Ontology Visualization: a Systematic Literature Analysis

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Abstract. The aim of this work is summarizing the current state of the art in the field of ontology visualization. For this purpose the method of systematic literature analysis has been applied. Publications on and in ESWC, ISWC, KEOD, AVI, and JUCS have been systematically searched for research results regarding ontology visualizations. Besides a general map of activity in the area, especially the context of ontology visualization and the nature of presented artefacts have been investigated. Furthermore, topics for future research are derived.

Key words: visualization tools, ontology, visualization, systematic literature analysis, SLA

1 Introduction

Visualization is an important task related to ontologies. Visualization is mainly based on a mapping from information to a graphical representation in order to facilitate data interpretation. It also provides ways to limit the amount of information that users receive, while keeping them "aware" of the total information space and reducing cognitive effort. For ontology visualization, this rule is also true. [1]

Visualization of ontologies is needed for showing their content and relations between their elements. A successfully generated visual representation of an ontology allows to reduce time spent working with the ontology. Visualization tools can also provide users an opportunity to create and edit ontologies.

Visualization is a powerful tool in the exploration and analysis of ontologies. On the other hand, the growing number and size of ontologies requires sophisticated visualization techniques that are capable to handle algorithmic, perceptual, and visual scalability problems [2].

This article aims to provide an overview of current state of the art in the field of ontology visualization. Thus, the central research question (RQ) is: "How is the area of ontology visualization covered by current scientific publications?" For this purpose the "Structured Literature Analysis" method (SLA) was used (e.g. [3]). The idea of an SLA is to give a summary of activity in an scientific area. Thus, identifying major research topics and problems and assessing the current level of activity.

The structure of this paper is organized as follows. The next section describes the SLA method and provides a description of the method's steps. This includes breaking down the central research question to more specific RQs. Sections 3 and 4 present the results of the SLA. The final section is devoted to conclusions.

2 Study Design and Overview

The following section describes the process of developing a systematic literature review. Prior to the review process, a topic of interest must be defined. This has been done by formulating the central research question in the previous section. Furthermore, research questions regarding this topic of interest need to be formulated. They represent the basis of the study and serve as a guidance during the data extraction. Regarding the topic of ontology visualization, the following research questions are in focus:

- *RQ1:* How much activity in the field of ontology visualization has been in the years 2007–2015?
- *RQ2:* What research topics (methods, tools, theories, examples, deployments, etc.) are being investigated?
- *RQ3:* Who is active in area of ontology visualization?
- *RQ4:* What research approaches are being used?
- *RQ5:* How is the context of ontology visualization approaches described?
- *RQ6:* Which topics in the field of ontology visualization need further research according to the authors?

The review process is divided into four different parts (see figure 1). The first activity is to identify conference series, journals and catalogues that are likely to represent the state of the art of research on the topic of interest. Here a base set of papers for review is extracted by keyword search. The second step is the exclusion/inclusion of papers based on title and abstract. Then, the remaining papers have to be classified and data has to be extracted with regard to the research questions. The fourth and last step is to analyse the extracted data. This review process is based on the guidelines for systematic literature reviews by Kitchenham [3] .The next paragraphs describe the performance of these steps in detail.

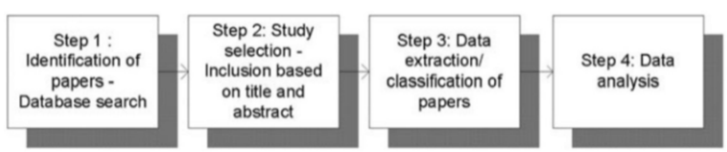

Fig. 1. Systematic Literature Review Process [4]

3 Identification and Selection of Papers

The first step is the identification of ontology visualization related papers in a selection of appropriate literature sources. As well-known representatives of conferences targeting at ontologies and semantic technologies, the International Semantic Web Conference (ISWC), the European Semantic Web Conference (ESWC), and the International Conference on Knowledge Engineering and Ontology Development (KEOD) have been selected. For the visualization domain, the Workshop on Advanced Visual Interfaces(AVI) has been chosen as a representative. Additionally, the Journal of Universal Computer Science (JUCS) has been searched for the occurrence of the topic in general computer science. For searching relevant information in the field of ontology visualization and reducing the number of articles the time-frame from 2007 to 2015 has been selected.

