Ontology Integration Approaches: A Systematic Mapping

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Abstract. *Ontology integration is an important topic of interest in Ontology Engineering. Integrating ontologies is a complex process that involves finding suitable ontologies, interpreting them and integrating them into a new integrated ontology. This paper presents a systematic mapping that investigated ontology integration approaches and provides a panorama of this topic. The results revealed a limited use of semantic relationships to map ontologies and a lack of concern with the integration scope, the goals the integrated ontology must achieve, search and selection of the ontologies to be integrated, and integration-based development processes.*

Keywords*: Ontology Integration, Systematic Mapping, Mapping Study*

1. Introduction

Nowadays, ontology engineers are supported by a wide range of ontology engineering methods and tools. However, building ontologies is still a difficult task. Integrating existing ontologies to develop a new one can be a useful approach. Ontology reuse allows speeding up the ontology development process, saving time and money, and promoting the application of good practices (Poveda Villalon *et al*., 2010). However, ontology reuse is a complex research issue and one of the most challenging areas of Ontology. Ontology engineers still face problems to select the right ontologies for reuse and integrate several ontologies into a new ontology (Park *et al*., 2011). Ontology integration involves merging, consolidating, analyzing, and modifying two or more ontologies into a new (integrated) ontology (Pinto and Martins, 2001). It depends on finding and reusing ontologies able to meet the requirements of the new ontology.

Ontology integration is related to knowledge sharing and reuse. Therefore, it is crucial in Ontology Engineering and has been a recurrent research topic (Blomqvist and Öhgren, 2008) . In some cases, ontology integration is approached in an isolated form (i.e., self-contained) and, in others, it is approached as part of the ontology development process. Due to the high number of ontology models available, ontology development has demanded efficient methods of reuse and integration (Caldarola *et al*., 2015).

Given the importance of ontology integration, we carried out a mapping study to investigate ontology integration approaches recorded in the literature. A mapping study is a secondary study designed to give an overview of a research area through classification and counting contributions in relation to the categories of that classification. It makes a broad study in a topic of a specific theme and aims to identify available evidence about that topic (Kitchenham and Charters, 2007). Moreover, the panorama provided by a mapping study allows identifying issues in the researched topic that should be addressed in future research.

In this study we are particularly interested in ontology integration approaches addressing the conceptual level. By “ontology integration approaches” we mean approaches (i.e., methods, techniques, processes) that integrate (by merging, consolidating, and, when necessary, modifying) two or more ontologies with the purpose of building a new integrated ontology (Pinto and Martins, 2001). In this sense, approaches that are limited to address ontology mapping, without producing a new integrated ontology, are out of the study scope. By “conceptual level” we mean that we are interested in approaches concerned with the meanings behind the concepts to perform the integration. No matter if they are exclusively conceptual or associated to operational concerns. Hence, approaches limited to propose operational solutions (i.e., focused on computational aspects) are out of the study scope.

This paper presents the mapping study and its main results. It is organized as follows: Section 2 provides the background for the paper, talking briefly about ontology integration; Section 3 presents the research protocol used in the study; Section 4 presents the obtained results; Section 5 discusses the findings that emerge from the results; Section 6 addresses the study limitations; and, finally, Section 7 presents our final considerations.

2. Ontology Integration

In the context of computer and information sciences, an ontology is an artifact that describes a certain reality with some purpose. As any artefact, ontologies have a lifecycle. They are designed, implemented, evaluated, modified, reused, etc. (Gangemi and Presutti, 2009). Ontology development is a complex task and even specialists face difficulties. Ontology reuse is a practice that can help in this matter, since existent ontologies can be reused to build new ones (Guizzardi *et al.*, 2013). Despite that, ontology engineers still face problems to select the most suitable ontologies and integrate them (Park *et al.*, 2011).

In the literature there are several definitions for ontology integration. In short, ontology integration can be defined as the process of integrating two or more source ontologies to build a new (integrated) ontology (Vergara *et al.,* 2003). During the integration process, it may be necessary to refine the source ontologies before integrating them. In addition, new concepts and relationships can be added to the integrated ontology, so that its requirements can be met. Given the strong relation between merging and integration, and the possible confusion this may cause, we explain them bellow.

