Evaluation of Ontology Mapping Representations

Hendrik Thomas[1], **Declan O'Sullivan**[1], **Rob Brennan** [1]

Abstract. A common approach to mitigate the effects of ontology heterogeneity is to discover and express the specific correspondences between different ontologies. An open research question is: how should such ontology mappings be represented. In recent years several proposals for an ontology mapping representation have been published, but till today no format is officially standardized or generally accepted in the community. In this paper we will present a new evaluation framework for ontology mapping representations for a pragmatic state of the art overview of their characteristics. In particular we are interested how current ontology mapping representations can support the management of ontology mappings (sharing, re-use, alteration) as well as how suitable they are for different mapping tasks.

1 INTRODUCTION

Ontologies are an important component for the implementation of the semantic web vision [1,2]. The promise of ontologies is to enable the sharing of a common understanding of a domain of interest that can be flexibly communicated between users and applications [3,4]. However, the actual conceptualization of a domain and the succeeding explication in an ontology language is a very heterogeneous process [5, 6]. For example, on a syntactical level a user can choose from a variety of ontology languages (e.g. RDF, OWL, Topic Maps, etc.) [5,7]. On a terminological level one can encounter all forms of mismatches related to the process of naming of ontology entities (e.g. synonymy, homonyms, multilanguage) [8]. Furthermore conceptual heterogeneity of ontologies arises due to the natural human diversity involved in modeling a domain [9,10], e.g. two ontologies could differ because they cover different (even overlapping) portions of the domain, provide a more (or less) detailed description or simply could reflect different viewpoints of the same domain. Finally, on a pragmatic level, one can encounter discrepancies related to the fact that different individuals may interpret the same ontology in different ways in different contexts [5,11]. Overall these levels of heterogeneities are major obstacles to the promised interoperability of ontologies [8].

A common approach to mitigate the effect of heterogeneity is to discover the specific correspondences between the different ontologies and to document these correspondences using an appropriate mapping expression [12, 13, 14]. In particular ontology mapping can be defined as the task of relating the vocabulary of two ontologies sharing the domain in such a way that the structure of ontological signatures and their intended interpretations are respected [15]. Despite the increasing tool support in the last years (e.g. MAFRA [16] COMA++ [17], Ontology Alignment API [9]) ontology mapping is still a challenging, complex and time-consuming process [9,12,15,18]. The different related issues in ontology mapping have been widely addressed in literature [5,12, 19].

One key aspect, which is still open to discussion, is the question: how should ontology mappings be explicit represented [9,19]? In this paper we define an ontology mapping representation as an explicit specification of the correspondence between ontologies to improve their interoperability. In recent years several proposals and recommendations for such an ontology mapping representation have been published, but till today no representation specific format is officially standardized or even generally accepted in the semantic web community [12, 20]. Thus an ontology engineer, when confronted with the need to merge or align multiple ontologies, has a choice between multiple currently available ontology mapping representations, each with their individual strengths and weaknesses for a specific mapping task.

Publications focusing on ontology mapping representations are relatively rare compared to the huge number focusing on other related questions, e.g. matching algorithms to identify mapping candidates (e.g. [21]). However, some previous studies on ontology mapping systems, in particular in [9,15,2,22,23], provide some insight. Most of these previous evaluations focus primarily on the technical capabilities of matching and mapping tools [20,24] and less on applicability of mappings representations for different mapping tasks [5, 18]. In addition, only sparse information has been published on the support of reusability and management of mappings, e.g. definitions of what meta-data types are supported. Finally, the evaluation processes as well as the criteria sets used have been heterogeneous, which makes it difficult to identify trends and improvements over time. In summary, a detailed evaluation framework as well as a comprehensive and up-to-date evaluation focusing on the capabilities of current ontology mapping representations is currently missing.

In this paper we will present a new evaluation framework for ontology representations used for a systematic analysis of ontology mapping formats that provides a state of the art overview of their characteristics. In particular we are interested how the ontology mapping representations can support the management of ontology mappings (sharing, re-use, alteration) as well as how suitable they are for different mapping tasks. The results of this evaluation will be of interest for understanding ontology mapping interoperability issues and also to support ontology engineers in choosing the most suitable mapping representation for their application.