Major scientific data bases have been used for searching. ISWC and ESWC are indexed at the Web of Science by Thomson/Reuters, KEOD, AVI, and JUCS at SCOPUS. The following search terms have been used:

SCOPUS:

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TITLE-ABS-KEY ( visual*  ontolog* ) )  AND  PUBYEAR  >  2006
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Web of Science:

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TS=(Ontolog* AND Visual*)
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Thus, title, abstract, and keywords have been searched for the occurrence of words containing ‘ontolog’and words containing ‘visual’. The search terms have been modified for each selected source in order to restrict results to that source. For example,

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AND ( CONF ( keod ))
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has been used in SCOPUS for selecting papers published at KEOD. The search form for the Web of Science separates the time frame from the search term. Therefore, the publication years are not part of the used search term. A summary of paper identification is shown in table 1. 52 papers have been identified in total.

Table 1. Paper Identification and Selection

Source	# Identified	# Selected	Selected Papers
ESWC	13	6	[5, 6, 7, 8, 9, 10]
ISWC	14	5	[11, 12, 13, 14, 15]
KEOD	17	3	[16, 17, 18]
AVI	3	1	[19]
JUCS	5	2	[20, 21]
All	**52**	**17**	

A selection of the papers which are relevant to the area of ontology visualization had to be made. For this purpose criteria for in\excluding were formulated:

– The paper must contain information about ontology visualization or at least mention some techniques or theories regarding the research area;
– Every paper should give some new information about the topic. Papers about approaches that have already been discussed in other papers, should be excluded.

For the selection, a table has been created, which contains the title, the status (accepted\declined) of a paper and the reason for declining. E.g. "Hontology: A Multilingual Ontology for the Accommodation Sector in the Tourism Industry" was declined with the reason that "No information was found about visualization". Applying these criteria, 17 articles have been selected.

4 Data Extraction and Analysis

This section describes results of the data analysis of resulting papers after collection and selection. It is based on the research questions that were given in section 2. For the data extraction, the selected articles have been read and their relevant data has been collected in a table for further working. An example of the data for a paper is presented in table 2.

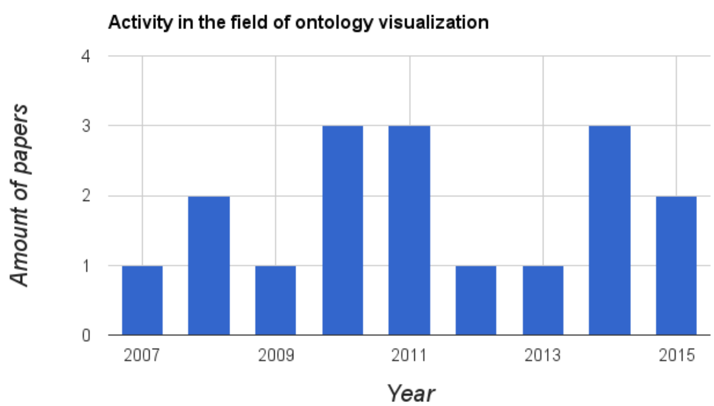

Fig. 2. Activity in the field of ontology visualization

4.1 RQ1: How much activity in the field of ontology visualization has been in the years 2007–2015?

Figure 2 shows the activity in the given time period. There is a minimum of activity from 2007 to 2009 with a local peak in 2008 (2 papers). A peak of

