Enterprise Ontologies: Open Issues and the State of Research
A Systematic Literature Review

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Abstract: The aim of this work focused on the content of the subject ”Enterprise Ontology”. We present our ongoing work on analysing literature about enterprise ontology models. The provision of this analysis is on the one hand a summary of some previously published papers according to the topic and at the same time a precise differentiation can be documented between each work. Our contributions are twofold: first, we show how to find appropriate literature according to specific criteria and second, we answer special research questions which belong to ”Enterprise Ontology”. Moreover, the results of the different authors presented in this paper are innovative visions about creating and implementing tools or ontological models.

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1 INTRODUCTION

The concept of an Enterprise Ontology (EO) has received some attention in the last years. Many papers have been published that show EOs as a tool for enterprise development. Benefits generated with the help of EO, can be direct savings (Gailly and Poels, 2009; Wautelet et al.,1998;Sunkle et al., 2013) or an increase of business process efficiency (Guangwen and Hu, 2009; Moura et al., 2010) for example.

This paper tries to find answers to questions regarding past and ongoing research on EO. Where appropriate it shows statistics of different aspects of scientific activities in the area. The result is a categorization of streams in EO research. Our systematic analysis does not go into every detail of the papers, nor does it discuss the opinion of all authors. The main aim of this paper is to give a summary which generally describes research activities in the area of EO.

The remainder of this paper is organized as follows. The next section generally introduces the concept of Enterprise Ontologies. Section 3 briefly discusses the process of a systematic literature review and its specific implementation for our investigation. This includes the formulation of the research questions. The findings of the performed literature review are described in section 4. The last section 5 outlines the most important conclusions.

2 ENTERPRISE ONTOLOGY

An ontology is an explicit specification of a conceptualization (Gruber, 1995). The ontology includes definitions of concepts and an indication of how concepts are inter-related which collectively impose a structure on the domain and constrain the possible interpretations of terms (Uschold, 1995) . The ontology is used to improve communication between either humans or computers. In the concrete, the ontology is used to assist in communication between human agents, to achieve interoperability among computer systems, or to improve the process and/or quality of engineering software systems (Jasper and Uschold, 1999). The combination of the computer systems of an enterprise, their connections to each other and the related exchange of information can be seen as the Enterprise Architecture (EA) (Stelzer 2010; Hanschke 2009; Meyer and Birsöz, 2009; Rosauer et al., 2004; Feldschmid, 2009) . Therefore, if the Enterprise Architecture is defined in an ontology, communication problems in EA related tasks can be reduced. Ontologies provide a tool for communication and for formalization.

Concretely, stakeholders of an enterprise can share exact and common interpretations of the Enterprise Architecture and its components. Furthermore, systems interoperability can be improved. This fosters internal system integration

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and external cooperation (Kang et al., 2010). In general, an EO is a formal and explicit specification of a shared conceptualization among a community of people of an enterprise (or a part of it). It includes static, kinematic, and dynamic aspects, for example reflecting the Enterprise Architecture.
In particular, an ontology satisfies the next five quality requirements (C_4E) (Dietz, 2006):

- Coherence - the different aspects of the models form a logical and truly integrated entirety
- Comprehensiveness - all relevant issues are covered, so the entirety is complete
- Consistency - the models are free from contradictions and irregularities
- Conciseness - the entirety is compact and succinct, no superfluous matters are contained in the models
- Essence - shows only the essence of the enterprise, its core structure

Enterprise ontologies can be used in many different sectors and various organizational roles, for example:

- Managers are enabled to understand the essence of their enterprise.
- Software developers can use a formal specification of organizational aspects .
- Employees are aware of the role they fulfil in the organization of the enterprise.
- Auditors - Enterprise Ontologies can provide full transparency to the operations of an enterprise.

3 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. 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 EO, the following questions drew our attention:

RQ1: How much research activity on the field of EO has there been since 2007?

RQ2: What research topics are being investigated?

RQ3: What research approaches are being used?

RQ4: What applications are seen for EOs?

RQ5: Which topics regarding EO 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 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 and Charters (Ivarsson and Gorschek, 2009) .The next paragraphs describe the performance of these steps in detail.