2 EVALUATION FRAMEWORK

In this section we outline our evaluation methodology, set high-level goals for ontology mapping representations and finally decompose each high-level goal into specific metrics that can be evaluated.

[1] Knowledge & Data Engineering Group, School of Computer Science and Statistics, O'Reilly Institute, Trinity College Dublin, Ireland, Email: {**Hendrik.Thomas,Declan.OSullivan,Rob.Brennan** }**@cs.tcd.ie**

2.1 Methodology

To be able to compare and evaluate ontology mapping representations, first we need to define a set of evaluation criteria. Then these criteria can be consistently applied to any desired representations. To derive the criteria we will apply the Goal Question Metric (GQM) method, this is a tried and tested method for a structured and replicable evaluation of software products [25,26]. GQM provides a hierarchical structured procedure starting with goals (object and the issue to be measured) for each relevant evaluation dimension [25]. Each goal is refined into several questions, to break down the issue to characterize the object of measurement. Each question is then refined into metrics (objective, subjective) in order to answer it in a quantitative way. The result of the application of the GQM method is a replicable and detailed specification of a measurement system targeting a particular set of issues and a set of rules for the interpretation of the measurement data [25].

In the following sub-sections we describe an evaluation framework for ontology mapping representations derived using this method.

2.2 Goals for Ontology Mapping Representations

The first task in the development of an evaluation framework is the identification of a suitable set of goals for ontology mapping representations. Turning to the literature of ontology alignment and mapping it can be observed that instances of ontology mapping types can be quite heterogeneous, ranging from simple equivalences relations, mathematical conversions too complex structural mappings [12,27,28]. Therefore one of the most fundamental goals of ontology mapping representations is (G1) *the ability to express a mapping relation*. The second aspect we considered is that the construction of a specific ontology mapping can be complex and time-consuming. In fact, it could be more complex than the knowledge expressed in the ontologies itself [12,20]. Instead of creating the same or similar mappings repeatedly it is important to have a goal (G2*) to enable sharing and reuse of existing mappings* to reduce the effort involved in the creation of mappings [8]. Besides these aspects, an ontology mapping representation (G3) *should be computationally efficient to process* [8] in order to support the pragmatic concerns of implementing ontology interoperability solutions.

In the following subsections a set of questions is derived for each of our three goals that expose the different evaluation criteria used to characterize ontology mapping representations.

2.3 Goal 1: Ability to Express a Mapping Relation

Ontology mapping representation applicability can be considered from the viewpoint of expressiveness in terms of which operators and functions are supported to express the relevant ontology elements in correspondence and their individual alignments [20].

The first question in this context is therefore: (Q1) which kinds of ontology elements can be addressed so they can become the subjects of a mapping? This includes a single relevant ontology entity, an individual ontology fragment (e.g. specified by a search query) as well as the ontology as a whole. To simplify the expression of correspondences between ontologies it is important to know (Q2) which predefined relation types are supported, e.g. equability, incompatibility [29]. The specific set of supported relation types and the number of predefined relation types are indicators of the applicability of the representation. Also relevant is the extendibility in terms of: is it possible to add new transformations or relation types and still preserve the interpretability and processing ability of the representation in applications, e.g. by using an ontology language [12]. Specific knowledge, e.g. the date of birth of Tim Berners Lee, can be represented in quite different formats or conventions [10]. As a result, ontology mappings often have to deal with all kinds of conversions to enable interoperability [5,8]. It is therefore interesting to define (Q3) which functions are supported by the ontology mapping representation to express conversion mappings? This includes functions to manipulate numerical vales, text and dates.

Probably the most complex task for an ontology engineer is the handling of conceptual heterogeneity, because there is always more than one valid way to model a domain of interest [8,18], e.g. an address can be represented a single property or as a list of instances. From an abstract point of view this means ontologies could differ because different ontology elements and/or relations are used to express the same meaning [10]. Therefore it is relevant to ask (Q4) what functions an ontology mapping representation supports to express how relevant knowledge can be extracted and rearranged to make it interoperable (structural mapping). This involves adding or removing classes, instances, attributes (e.g. variant name in Topic Maps) and relations. It is also relevant if such a structural mapping is limited to a single representation language or not, e.g. can a mapping format express the mapping between RDF and Topic Maps which have different syntax and semantics [30, 31].RDF and Topic Maps which have a different syntax and semantics [30, 31].