According to Pinto *et al.* (1999), there are three different situations involving ontology integration: (i) development of a new ontology reusing other ontologies; (ii) merging of different ontologies that deal with the same subject, resulting in a single ontology unifying them; (iii) integration of ontologies into applications. In the first case, a new ontology has to be developed and there are available ontologies that meet the new ontology requirements; then these ontologies are reused to build a new one. In the second case, the new ontology joins ideas, concepts, distinctions, axioms, etc. (i.e., knowledge) of ontologies in the same domain. When ontologies are merged, a new ontology is created and it unifies concepts, terminologies, definitions, constraints, etc. In the third case, different ontologies are introduced into one application to specify or implement a knowledge-based system.

In both, integration and merging, there are, on one hand, source ontologies and, on the other, the resulting ontology, obtained by reusing the source ontologies. In the *integration* process, after the integration it is possible to identify in the resulting ontology regions from the source ontologies. The domains of the source ontologies are different from the domain of the resulting ontology, although there may be a relation between them. The concepts from the source ontologies can be reused in the integrated ontology as they are, they can be adapted (or modified), specialized or added to new concepts. In *merging*, the goal is to build a more comprehensive ontology about a subject, gathering, in a coherent way, knowledge from other ontologies in the same subject. Thus, the subject of the merged ontologies and the resulting ontology is the same. After merging, it may be difficult to identify regions from the source ontologies in the resulting ontology.

3. The Research Protocol

The study was performed following the approach defined in (Kitchenham and Charters, 2007), which involves: *planning*, when the research protocol is defined; *conducting*, when the protocol is executed and data are extracted, analyzed, and recorded; and *reporting*, when the results are recorded and made available to potential interested parties. In this section we present the main parts of the research protocol used in the study.

The study **goal** was to investigate ontology integration approaches addressing the conceptual level. For achieving this goal, we defined thirteen research questions (RQ) that are shown in Table 1.

The **search string** adopted in the study is composed of terms related to ontology integration and approach. The following search string was used: *(("ontology interoperability") OR ("ontology integration") OR ("ontology merging")) AND ((“approach”) OR (“method”) OR (“framework”) OR ("strategy") OR ("process"))*. As discussed, we are interested in approaches that integrate (by merging, consolidating, and, when necessary, modifying) two or more ontologies with the purpose of building a new ontology. Therefore, in the search string we included *merging* among the terms related to integration. For establishing the string, we performed some tests using different terms, logical connectors, and combinations among them. More restrictive strings excluded some important publications identified during the informal literature review that preceded the study. These publications were used as control publications, meaning that the search string should be able to retrieve them. We decided to use a comprehensive string that provided better results in terms of number and relevance of the selected publications, even thought it had selected many publications eliminated in subsequent steps.

The search was performed in the following six **sources:** IEEE Xplore, ACM Digital Library, Scopus, Science Direct, Engineering Village and Web of Science.

Publications selection was performed in four steps. In *Preliminary Selection and Cataloging (S1)*, the search string was applied in the search mechanism of each digital library (we limited the search scope to title, abstract and keywords metadata fields). After that, in *Duplications Removal (S2),* publications indexed in more than one digital library were identified and duplications were removed. In *Selection of Relevant Publications – 1st filter (S3),* the abstracts of the selected publications were analyzed considering the following inclusion (IC) and exclusion (EC) criteria: (IC1) the publication presents an approach for ontology integration addressing the conceptual level; (EC1) the publication is not written in English; (EC2) the publication does not have an abstract; (EC3) the publication is a copy or an older version of an already selected publication; (EC4) the publication is a secondary study, a tertiary study, a summary or an editorial; (EC5) the publication was published as an abstract. In *Selection of Relevant Publications – 2nd filter (S4),* the full text of the publications selected in S3 were read and analyzed considering the cited inclusion and exclusion criteria plus (EC6) The full text of the publication is not available. Publication selection was performed by the first and second authors. For each publication, an identifier was defined and the following information was recorded: title, authors, year, reference and source. Publication selection was reviewed by the third author, who performed the publication selection procedure and reviewed the all the results obtained by the other authors in each step. Discordances were discussed and resolved in meetings.