Table 2. Example of data collection

Field	**Description**	**Example**
Title	The title of the paper	Visualizing Ontologies: A Case Study
Link	Reference to the full text	Link
Publication (RQ1)	Year of Publication	2011
Topics (RQ2)	Keywords and main topics of the paper	knowledge representation languages, semantic Web, software tools
Author (RQ3)	Authors of the paper and their institutes and countries	"Howse, J.; Stapleton, G.; Chapman, P (Visual Modelling Group, Univ. of Brighton, Brighton, UK), Taylor, K. (CSIRO, Australian Nat. Univ., Canberra, NSW, Australia)"
Research Approaches (RQ4)	Type of used research approach	Case study
Context (RQ5)	Context may include the purpose, the focus, the roles, and the addressed problems of the visualization	"Using ontologies for shared development, OWL don't fetch to this task, people used concept diagrams (extended Euler diagrams)"
Further work (RQ6)	What authors plan to do in the future	"Implement visualization tool for concept diagrams; Translate sketches of concept diagrams to symbolic form"

activity was reached in 2010 and 2011— 3 articles were published. After only 1 published article in 2012 an 2013, the number of relevant publications increased again in the year 2014 and 2015. In average 2 articles were published per year from 2007 to 2015. Activity in the field of ontology visualization is low (only 18 papers in 9 years were written and published in our dataset.), but stable.

4.2 RQ2: What research topics are being investigated?

The field of ontology visualization contains many topics and themes: e.g. methods, tools, theories, examples, deployment, case studies, etc. There are many possible ways to group papers into topics. However, the focus lies on the created artefact. Thus, 3 clusters have been identified (see fig. 3):

1. **Visualization tools** — this topic describes creating new visualization tools. This usually includes creating algorithms\methods, which provide visualization. Examples of this kind of papers are: [9, 19, 6]; There are also some articles ([7, 5]) that do not describe stand-alone ontology visualization tools but plug-ins for existing ontology editing and visualization applications. Concretely, Prótége [1] was chosen as base application, because this project is

[1] http://protege.stanford.edu/

widely used in the ontology community and provides users an efficient system for implementing own plug-ins, which significantly increase Prótége's functionality.
2. **Comparative Study** — this kind of article describes methods, tools and techniques of ontology visualization and makes detailed *comparisons* with each other. Examples: [13, 20].
3. **Visualization Approach** — these papers offer something new in the field of ontology visualization. E.g. using extended Euler diagrams for data visualization ([11]) or using UML Activity diagrams for identical purposes [17, 11, 16].

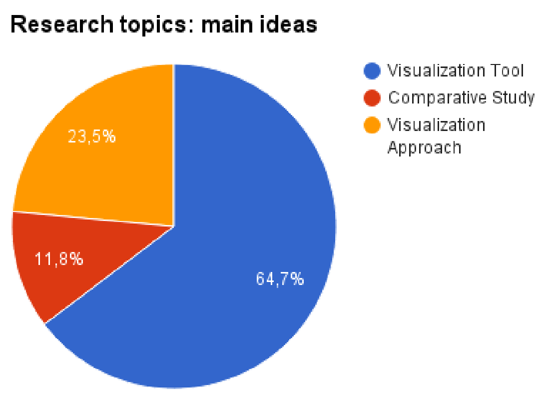

Fig. 3. Research topics

4.3 RQ3: Who is active in area of ontology visualization?

This question aims to highlight scientific groups or individuals who work in the field of ontology visualization. Most of the active institutes\universities are located in Europe — 19 of 26 different universities are involved in ontology visualization research. The most active countries in the field of ontology visualization are:

– UK (papers: [11, 12, 17, 14, 15], total amount of authors: 15);
– USA (papers: [13, 7, 14], total amount of authors: 7);
– Germany (papers: [5, 15], total amount of authors: 4);
– Latvia (paper: [9], total amount of authors: 5);
– Belgium (paper: [19], total amount of authors: 4);
– Greece (paper: [6], total amount of authors: 4).