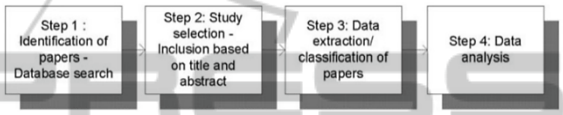

Figure 1: Review Process (Ivarsson and Gorschek, 2009).

3.1 Identification of Papers

The first step was the identification of EO related papers in a selection of appropriate literature sources. Sources were the journals on ”Computers in Industry” (CII), Information Systems (IS), Expert Systems with Applications (ESA) and the digital libraries of Springer, of the Association for Computing Machinery (ACM), of the Computer Society (CSDL), and of the Institute of Electrical and Electronics Engineers (IEEE).

In order ensure a comprehensive and unbiased identification, certain keywords have been determined to apply them in the search process.

These keywords were elaborated by test searches or by altering the form of the words, e.g. plural. Figure 2 presents the search terms used. Papers have only been selected if one of the keywords appeared in the title or abstract. A full text search would have resulted in too many irrelevant papers. (Ivarsson and Gorschek, 2009; Kitchenham, 2004).

3.2 Paper Selection

In this step, the abstract is examined to reduce the remaining research papers to the ones which are relevant for answering the research questions. A main criterion for the selection was that the paper has to deal with the topic EO by investigating methods, tools, theories, examples, deployment, evaluation etc. Additionally, only research papers have been included because our focus lies on

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keywords	CII	IS	ESA	Springer	ACM	CSDL	IEEE
enterprise ontologies	204	95	281	399	78	191	2
enterprise ontology	204	95	281	399	278	191	23
organizational ontologies	134	74	204	63	10	12	0
organizational ontology	134	74	204	63	15	12	0
organisational ontologies	134	74	204	63	15	37	0
organisational ontology	134	74	204	63	44	37	6
ontology business	208	125	504	53	50	145	2
organisation ontologies	199	137	502	104	8	220	0
organisation ontology	199	137	502	104	20	220	0
organization ontologies	199	137	502	104	5	220	1
organization ontology	199	137	502	104	20	220	6
Sum	1948	1159	3890	1519	543	1505	40
sorted by reading abstract only	7	6	9	43	4	0	35
sorted by reading whole content	**3**	**2**	**6**	**10**	**0**	**0**	**19**
Final sum of papers	**40**						

Figure 2: Paper Selection - Overview.

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research streams.

Regarding the abstract in- or exclusion of papers was based on the following rule:

Include: One of the activities like investigating methods, tools, theories, examples, deployment, evaluation etc. is named as a main contribution of the paper.

Exclude: Otherwise

3.3 Data Extraction

This process was based on full text studying. Relevant data was mapped directly to the research questions and stored in a table. For each selected paper, this table contained a reference to the original paper and paper meta-data like the author and the author's affiliation. Later a classification of the paper content with regard to the research questions was added. (Ivarsson and Gorschek, 2009).

3.4 Data Analysis

The data analysis summarizes the results of the data extraction and provides answers to the research questions. The analysis can be descriptive or quantitative. Quantitative and descriptive information should be arranged in tables or figures with respect to the research questions. These tables or figures should highlight the differences and similarities of the papers. Regarding the classification of paper content there is an iteration between data extraction and data analysis. For example, the classification scheme of research approaches (RQ 3) is based on the approaches found by performing the paper analysis. (Ivarsson and Gorschek, 2009; Kitchenham, 2004).

3.5 Threats to Validity

There are two main threats to validity. First, there is the selection bias. The sample taken for literature review may not represent the current state of research. Nevertheless, figure 2 shows a broad base of identified papers regarding the topic. Thus, our selection is considered to be representative. The second threat lies in the process of data extraction. For example, the classification of the papers is based on subjective decisions to some extent. The research questions help to reach a certain level objectivity. Additionally, the data extraction process has been done by three persons on order to reduce the individual influence of a single subject.