Table 1 - Research Questions

ID	Research Question	Rationale
RQ01	Which ontology integration approaches addressing the conceptual level have been presented in the literature?	Identify ontology integration approaches addressing the conceptual level recorded in the literature
RQ02	When and in which type of vehicle (journal/conference/workshop) have the publications been published?	Provide an overview about when and where the publications have been published as a way of analyzing the maturity of the research topic. Moreover, verify the distribution of publications per time and per publication vehicle.
RQ03	Which type of research has been done?	Identify the type of research using the classification defined in (Wieringa *et al*., 2006). A panorama about the research types can indicate the maturity level of the research topic.
RQ04	What is the basic principle of the ontology integration approach?	Identify the main characteristics of the ontology integration approaches and verify if there is a predominance of some of them.
RQ05	Which are the steps of the ontology integration approach? Are they explicitly defined?	Investigate if there has been concern with defining systematic processes for ontology integration and which steps have been proposed.
RQ06	Does the approach refer to ontology integration, ontology merging or both?	Identify the type of approach according to the classification defined in (Pinto and Martins, 2001).
RQ07	Is the ontology integration approach related to some ontology engineering method? If it is the case, which is the method and how does the approach relate to it?	Investigate whether integration approaches have been proposed in the context of broader ontology engineering methods and how the approach relates to the method.
RQ08	Is the ontology integration approach guided by goals?	Investigate whether goals have been used to support ontology integration.
RQ09	Does the ontology integration approach use competence questions?	Investigate whether competence questions have been used to support ontology integration.
RQ10	Does the ontology integration approach use pre-selected ontologies, or does it aid in the selection of the ontologies to be integrated?	Investigate whether the integration approaches provide mechanisms to support the selection of the ontologies to be integrated.
RQ11	Does the ontology integration approach address only the conceptual level or also the operational level?	Investigate whether ontology integration approaches addressing the conceptual level have also addressed the operational level.
RQ12	Is the ontology integration approach automatic, semiautomatic or non-automatic?	Investigate whether computational assistance have been used to support the ontology integration approaches.
RQ13	Which types of semantic relationships between concepts are addressed in the ontology integration approach?	Identify the types of semantic relationships between concepts (e.g., equivalence, specialization, generalization, etc.) have been addressed in the ontology integration approaches.

After selecting the publications, data were extracted and recorded. **Data extraction and recording** consisted of extracting data from the publications for each research question and recording them in a form designed as a spreadsheet. Data extraction was performed by the first author and reviewed by the third author. Once data were validated, **data interpretation and analysis** were carried out. Quantitative data were tabulated and used in graphs and statistical analysis. Qualitative analysis was performed considering the findings, their relation to the research questions and the systematic mapping purpose. Data interpretation and analysis were performed by the first author and reviewed by the third author. Discordances were discussed and resolved in meetings.

4. Data Synthesis

The systematic mapping considered studies published until November of 2017. In the first step (S1) 1816 publications were obtained (229 from IEEE Xplore, 616 from Scopus, 49 from ACM, 57 from Science Direct, 512 from Engineering Village and 353 from Web of Science). In the second step (S2) duplications were removed, remaining 591 publications. In the third step (S3), 232 publications were selected (a reduction of about 61%). In the fourth step (S4) 15 publications were selected (a reduction of about 93%). The expressive reduction in S4 was due to the fact that most analyzed approaches addressed only the operational level. Next, we present the main results for each research questions (RQ).

RQ01. Which approaches of ontology integration addressing the conceptual level have been presented in the literature? - Table 2 presents a summary of the ontology integration approaches found in the study.

RQ02. When and in which type of vehicle (journal/conference/workshop) have the studies been published? - The publications selected were published between 2001 and 2017, as shown in Figure 1. Regarding the publication vehicle, four studies (27%) were published in journals, ten studies (66%) in conferences and one (7%) in workshops.