The average number of authors, who worked on the articles is 3.65 persons per article. Most of papers (9) were written by teams from within one country. None of the authors of the selected papers created more than one paper. Also, only one university (*Stanford University*) published papers from different authors. Summarizing these facts, it seems, that working in the field of ontology visualization is complicated and consumes a lot of time.

4.4 RQ4: What research approaches are being used?

For a complete analysis of the field of ontology visualization it is necessary to gather the research approaches chosen by the respective authors. The classification of research approaches is based on the work of Robson [22]. 3 main groups have been identified in the selected papers: *Case study*, *Prototyping*, and *Survey*. Additionally, one of the papers is based on *Grounded Theory*. The distribution of group members is shown in fig. 4. As expected from RQ2 — most of the papers belong to the *Prototyping* group, because most papers describe new visualization tools and plug-ins.

The apers in the *prototyping* group have content about creating, developing, and evaluation of visualization tools or plug-ins. Also, the papers describe main features of visualization tools. An example of this kind of paper is: [5].

The *Case study* group includes papers, which offer some specific case and provide a detailed description of this case. For example, paper [11] shows how to use concept diagrams (extended Eulers diagrams) on detailed examples. Some papers, that are included in the *prototyping* group, also use the *case study* method. E.g. paper [18] describes how to use the visualization of ontologies for helping a military commander to make decisions or paper [10] describes how to use ontology visualization in ornithology.

The last group — *Survey* — contains papers that used data from questionnaires, interviews and observation for research. E.g. paper [13] used data from surveys and questionnaires for deciding which way of ontology visualization is better: indented tree or graph visualization. Also, some papers, which describe prototypes additionally use this research approach. E.g. paper [12] used experts for evaluating task performance of the presented visualization tool (*survey*), and also used *Grounded Theory* in order to build categories for expert's comments. Overall, some of the papers used triangulation (a method mix) in order to improve validity. Research on ontology visualization is mainly tool driven. Thus, research methods that support artefact evaluation prevail (*Prototyping, Case Study,Expert Survey*).

4.5 RQ5: How is the context of ontology visualization approaches described?

This question aims to highlight the context in which the approaches and tools are intended to be applied. The following aspects of context have been selected for investigation: (1) User Groups (2) Application Domains (3) Data Representation (4) Visualization Techniques and (5) Problems and Issues.

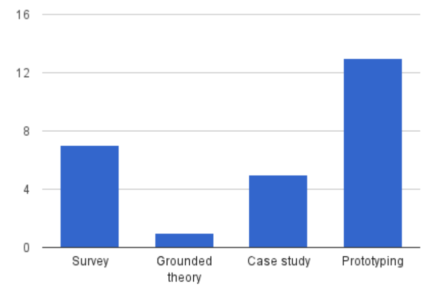

Fig. 4. Research approaches distribution

1. **User groups** — Tools for visualization of ontologies can be designed for the use by domain experts, who aren't familiar with ontologies and for ontology engineers, who work in this field. The choice of targeted end users has an significant impact on tool's design and features and usually it is hard to combine both user's way of working.
   The papers [5, 6, 19] describe tools for users, who are not familiar with ontologies, and the papers [12, 7, 8] are positioned as tools for experts in field of ontology engineering.
2. **Application Domains** — Visualization of ontologies can be applied in various domains. Papers present cases of using ontology visualization in research and education [16], shared development [11], military [18], medicine [15], biology science [10].Thus, 5 papers discussed domain specific visualizations of ontologies [16, 9, 10, 14, 15] while the rest provided general approaches.
3. **Data Representation** — In most cases visualization tools of ontologies work with RDF and OWL data. But some authors offers other data structures. E.g., paper [17] works with UML Activity diagrams which could be converted into OWL ontologies. The authors of paper [7] work with OWL extended by SWRL (Semantic Web Rule Language) rules. Hence, 7 papers addressed the visualization of OWL ontologies while 6 considered RDF/S. Among all the presented tools for ontology visualization only 8 were able to address A-Box data. A special example is [7], it presents a tool for SWRL rule visualization. Thus, an additional ontology part is in focus here.
4. **Visualization Techniques** — Data can be presented in different ways. Choosing a method of visualization has effects on quality and understandability of models. It is required to choose right view for various purposes. The most common way of ontology visualization is using plain 2D graphs. This form of ontology data presentation is familiar and intuitive to users. Papers [12, 7, 6, 5, 18] use this method for data visualization. But other authors of the selected papers used other or more specialized solutions:

