind of domain that encompass others domains and hence we can infer the use of the networks in several applications.

We present answer to RQ1 and RQ2 in Table 5, showing challenges and applications to which they relate.. We have found four challenges: network consistency detection, network revision and repairing, network creation and management and inter-network matching. The first and the second were mentioned in the articles selected and the third and forth were inferred by the network of ontologies definitions presented in some articles.

In (SUÁREZ-FIGUEROA, et al, 2012) was presented a methodology to build ontologies and a tool to manage lifecycles. However, it does not define activities related to network of ontologies administration including user access and rights, node management, network troubleshooting and other typical activities in network environments.

Although the ontology matching problem was not directly mentioned by the articles authors, we had to consider that matching in network context is an underlying activity needed to detect network inconsistency, to perform network alignment repair or even to repair ontologies in networks, if necessary. We also had to consider typical tasks over networks, such as locating the best ontology within a network to serve as a starting point for a matching process. These problems were not covered in (SHVAIKO and EUZENAT, 2013).

Table 5. Identified Challenges and Applications

Paper# (referenced as Table 4)	Network of Ontologies Definition	Challenges	Application
1	✓	network consistency detection	N/A
2	✓	network revision and repairing	N/A
3		network revision and repairing	N/A

4		network revision and repairing	N/A
5	✓	network consistency detection	health
6		network consistency detection	semantic web
7	✓	network revision and repairing	semantic web, health
8		network consistency detection	web site recommendation system
9		network revision and repairing	N/A
10		network revision and repairing	N/A

In Table 6 we relate the known research areas (presented in second column of Table 1) to the four “new” challenges we found after this systematic mapping. Some challenges are related to more than one research area. Following we compared the network of ontologies challenges (called here as “new”) with the “research areas” and finally relate “new” challenges with “old” ones (Table 7).

Table 6. Research Areas and New Challenges

	New Challenges			
Research Areas	Network Creation and Management	Network Consistency Detection	Inter-network matching	Network Revision and Repairing
Measurement			✓	✓
Methodologies			✓	✓
Parallelization			✓	✓
Distribution			✓	✓
Approximation			✓	✓
Modularization			✓	✓
Optimization			✓	✓
Knowledge querying			✓	
Reuse			✓	
Integration			✓	✓
Usability		✓	✓	✓
Standardization	✓	✓	✓	
Trustworthiness		✓	✓	✓

A close look into Table 6 reveals standardization as a promising area, since it is related to three out of four challenges we found. We can say the same about trustworthiness and usability. Measurement, methodologies, parallelization, distribution, approximation, modularization, optimization, and integrations relate with two challenges and seem to be a popular theme in ontology network studies. On the other side, knowledge querying relates with only one chalenge and reuse may be seen as niche problems specifically related to some domains or applications.

Relating "old" with "new" challenges produces Table 7. We may infer, for instance, that the results from user involvement found in research may be reused to address network consistency detection, inter-network matching or network revision and repairing, since the research areas between them are similar as shown in Table 1 and 6. It means the techniques developed to increase the usability and consequently speed up and bring more quality to experts work while analysing the matching process, may be replicated when the experts tried to identify, solve inconsistencies or search for alignments oportunities in a network of ontologies. Thus this can be used to accelerate the research progress.

Table 7. Old x New Challenges

Old Challenges / New Challenges	Network Creation and Management	Network Consistency Detection	Inter-network matching	Network Revision and Repairing
(i) Large-scale matching evaluation			✓	✓
(ii) Efficiency of matching techniques			✓	✓
(iii) Matching with background knowledge			✓	
(iv) Matcher selection, combination and tuning			✓	✓
(v) User involvement		✓	✓	✓
(vi) Explanation of matching results		✓	✓	
(vii) Social and collaborative matching		✓	✓	✓
(viii) Alignment management: infrastructure and support	✓		✓	

We now briefly present some results about systematic mapping secondary questions. Regarding RQ1.1 and RQ1.2, as we presented in Table 5 and Table 6, challenges appear to be different in a first view, but when carefully looking we could relate them when using a different level of abstraction as "research areas". Regarding to RQ1.3, we found that most of the papers are published after 2010 (including 2010 they were 61 papers) and we can highlight the years of 2011 and 2015 with 15 and 12 papers respectively. Main publishers were "CEUR Workshop Proceedings" with 11 papers and "Lecture Notes in Computer Science" with 6 papers. Regarding RQ1.4, even though there are others, case studies and experimentation were the most used methods, showing the high relevance of them in Computer Science research. Regarding RQ2.1, looking in table 5 and during publications analysis we summarized the applications and may infer there is already some applicability of network of ontologies in industry, but they are still related to only some domains. However, we can notice that "semantic web" is a subject with applications in many domains.