Tab. 1 gives an overview of all deducted criteria for this goal.

Criteria	**Type**	**Examples**
Question 1: Which kind of ontology elements can be addressed?		
Single ontology element	yes|no	OWL class, property
Ontology fragment	yes|no	SPARQUL Query: SELECT ?x WHERE { ?x <http:// vcard-rdf/3.0#FN> "John" }
Ontology as a whole	yes|no	http://kdeg.org/nembes.owl
Question 2: Which relations types are predefined?		
Amount predefined types	0..X	3
List of predefined types	list	equivalence, subsumption
Extensibility	yes|no	add a "neighbour" relation
Question 3: Which function for conversion mappings are supported?		
Numerical function	yes|no	add, subtract, multiply
String functions	yes|no	delete leading white spaces
Date functions	yes|no	2006/12/31 to 31/12/2006
Question 4: Which function for structural mappings are supported?		
Add / remove classes	yes|no	remove class town
Add / remove instances	yes|no	add instance Dubln
Add remove relation	yes|no	add Dublin is-part-of Ireland
Add remove attributes	yes|no	remove a variant name
Language specific	yes|no	OWL specific mapping

Table 1. Goal 1: Ability to Express a Mapping Relation

2.4 Goal 2: Enable Sharing and Reuse of Existing Mappings

To make a decision as to if and how a mapping can be reused or updated it is essential to understand how the mapping was created in the first place. An analysis of the life cycle of an individual ontology mapping is helpful to identify relevant decisions and information sources used, e.g. which matching algorithms have been used to identify the mapping candidates [16, 12,32]. Meta-data documenting this lifecycle is essential to facilitate sharing and reuse of mappings. An ontology mapping representation should provide suitable placeholders to store and make this kind of information retrievable in a structured and predictable way [33].

Previously we have defined a mapping lifecycle [12]. The first stage of the ontology mapping lifecycle is the characterization phase which needs to be documented in the mapping representation and thus forms our first question of this goal (Q1). In the characterization phase the ontologies are analyzed with respect to their amenability for mapping. This involves the initial discovery of the ontologies; hence an ontology mapping representation needs to provide information to identify the ontologies which are the subject of the mapping like an identifier, path or an URL. However, ontologies may change over time and therefore additional ontology versioning information is useful to decide if a mapping is still appropriate [8,10]. Furthermore information on the format of the mapped ontologies are helpful to decide if an existing mapping is applicable in a different context, e.g. OWL DL or full [12]. Due to the syntactical heterogeneity many mapping tools require an initial transformation into an internal canonical format [17]. This has an impact on the supported ontology syntax and a mapping representation should include information on the canonical format used. Due to the terminological heterogeneity in this phase usually the content of the ontology is analyzed in order to characterize the nature of the terms used [8]. Descriptions of term construction rules or domain-specific thesauri/vocabularies used can influence the selection of an appropriate matching algorithm and should therefore be documented in the mapping representation [34]. In general, poor quality ontologies or divergent modeling approaches can make mapping attempts quite difficult or even impossible [35]. As a result, measures (qualitative and quantitative) of the ontology and the modeling approach applied are useful to understand the decisions made in the mapping process [12,36]. Another vital part of this life cycle phase is the decision whether matching should be attempted between ontologies. This decision can be influenced by organizational policies which govern the expenditure of resources [37]. If so, these policies should be documented because they are vital to understand future mappings.

One of the most important tasks in this phase is the identification of mapping candidates, either identified by manual selection or by an automated matching algorithm. If candidates have been manually selected, detailed information on this process (participants, time, context) as well as on the provenance of the data needs to be accessible. For example, if mappings are reused in a different organization, another role might be more appropriate for selection of mapping candidates [38]. Alternatively a wide range of matching algorithms can be applied, ranging from lexical to semantic model-based matching schemes [21]. The matching algorithm has a major impact on mapping creation and therefore it is essential to document the name as well as the specific configuration of the matching algorithms used [9]. Different matcher algorithm might be suitable for mapping task and therefore any information related to the matcher selection process is helpful, e.g. type of the matcher (string, language, constraint, linguistic, reuse, graph, taxonomy, model or combination based [21].