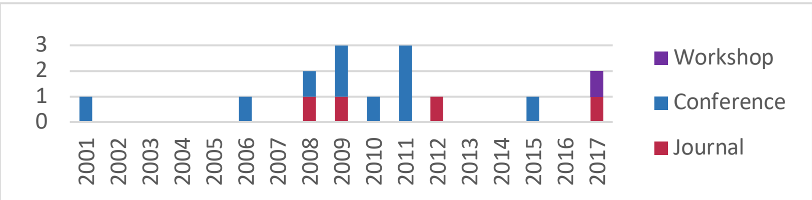

Figure 1 - Year and Publication Vehicle

RQ03.Which type of research has been done?- According to the classification presented in (Wieringa *et al.*, 2006) and considering that a publication can be classified in more than one type, all the analyzed publications were classified as *Proposal of Solution*. Eight of them ([P03], [P04], [P07], [P08], [P09], [P11], [P12], [P15]) (53%) are also *Validation Research*, because they use proof of concept, experiment, prototype or something similar to evaluate the proposal. No publication was classified as *Evaluation Research*, which means that none of the proposals have been applied in a real environment.

RQ04. What is the basic principle of the ontology integration approach? - The main principles identified were: similarity calculation, semantic mappings and integration operations. The former is about using heuristics to calculate proximity between names, structures and concepts in order to find equivalences. The second is used to find semantic relationships between concepts and indicate the proximity level between them in a qualitative form. The last refers to operations involving terminology, definition and documentation of concepts to make the integrated ontology consistent. Five approaches (33%) ([P06], [P10], [P11], [P13], [P15]) use similarity calculation, seven (47%) ([P04], [P05], [P07], [P08], [P09], [P12], [P14]) use semantic mappings and two ([P01], [P03]) (13%) apply integration operations. [P02] is the only approach combining different principles. It uses similarity calculation and semantic mappings.

Table 2 Integration approaches.

ID	Reference	Description
[P01]	(Pinto and Martins, 2001)	Proposes an ontology integration process that can be used in combination with other methods to build ontologies when the ontologies to be integrated are not pre-selected.
[P02]	(Miyoung *et al.*, 2006)	Ontology merging approach that considers vertical and horizontal integration and uses WordNet.
[P03]	(Blomqvist and Öhgren, 2008)	Method proposed to the automotive suppliers domain. It considers the development of an ontology from the integration of two others, one manually developed and the other automatically developed.
[P04]	(Geum *et al.*, 2008)	Aims to generate new concepts related to services from ontology integration. It includes three steps: service ontologies development, ontology integration and generation of new service concepts.
[P05]	(Châabane *et al.*, 2009)	Geographic ontology merging method consisting of three phases: determine the n-ary correspondences between the ontologies; identify mappings between the concepts of the candidate ontologies; rule-based merging to produce a global ontology.
[P06]	(Chen *et al.*, 2009)	Framework based on web services for knowledge integration from ontology integration.
[P07]	(Heer *et al.*, 2009)	Approach in which several ontologies can be merged into one using semantic correspondences. It is based on the assumption that all ontologies use a common top-level ontology.
[P08]	(Hu and Wang, 2010)	Presents merging heuristics/algorithms based on category theory for geology ontologies.
[P09]	(Juárez *et al.*, 2011)	Method that receives a set of source ontologies and a merging parameter and produces a domain ontology unifying knowledge from the source ontologies that meet the merging parameter.
[P10]	(Leung *et al.*, 2011)	Ontology development method that integrates methods of reuse and a system to support integration.
[P11]	(Lv, 2011)	Approach combining integration heuristics/algorithms and similarity measures to integrate ontologies.
[P12]	(Petrov *et al.*, 2012)	Intelligent system that supports merging of anatomical ontologies. It is based on directed acyclic graph models and three integration heuristics/algorithms.
[P13]	(Bova *et al.*, 2015)	Approach to integrate ontologies to support data interoperability and knowledge representation in intelligent information systems.
[P14]	(Cuenca *et al.*, 2017)	It deals with integration within the OEMA (Ontology for Energy Management Applications) ontology network, which is composed of eight interconnected domain ontologies.
[P15]	(Bova *et al.*, 2015)	Method that considers three processes and semantic mappings to integrate two ontologies.

RQ05. Which are the steps of the ontology integration approach? Are they explicitly defined? - Only the approach addressed in [P02] does not present steps explicitly defined. Table 3 presents the steps of each approach.