4.2 Threats to Validity

This systematic mapping has construct and conclusion threats that can influence the validity of the results (WOHLIN, et al, 2012).

Construct threats: Network of ontologies challenges and applications, which are focus of this study, are relatively recent. There is still little research about them in the literature. The search scope was gathered from papers and summarized using the experience and knowledge from the authors. Hence, this process is subject to some level of interpretation that may vary according with expertise and point of view. Because of that, the authors interpreted, based on almost intrinsic relationship between challenges characteristics, considering their relevant aspects and proceeding with association.

We could not consider only papers with experimental evidence about proposed challenges and applications usage. In order to minimize this threat, we recorded practices and applications evidence level for considered challenges in general results analysis. Due its relevance and comprehensiveness, Scopus search database was chosen as the search source. However, Scopus may not have access to some papers. This may cause changes in the results, even though all control papers were presented in the first search. To investigate this threat, we include in future work a topic expanding the scope before doing tests with tools and techniques we have found.

Conclusion threats: After applying criteria selection and exclusion, only 69% of the papers selected by the search string remained as part of systematic mapping scope. The full text of only few papers was not available for reading. To avoid premature elimination and reduce this threat, we looked for them in another database with success. So in the third step the percentage was unchanged.

The search period was limited to the last ten years. This decision was made due to the low amount of papers about the theme we had found in an informal search. Thus we considered to limit only the initial search until 2007 and cover more papers in phase three, when we applied snowballing techniques. We also discarded 2017 year itself to avoid register incomplete references. However, papers from 2017 were covered by snowballing too. Considering 2007 as cut-off year, 67 papers were found. Moreover, this threat is minimized because of the almost absence of papers before 2007 and the fact they may be manually discovered. Therefore, we believe that the impact of limiting papers to 2007 on is low to this study's results.

4.3 Further Work and Remarks

By analyzing identified challenges and relating them to known ones though another level of abstraction, we noticed they could indicate reusing of some techniques in network of ontologies context without or with few adaptations. This relation may be relevant when we start to look for answers to challenges we have pointed out.

This paper is part of ongoing research. As future work, we plan to extend the systematic mapping to other research databases. Moreover, we plan to detail challenges and track advances in this area proposing opportunities for new researchers. We also plan to conduct experiments using some techniques we found, to clarify strength and weak points of each approach, aiming to get a deeper understanding to future studies.

We expect the list of challenges and research areas we presented can help new students to understand the networks of ontologies opportunities and to faster address their goals. They can use relations from challenges and research areas as a start point and choose what to address first and focusing efforts according with their preferences.

In the context of challenges, we understand that another limitation is the absence of detailed information about the consolidated knowledge and techniques used by authors to detect and repair alignments and to deal with the inconsistency. Thus, in response to that limitation, we plan to create a knowledge dictionary to map definitions and approaches used by author and by techniques guiding research team.

5 Systematic Mapping Execution

This paper presented a mapping study aiming to identify challenges in networks of ontologies research. We started with 67 papers initially to finally consider 10.

We found challenges not directly related to challenges presented by (SHVAIKO and EUZENAT, 2013), which were focused in matching issue, while in this work we were concerned about detecting consistency and repair alignments considering the network context. The inter network matching problem was not mentioned in selected papers and may require more investigation to verify if is a real challenge or only a more general case of ontology matching. The four challenges we found are not directly related to the eight described in (SHVAIKO and EUZENAT, 2013), but using related research areas from each challenge, we could find similarities between the "new" and "old" ones, infer best areas to focus research efforts and also areas from "new" challenges that can reuse results from "old".

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