The second stage of the ontology mapping lifecycle (Q2) is the mapping phase which needs to be documented in the mapping representation [12]. The objective of this phase is generation of the information necessary for the execution of mappings as well as the creation of mappings that are relevant to the context of usage. As in the previous phase, it is necessary to check possible mappings against organization policies which need to be documented [12,37].

The determination of mappings by applications as well as humans from matching candidates is difficult and involves a certain level of uncertainty [8,17]. Suitable points of reference help to make the deduction process more predictable [12]. This includes pre-existing validated and trusted mappings or an explicit definition of the mapping context. Based on this information, a variety of strategies may be suitable for creating the mappings. For future reuse it is therefore important to know which specific strategy was applied [12]. It is also relevant to record any confidence value calculated or assigned to the mapping during the mapping or match generation processes.

Criteria	**Type**	**Examples**
Question 1: How is the characterization phase documented?		
Ontology identifiers	yes|no	string based matcher
Version information	yes|no	ontology version 1.5.4.
Ontology format(s)	yes|no	OWL lite, RDF(s)
Canonical format	yes|no	XML schema used in OISIN framework [12]
Terms used	yes|no	link to relevant thesauri
Ontology measures	yes|no	count of classes
Matching policies applied	yes|no	policy of organisation A
Type of matching creation	yes|no	automated or manual
Info on manual matching	yes|no	link to documentation
identifier of the used matcher	yes|no	model based matcher
Matcher configuration	yes|no	parameter
Matcher type	yes|no	linguistic based matcher
Question 2: How is the mapping phase documented?		
Matching policies applied	yes|no	policy of organisation A
Used pre-validated mappings	yes|no	A;creator = B;author
Mapping context	yes|no	specification of use-cases
Confidence level	yes|no	5 of 10
Mapping strategy	yes|no	OISIN framework [12]
Question 3: How is the management phase documented?		
Distribution system	yes|no	peer-to-peer network
Version information	yes|no	map version 1.2.3
Format information	yes|no	INRIA 1.0
Conflict/consistency check	yes|no	conflict mapA vs. mapB
Author information	yes|no	Hendrik Thomas
Date of creation	yes|no	19.12.2008 17:00
Authority for changes	yes|no	see http://onto.authority.ie
Dependencies	yes|no	mapping A depends on B
Change propagation method	yes|no	newsgroups announcement
Question 4: How is the interpretation of the meta-data supported?		
URI to identify entities	yes|no	http://cs.tcd.ie/onto/fname
Human-readable labels	yes|no	first Name
Documentation	List	source code, publications
Documentation URI	yes|no	http://cs.tcd.ie/onto/docu

Table 2. Goal 2: Enable Sharing & Reuse of Existing Mappings

The last phase of the mapping life-cycle (Q3) is the management phase which needs to be documented in the mapping representation. Any distributed system may be suitable for sharing mappings but the mapping representation should at least specify where to find the latest mapping sources as well as version information in order to keep track of mapping updates. Also any representation should explicitly specify its own format version, to support forward and backward compatibility. If mappings are used in a different contexts it is necessary to verify if they are consistent or in conflict with the existing mappings. A mapping representation could support this challenging task by providing a placeholder for relevant information, e.g. a suggested detection strategy. In addition existing mapping information can be altered or withdrawn, e.g. if they are erroneous [10,35]. A mapping representation should provide lifecycle information to support this, for example [12]: Who created the mapping and who has authorization to make changes. Which existing mappings are influenced by the proposed alteration? How will the change be propagated?

Another important issue in this context is (Q4) how is the interpretation of the meta-data supported by the mapping representation? Applications commonly use unique URIs for unambiguous identification of entities [2]. However, humans depend on human-readable labels as well as sufficient documentation (source code, tutorials, publications) which explain how specific meta-data should be interpreted. Similar to the subject indictor resources of Topic Maps [34,39] it is also useful that the URI of the meta-data field should refer to such an explanatory document to make the representation more self-explanatory to a human. Table 2 gives an overview of all deducted criteria for the second goal.