RQ06. Does the approach refer to ontology integration, ontology merging or both? - Five approaches (33%) ([P01], [P06], [P11], [P13], [P15]) refer to ontology integration, while nine (60%) P02], [P03], [P04], [P05], [P07], [P08], [P09], [P12], [P14]) refer to ontology merging. The approach reported in [P10] refer to both, integration and merging.

Table 3 – Steps of the ontology integration approaches

ID	Title
[P01]	Identify integration possibility, Identify modules, Identify ontological commitments and assumptions, Identify knowledge to be represented, Identify candidate ontologies, Obtain candidate ontologies, Study candidate ontologies, Select candidate ontologies, Apply integration operations, Analyze the resulting ontology
[P03]	Add top level concepts to both ontologies, Add intermediate concepts, Add more specific concepts, Include attributes and relationships
[P04]	Find ontology concepts and service descriptions to be integrated, Create new relationships with the descriptions and related concepts
[P05]	Find correspondences, Mapping, Merging
[P06]	Receive ontologies to be integrated, Perform similarity calculation of the ontology concepts, Merge the ontologies top-level concepts, Merge the subsequent concepts
[P07]	Ontology alignment, Ontology merging
[P08]	Establish the semantic relations between two geological ontologies, Merge synonyms in the overlapping set as a new concept, Add other concepts from source ontologies that do not belong to the semantic overlapping set, Add semantic relation (hyponym) in the semantic overlapping set, Add new semantic relations to the resulting ontology
[P09]	Source ontologies evaluation, Merging parameters definition, Equivalence mapping, Mapping filtering, Ontology merging using filtering results.
[P10]	Candidate ontologies identification, Concepts evaluation, Source ontologies identification and categorization, Knowledge modules modification, Connection points identification, Basic ontology building, Knowledge modules integration
[P11]	Identify alignment between entities, Find ontologies portions that overlap and integrate the ontologies, Perform the pruning of the integrated ontology through redundancy detection, Check the integrated ontology consistence
[P12]	Mapp the two input ontologies, Merge input ontologies in a super ontology
[P13]	Ontologies comparison, Concepts integration, Result checking, Interpretation, Ontology matching
[P14]	Ontology structure definition, Ontology selection for reuse, Addition of new information to the ontology, Ontology integration
[P15]	Semantic similarity calculation, Merging of concepts, Knowledge model building based on network, Model decomposition in blocks, Blocks rebuilding using semantic mappings between the concepts, Integrated ontology generation

RQ07. Is the ontology integration approach related to some ontology engineering method? If it is the case, which is the method and how does the approach relate to it? - 12 publications (80%) propose approaches addressing ontology integration in isolation (i.e., given two or more pre-selected ontologies, how to integrate them). Only three publications (20%) propose ontology integration approaches as part of a broader ontology engineering processes. In [P03], the integration approach refers to the ontology merging phase of SEMCO, an ontology engineering method that involves ontology development, ontology evaluation and ontology merging. In [P10], the integration approach is performed in the context of the analysis, design and implementation phases of the Method for Integration-Oriented Ontology Development, which includes preparation, analysis, design, implementation and maintenance. In [P14], the approach is performed in the context of the first, second and fourth phases of an ontology development method that includes requirements definition, ontology selection for reuse, implementation, ontology integration and evaluation.

RQ08. Is the approach guided by goals? - None of the approaches uses goals to support ontology integration.

RQ09. Does ontology integration use competence questions? - Only one approach ([P10]) uses competence questions to support ontology integration.

RQ10. Does the ontology integration approach use pre-selected ontologies, or does it aid in the selection of the ontologies to be integrated? - 12 approaches (80%) consider pre-selected ontologies for integration, that is, they assume that there are two or more selected ontologies that need to be integrated and focus on more specific issues of the integration problem (e.g., how to integrate concepts). Only three approaches (20%) ([P01], [P10], [P14]) define ontology selection as a step of the ontology integration approach.

RQ11. Does the ontology integration approach address only the conceptual level or also the operational level? - Only the approach presented in [P01] does not address the operational level. All others (93%) address both levels.

RQ12. Is the ontology integration approach automatic semiautomatic or non-automatic? - Six approaches (40%) ([P08], [P09], [P11], [P12], [P13], [P15]) provide automatic solutions, four (27%) propose semiautomatic solutions ([P02], [P07], [P10], [P14]) and three (20%) do not provide any computational assistance ([P01], [P03], [P05]). In ([P04], [P06] (13%) it was not possible to conclude if there is or is not computational assistance.