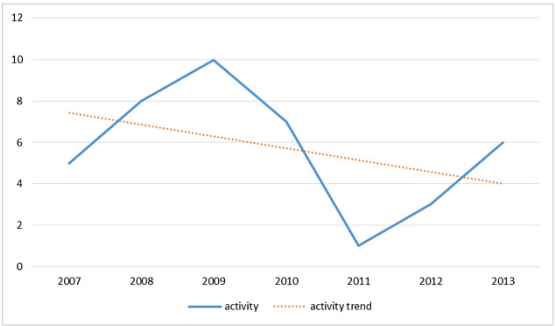

Figure 3: Research activity on the field of EO.

4 RESULTS AND ANALYSIS

In the previous sections the purpose and the process of the systematic literature review have been described. This section describes the results of data analysis. The research questions that have been formulated at the beginning are used to structure the results.

RQ1: How much activity on the field of "Enterprise Ontology" has there been since 2007?

In general, there has been some activity in the research area of EOs in the period from 2007 to today. Figure 3 shows the activity in a graph.

The blue line describes the absolute number of papers that have been found in the corresponding year. There are two major turning points. The peak of activity was in the year 2009 and the bottom in 2011. After 2011 the activity increases but the number of papers has not yet been as high as in 2009. The orange line displays the trend over the complete period of time. Apparently, the trend of the research in the field of EOs decreases slightly. Nevertheless, since there was a turning point in 2011 it seems that EO research will get more attention in the next years.

RQ2: What research topics are being investigated?

There is no dominant research topic that is covered by the majority of the selected papers. But the classification by research topics lead to a ranking. The following overview shows the quantities of papers that are summed up to a topic (see figure 4):

- 11 papers are related to the topic of *Creating Enterprise Ontologies*; an example of this class is the paper "Enterprise Ontology - Diagnostic Approach". It deals with the construction of an enterprise ontology with the purpose of diagnosing economic situations.(Andreasik, 2008)
- 9 papers are related to the use of *Enterprise Ontologies as Supportive Tools for information systems*; an example for this class is the paper "TCM (Traditional Chinese Medicine) Telemedicine with Enterprise Ontology Support a Form of Consensus-Certified Collective Human Intelligence" which is about constructing telemedicine systems with EO support. (Wilfred et al., 2009)
- 5 papers are related to the *Mapping and Modelling of Enterprise Ontologies*. The difference between this topic and *Creating Enterprise Ontologies* lies in the focus on altering existing ontologies in contrast to ontology creation; an example for this class is the paper "Towards Ontology-Driven Information Systems: Redesign and Formalization of the REA Ontology" which is about the transformation of EOs (Gailly and Poels, 2007)
- 4 papers are about Tools and *Examples of Enterprise Ontologies*; an example for this class is the paper "A Core Ontology for Business Process Analysis" which deals with an example of an ontology that enhances business process analysis. (Pedrinaci et al., 2008)
- 3 papers are related to *Enterprise Ontology based Frameworks*; an example for this class is the paper "Organization-Ontology Based Framework for Implementing the Business Understanding Phase of Data Mining Projects" which presents theoretical work on an ontological framework. (Sharma and Osei-Bryson, 2008)

The topics of the remaining 8 papers cannot be assigned to classes defining a general topic. They are summarized in the class *Other*. The following chart provides a graphical overview of the allocation.

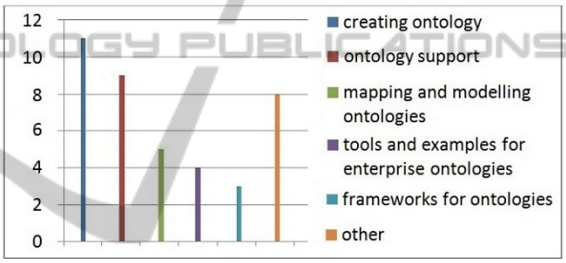

Figure 4: Research topics.

RQ3: What research approaches are being used?