2.5 Goal 3: Computationally Efficient to Process

A first aspect is the (Q1) compatibility of the representation. It is thereby relevant whether the representation is implementation independent or is limited to a specific application. Also relevant is the question how easily the representation can be manipulated, e.g. by using a common syntax like RDF. The second aspect (Q2) are tools to support creation, sharing [40], management and visualization of mapping results and representations. Table 3 gives an overview of all deducted criteria for the third goal.

Criteria	Type	Examples
Question 1: How is the comparative is the representation?		
Implementation independent	yes|no	MAFRA format
Syntax	yes|no	XML, RDF, OWL
Question 1: What tool support is available?		
Creation & editing tools	List	Ontology Alignment API
Sharing tools	List	-
Management tools	List	COMA++
Mapping visualization tools	List	MAFRA

Table 3. Goal G3: Computationally Efficient to Process

2.6 Selection of Ontology Mapping Representations

In addition to the previous defined criteria the evaluation framework must also contain a set of rules defining how a specific evaluation should be conducted. The key question is: which ontology mappings representations should be included in the evaluation? Currently there are several non-ontology based (e.g. Text, XML) and ontology based (e.g. RDF, OWL [2]) languages used to express mappings [8]. The problem is that there is no consistent usage of these languages or formats. In fact many mapping tools use the same languages to express mapping results (e.g. RDF is very common) but in different ways and as a consequence they support different functions and operators to express mappings [8,12]. From a pragmatic point of view it is therefore not enough to evaluate a representation language like OWL in isolation. It is more important to understand how ontology mapping representations instances are supported by the individual ontology mapping tools.

3 SUMMARY AND OUTLOOK

In our evaluation we analyzed overall 13 different mapping and matching applications (see appendix for a complete list). The selection include historical relevant and established tools but also examples of leading up-to-date matching application [24]. For each of the 22 supported ontology mapping representation instances, 31 different evaluation parameters were determined. The evaluation was conducted in early 2009 by the authors in the Knowledge and Data Engineering Group, Trinity College (Dublin). The complete evaluation results are available online at: *https://www.cs.tcd.ie/~thomash/mapping_eva/home.php.*

The evaluation created a large amount of data and the upcoming workshop is a perfect opportunity to discuss our results with researchers and industry partners in order to identify issues and to develop a better understanding of the advantages and limitations of current mapping representations. Also we hope for feedback to optimize our current evaluation framework and suggestions for other ontology mapping systems which need be include into our next evaluation.

In conclusion, the previous remarkable efforts to support the creation of ontology mappings are just the first step. Further research is needed to develop a powerful mapping representation which is essential for the management, sharing and reuse of ontology mappings to even begin to support the flexible communication of a common understanding of a domain between users and applications a scale large enough to control the overall information glut [2].

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APPENDIX A OVERVIEW OF EVALUATED APPLICATIONS

Application	Link
Alignment API	http://alignapi.gforge.inria.fr/
Anchor-PROMPT	http://protege.stanford.edu/plugins/ prompt/prompt.html
COMA++	http://dbs.uni-leipzig.de/Research/coma.html
Context Matching Algorithm (CtxMatch)	http://dit.unitn.it/~zanobini/ downloads.html
CROSI Mapping System (CMS)	http://www.aktors.org/crosi/
Falcon-AO	http://iws.seu.edu.cn/projects/matching/projects.jsp
Framework for Ontology Alignment and Mapping (FOAM)	http://www.aifb.uni-karlsruhe.de/ WBS/meh/foam/
Lily	http://ontomappinglab.googlepages.com/lily.htm
MAFRA	http://mafra-toolkit.sourceforge.net
MapOnto	http://www.cs.toronto.edu/ semanticweb/maponto/
OntoBuilder	http://iew3.technion.ac.il/ OntoBuilder
Ontology Mapping Tool OMT)	http://www.wsmx.org/
Risk Minimization based Ontology Mapping (RiMOM)	http://keg.cs.tsinghua.edu.cn/project/RiMOM/