RQ13. Which types of semantic relationships between concepts are addressed in the approach? - Table 4 presents the identified semantic relationships and the approaches that address each of them. In the table, semantically equivalent relationships are listed separated by "/".

Table 4 – Semantic relationships addressed in the integration approaches

Semantic Relationship	Publications
Equivalence/Synonyms/Identity Semantic	[P02], [P04], [P05], [P07], [P08], [P09], [P11], [P12], [P13], [P15]
Specialization/hyponym/*Subsumption*	[P02], [P06], [P08], [P11], [P13], [P14]
Generalization/Hypernym	[P06], [P07], [P08], [P13], [P14]
Part Of/Part-Whole	[P04], [P08], [P12]
Overlap/Partial Equivalence	[P02], [P06], [P07], [P13],
Disjoint	[P02], [P07],
Dependency	[P08],
Spatial Identity	[P05]
Undefined	[P01], [P03], [P10]

5. Discussion

By analysing the publications distribution over the years (RQ02), it is possible to notice that although there has been research about the topic since 2001, it has not been regular. Moreover, considering the publication vehicles (RQ02) (there is a predominance of conferences instead of journals) and the types of research (RQ03), we can conclude that the topic has been explored but it is not mature yet. The lack of studies classified as Evaluation Research indicates that the approaches have not reached the practice.

With respect to the basic principle of the approaches (RQ04), the majority of them concern finding similarities or semantic relationships between concepts. These results show that integration approaches have been concerned with establishing relations between the ontologies concepts, which is very important to integration.

There have been concern with defining systematic processes for ontology integration (RQ05). Some steps are cited in several approaches, such as identification of mappings between concepts and merging/integration of concepts. Since these are core activities to integrate ontologies, it is not surprising that they are in most of the approaches. Besides these activities, integration approaches related to broader ontology engineering methods also include activities related to ontologies search and selection. Nevertheless, only three approaches ([1], [11], [14]) address ontology evaluation, even though this is an important activity in of ontology development. Only two approaches ([1] and [10]) address ontology modularization, an important aspect to manage complexity of ontologies. In the view of the above, we can notice that most of the integration approaches have been focused only on integration activities. In fact, most approaches are not concerned with the entire ontology development process (RQ07). As a consequence, these approaches ignore important steps in ontology development such as requirements elicitation, modularization, testing and evaluation.

There is a predominance of merging approaches (RQ06). This is probably due to two main reasons: (i) approaches focusing on more specific integration problems (e.g., how to integrate similar concepts) can deal with them by merging ontologies (i.e., there is no need to add new concepts to the integrated ontology); and (ii) merging can be seen as part of the integration process, i.e., ontology integration involves merging, since after merging ontologies, new concepts can be added to the resulting ontology.

Integration approaches have not been concerned with defining the goals the integrated ontology should achieve (RQ08). Most of the analyzed approaches were defined to be used in a specific situation (e.g., given two pre-selected ontologies, how to integrate them). Thus, a big picture of the goals the integrated ontology should achieve is not explored. Goals can be used to express the design rationale behind an ontology and can be helpful in the search for the ontologies to be integrated. Since most of the approaches (80%) use pre-selected ontologies (RQ10), they have not addressed issues that could help ontology search and selection. Moreover, since most approaches do not include steps to identify the integration goals, it is natural that they also are not concerned with defining the integration scope by means of competency questions (RQ09), which has to be made prior to carry out the integration itself.

Only one of the analyzed approaches does not address the operational level (RQ11). Most of the analyzed approaches were defined to deal with a specific situation, often related to computational applications. Thus, it is not surprising that most of the approaches address not only the conceptual but also the operational level. This can also be influenced by the fact that most of the ontologies available on the Web and used to form the Semantic Web are available only in their operational form. With the growth of the Semantic Web, there is also a growing need to integrate these ontologies. This also can explain the predominance of approaches with automatic or semiautomatic solutions (RQ12). As ontology integration can be a hard process when the ontologies to be integrated are large or heavy, the approaches have automated the process in order to request less intervention from the users.