The most common research methods used to evaluate the subject EOs are *Theoretical Work* (54%) followed by *Prototyping* (27%)(see also figure 5). An interesting point is that our research shows a significant count of *Experiments* and *Case Studies*. The reason might be that this research methods focus on verification and evaluation of already existing prototypes and techniques in the area of EOs. The large number of papers containing just *Theoretical Work* may have its reason in the lower amount of resources needed. Additionally there might be too much attention to theoretical work in the community. "As recent developments in the sciences demonstrate, this often goes hand in hand with a misrepresentation of the role of theoretical work". (Atmanspacher, 2010)

On the other hand, the topic EO is still in the early stages of research. Therefore, it might be that many issues must be clarified in advance before the approaches can be applied in practice. This could explain the high number of papers having *Theoretical Work* as research approach. However,

our study also shows a remarkable number of papers on a *Prototype* which does not fit to the previous assumption. There are many approaches, methods, and applications (see RQ 4) for Enterprise Ontologies that have already been validated in practice.

RQ4: What applications are seen for "Enterprise Ontology"?

Based on the literature review, there are different purposes of EOs that can be categorized into the following classes:

Creating Artefacts

A variety of approaches have been found concerning the use of EOs for the creation of new methods and applications solving enterprise problems. Based on an EO it is possible to create a Corporate Memory (Probst and Jussupova-Mariethoz, 2007), Value- and Design-Chains (Chae et al., 2009) , Information Systems (Schartz et al., 2010) , Reports (Schartz et al., 2010) , a Diagnosis of an economic situation (Andreasik, 2008) of a company.

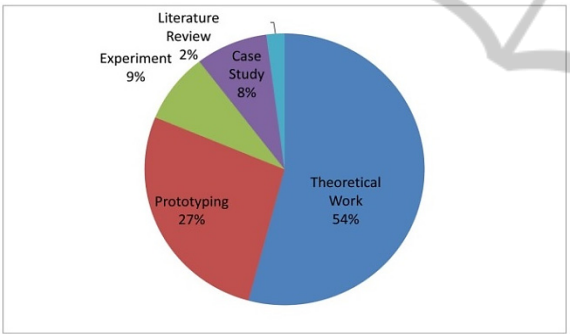

Figure 5: Research Approaches.

Interoperability and Translating/Mapping

Approaches to realize interoperability in several application areas have been discovered. With "Ontology Mapping" (Harding and Kumar, 2013) it is possible to convert existing ontologies into a state where all ontologies can be connected with each other. In addition, there are mapping methods in order to translate an EO into a full functional information system (Hysmans et al., 2010) . Another approach is semantic interoperability (Chae et al., 2009). Here, the focus lies on the integration of enterprise values with consideration of the meanings underlying these values. Finally there are also possibilities to make heterogeneous information massifs of business applications interoperable (Leppänen, 2007; Gailly and Poels, 2007).

Integration and Collaboration

In addition to the integration of information systems and the collaboration of enterprises (Lee et al., 2010; Chae et al., 2009) , there are also applications to align business ontologies for integrating heterogeneous business processes (Jung, 2009). Furthermore, there are possibilities for planning and integrating businesses (Zordan and Umar, 2009) with EOs and also approaches to integrate entire businesses (Gailly and Poels, 2007; Leppänen, 2007).

Support and Handling Knowledge

Enterprise Ontologies offer the opportunity to support business processes (Starzecka et al., 2008; Lee et al., 2010) , improving quality in education (Isbandi, 2013) and dealing with competency models (Sanchez-Alonso et al., 2012). Furthermore, managers and other leading actors can use EOs for better decision making (Isbandi, 2013) . In addition, EOs can be used to control the quality for enterprise models and can assist at data mining (Liu et al., 2007) . Moreover, EOs can form a base for knowledge-management (Woo et al., 2009) , support collecting knowledge (Chen, 2008; Starzecka et al., 2008) and knowledge sharing with different participants (Wang et al., 2008) .

Summarized, EOs offer many possible applications as shown above. Though, the strength of EOs is the support of enterprises at realizing interoperability, integration and collaboration. Another important and usefully application is managing information and knowledge of enterprises.

RQ5: Which topics on the field of "Enterprise Ontology" need further research according to the authors?

In order to summarize potential future research streams regarding EOs, a classification scheme based on the outlook sections of the selected papers has been constructed. Based on our results we were able to determine the structure as follows.