   - 3-dimensional graph visualization layout was used by the authors of paper [14] ;
   - OWL classes in paper [9] were presented as UML classes, data properties as class attributes, object properties as associations, individuals as objects, cardinality restrictions on association domain class as UML cardinalities;
   - The authors of article [8] have adopted the single-view visualizing paradigm enabling selective detailed views which has turned out to be adequate for visualizing concept and property hierarchies of a large amount of data in ontologies;
   - Radial tree was used in paper [19] for representing all available OWL classes of DBpedia and various kinds of charts were chosen for showing information extracted from DBpedia;
   - Concept diagrams (extended Euler diagrams) were used for allowing disparate groups of ontology developers and users to communicate effectively by the authors of paper [11].
5. **Issues and problems** — The authors describe different problems, which they faced during their research. One of the issues is making tools more friendly for end users. Articles said, that "ontologies are no longer developed and used exclusively by specialized researchers and practitioners" (paper [12]), "visualizations for ontologies have been developed in the last couple of years, they either focus on specific ontology aspects or are hard to read for non-expert use" (paper [5]). This issue has been tried to solve by adding such capabilities as zooming and hiding parts of the ontology, history browsing, saving and loading of customized ontologies views, graphical zooming, layout customization (paper [12]); colour schema for elements, using force-direct layout, layout animation (paper [5]).
   Another issue addressed by the authors is working with large data ontologies. "Little has yet been done to support ontology users or developers to visually edit or explore such large volumes of interrelated individuals" (paper [8]), "ontologies can encapsulate a large amount of information (hundreds of thousands of classes and relationships, for example). The main problems of current tools for ontology visualization are common to any tool for graph visualization: problems of scale versus amount of information that need to be presented." (paper [1]).

4.6 RQ6: What are Future Research Topics?

The papers that presented visualization tools generally named adding functionality, proving scalability, and tool integration into ontology engineering environments as future tasks. Those who presented visualization approaches named the development of tools as the next step. However, most of the identified papers stress the fact of lacking evaluation of approaches and tools. Evaluation so far is only based on small samples, uses cases and specific domains. Thus, a generalization and the practical usage in research or industry scenarios are also topics for future research.

At last, two papers named virtual reality applications as a field for future research [18, 14].

5 Conclusion

There is constant activity on the field of ontology visualization. This fact proves that this topic is of interest today and it may evolve in the near future. Many tools and methods for ontology visualization appear in the literature. Most of the analyzed papers focus on concrete tools, but not on the algorithms or usage of ontologies and ontology visualization.

The authors of the selected papers have pointed on the next topics that need further research:

- Further development, improvement and integration into enterprise of visualization tools (papers [12, 5]);
- More functionality for user-friendly interface (paper [19]);
- Scalability (papers [6, 8, 15]).

The fact that no second publications on the area have been found for the authors of the selected papers leads to the assumption that these issues for future research are still open and difficult to handle.

Regarding the quality of the performed SLA, publication sources of the semantic web community (ESCW, ISWC, KEOD) are over-represented. Thus, the literature search can be extended for example by looking into the visualization community. Furthermore, the search terms could be extended. A possible additional term would be 'Conceptual Model'. Though Ontologies and Conceptual Models are not the same, they are quite similar.

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