Finally, the approaches have addressed few types of semantic relations (RQ13). Some approaches use only the equivalence relation, which limits the integration approach. Addressing only the equivalence relation leads to miss important mappings when the overlap of definitions and properties from different concepts is not complete. One of the reasons for some approaches to consider only the equivalence relation is their focus on operational solutions. Implementing heuristics to find equivalence mappings is easier than heuristics to find other types of semantic relations. However, ideally, the integration approaches should deal with a diversity of semantic relations, to enable proper identification of mappings between the ontologies to be integrated.

6. Limitations of the Study

Usually, when conducting secondary studies, researchers need to make a lot of decisions and exercise a lot of judgement. The decisions taken by researchers and the judgments influence the outcome both in terms of which publications are selected and what the researchers conclude from their secondary studies (Wohlin *et al*., 2012). Thus, as in any study, the study presented in this paper has some limitations.

Some of the challenges researchers may face during a systematic mapping are: (i) how to select a comprehensive and relevant source of publications; (ii) how to consistently apply the inclusion/exclusion criteria; (iii) how to classify and interpret data. In this study, we experienced these challenges and we take some actions aiming at minimizing the influence on the results.

With respect to (i), the study considered six digital libraries as source of publications. They were selected based on other secondary studies recorded in the literature, as well as on other secondary studies carried out in the research group in which this work was carried out (NEMO). While this set of digital libraries represents a comprehensive source of publications, the exclusion of other sources and the fact that we did not perform snowballing may have left some valuable publications out of the analysis.

As for (ii), publications selection and data extraction were initially performed by two of the authors and some subjectivity may have been incorporated, especially regarding the level addressed by the approach (conceptual or operational). Information contained in the publications could lead to a misunderstanding about this aspect. In order to reduce this subjectivity, the third author reviewed publications selection and data extraction and, in case of discordance or possible bias, discussions were held until a consensus was reached. With regard to the selection made from the search string, terminological problems may have led to not select some publications. In order to minimize this possibility, simulations were performed with variations of the string until obtaining the one that was used.

With respect to (iii), a classification scheme was defined for each research question. Some categories were based on classifications previously proposed in the literature (for example, for type of research we used the classification defined in (Wieringa *et al*., 2006)). Other categories were established during data extraction, based on data provided by the analyzed publications (e.g., types of semantic relations and categories of the approaches basic principle). Determining the categories and how the publications fit into them involves a lot of judgment. Data extraction and classification were performed by the first author and reviewed by the third. Even so, it is possible that other researchers would obtain different results.

7. Final Considerations

This paper presented a systematic mapping that investigated ontology integration approaches addressing the conceptual level. 591 publications were analyzed and 15 approaches were identified. Before performing the systematic mapping, we investigated the literature searching for secondary studies on ontology integration. Since no secondary study was found on the research topic, we decided to perform the systematic mapping.

The mapping results provide an overview of the research related to the investigated topic. In short, integration approaches, even when addressing the conceptual level, have also addressed (and, many times, focused on) the operational level. Most of the approaches have been proposed to address specific situations or specific integration problems. There has been concern with defining a systematic process to guide integration. However, in most cases, the integration process is not embedded in a broader ontology development process and considers the integration of pre-selected ontologies, without addressing search and selection of ontologies. Goals and competence questions have not been used to support ontology integration. Finally, approaches have considered few types of semantic relations, which tends to limit the mapping and integration of ontologies.

These results point to some gaps in the context of integrating ontologies at conceptual level: (i) lack of concern with defining the scope for the integrated ontology prior to the integration process; (ii) lack of concern with the goals that the integrated ontology must achieve; (iii) lack of concern with search and selection of ontologies to be integrated; (iv) limited use of semantic relations to map ontologies; and (v) lack of integration-based development processes that address the development of an integrated ontology considering the main phases of ontology engineering. These gaps provide a roadmap of issues to be explored in future researches.

As future work, we plan to investigate ontology integration approaches addressing only the operational level and verify if the concerns at this level are different than the ones we identified in this study. Moreover, considering the gaps we perceived from this study, we have proposed a goal-oriented systematic approach to develop ontologies based on integration and a framework to support our approach.

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