Validation of Proposed Approaches

Most of the authors say that their approaches have to be validated (Starzecka, 2008; Harding and Kumar, 2013; Lee et al., 2010; Huysmans et al., 2010; Latifi et al., 2011; Isbandi, 2013; Sharma and Osei-Bryson, 2008; Moura et al., 2010; Pedrinaci et al., 2008; Gailly and Poels, 2007; Gailly and Poels, 2007a; Gailly and Poels, 2009; Wautelet et al., 2009; Jung, 2009; Jiang et al., 2010). This can be proven for example by surveys, practical implementations in companies or maybe expert surveys. It needs to mentioned that most paper's basic idea is to create

an ontology or to use ontologies to support (enterprise) systems (see RQ2). The result of that fact is that the authors need feedback from other instances, because most of their ideas are theoretical works or prototypes (see RQ3).

New classification of Business Values in Real life

A topic for further research activities is the classification of business values. The classification of these values includes the relationships between business strategies, business processes and enterprise resources explicitly (Woo et al., 2009; Lee et al., 2010; Latifi et al., 2011; Isbandi, 2013; Sharma and Osei-Bryson, 2008; Starzecka et al., 2008; Gailly and Poels, 2007; Wautelet et al., 2009; Schütz et al., 2013; Zordan and Umar, 2009; Andreasik, 2008). With the support or integration of EO in the field of these business interconnections researches could access the next level of the business environment. Members of enterprises could help to interpret the new information, because the semantics need to be clarified.

Collaborate with EO through Semantic synchronization

Some authors think that a specific ontology can increase interoperability between systems (Leppänen, 2007). With the help of semantic operations the user or a system can interact in a more understandable way with another system. The next step will be combining two or more ontologies (Schwart et al., 2010; Pooley and Chen, 2009; Gaaloul et al., 2012; Soussi and Aufaure, 2012; Poels and Decreus, 2008) in order to allow collaboration in a bigger scale regarding the content.

Get more Efficiencies and Improvements with the help of EO

Some problems occur in the understanding of controlling approaches. Some authors created different tools or models, which could handle this problem. For example a metrics computation engine (Lee et al., 2010;Pedrinaci et al., 2008; Probst and Jussupova-Mariethoz, 2007) which detects process deviations or a knowledge base construction (Li and Huang, 2008) , which could give useful controlling information. These ontology applications can realize for example efficiency improvements (Moura et al., 2010; Yao et al., 2009; Xie, 2009; Chen, 2008; Sanchez-Alonso et al. 2012) or can help in problem analysis (Wilfred et al., 2009; Santos et al., 2013; Wang et al., 2008; Sunkle et al., 2013). The goal is to maximize interoperability of controlling systems, the profit or the accuracy of information and to minimize complexity in systems and in system interaction.

The extension of EO

There are different ontologies which represent economic values. For example REA (McCarthy and Geerts, 2002), the e3-value ontology (Gordijn, 2002), and the e-Business Model Ontology (e-BMO) (Osterwalder, 2004). Based on these some authors intent to provide extensions (Gailly and Poels, 2009; Gailly et al., 2013; Sunkle et al., 2013). Mostly these papers provide ontology prototypes. Thus, here is a potential ti investigate the practical utility of these prototypes and to discuss further improvements.

5 CONCLUSIONS

The presented systematic literature review analysed the field of Enterprise Ontology research. Out of 135 initially found articles, 40, reaching from 2007 to 2013, have been finally included in the review. Regarding the publication activity, the period of 2007-2013 shows that the previously falling trend may turn into a positive direction in the near future.

The evaluation of the papers has shown that most of the content relates to the creation of ontologies or the use of particular ontologies. Detailed core concepts are the creation of a new application software or methods to deal with a special problem. The realization of interoperability or the integration of different information massifs is another core concept. It is also important to mention that ontologies contribute to handling knowledge of an enterprise and to the translation or mapping of information.

A further important fact is that Enterprise ontologies can be used for collaboration between companies and are used to support various business processes.

Finally, Enterprise Ontologies provide an interesting research topic which has the potential for further research activities and practical integration into enterprises. The results may be used for example as quality indicators, which may be included into industrial and standardized models and methods.

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