Ontology Mapping Representations: a Pragmatic Evaluation

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Abstract— A common approach to mitigate the effects of ontology heterogeneity is to discover and express the specific correspondences (mappings) 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 as yet no format is officially standardised or generally accepted in the community. In this paper we will present the results of a systematic analysis of ontology mapping representations to provide 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.

I. INTRODUCTION

Ontologies are an important component for implementation of the semantic web vision [1]. The promise of ontologies is to enable the sharing of a common understanding of a domain that can be flexibly communicated between users and applications [2,3]. However, the actual conceptualisation of a domain and the subsequent explication in an ontology language is a very heterogeneous process [4]. For example conceptual heterogeneity arises due to the natural human diversity involved in modelling a domain [5], e.g. two ontologies could differ because they provide a more (or less) detailed description or could reflect different viewpoints of the same domain. These different levels of heterogeneities [6] are major obstacles to the promise of interoperability based on ontologies [7].

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 ontology mapping expression [8,9]. We define ontology mapping as the task of relating the vocabulary of two ontologies sharing a domain in such a way that the structure of ontological signatures and their intended interpretations are respected [10].

One aspect, which is still open to discussion, is: how should ontology mappings be represented [6,8,11]? 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 as yet no representation specific format is standardised or even generally accepted in the semantic web community [8,12]. 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 representations of ontology mapping are relatively rare compared to the huge number focusing on other related questions for matching and mapping, e.g. matching algorithms to identify mapping candidates [13]. However, some previous studies on ontology matching and mapping systems provide some insight [10,11,12]. Most of these previous evaluations focus primarily on the technical capabilities of matching and mapping tools [12,14] and less on applicability of mappings representations [6]. In addition, only sparse information has been published on the support of reusability and management of mappings, e.g. specification of supporting meta-data [11]. Finally, the evaluation processes and criteria sets used in previous work have been quite 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 present the results of a systematic analysis of ontology mapping representations to provide a pragmatic 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 will also support ontology engineers in choosing the most suitable mapping representation for their application.

II. EVALUATION FRAMEWORK

A. *Methodology*

To derive metrics for an evaluation of mapping representations we apply the Goal Question Metric (GQM) method as a tried and tested method for a structured and replicable evaluation of software products [15]. GQM provides a hierarchical structured procedure starting with goals for each relevant evaluation dimension [15]. 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 relevant issues [15]. In the following subsections we give a brief introductionto our evaluation framework for ontology mapping representations derived using the GTM method. The framework reflects our evaluation focus on management and applicability of ontology mapping representations. A detailed description of the framework can be found in [16].

B. Evaluation Goals, Questions and Metrics

Turning to the literature of ontology mappings it can be observed that instances of mapping relations can be quite heterogeneous, ranging from simple equivalence relations or mathematical conversions to complex structural mappings [5,11,12]. Therefore one of the fundamental goals of ontology mapping representations is (G1) *the ability to express a mapping relation*. Relevant for this goal are the ontology elements which can be addressed as well as the different kinds of mapping relation types which are supported. In addition we need to consider the supported operators and functions for the expression of conversion and structural mappings. Table I gives an overview of all deduced criteria for this goal [16].

TABLE I GOAL 1: ABILITY TO EXPRESS A MAPPING RELATION

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	SELECT ?x WHERE {?x ?y ?z}
Ontology as a whole	yes|no	http://kdeg.org/nembes.owl
Question 2: Which relations types are predefined?		
Count of predefined types	0..X	3
List of predefined types	list	equivalence, subsumption
Extensibility	yes|no	add a "neighbor" 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 Dublin
Add remove relation	yes|no	add Dublin is-part-of Ireland
Add remove attributes	yes|no	remove a variant name

The second aspect is that (G2) *ontology mapping representation should be computationally efficient to process* [7,11] in order to support the pragmatic concerns of implementing ontology interoperability solutions. Table III gives an overview of all deducted criteria for this goal.

TABLE II GOAL 2: COMPUTATIONALLY EFFICIENT TO PROCESS

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

Besides these aspects we need to consider that the construction of a specific ontology mapping can be complex and time-consuming [12]. 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 [7,8]. To decide if an ontology mapping can be reused, it is essential to understand how the mapping was created. An analysis of the life cycle of an ontology mapping [7] is helpful for identification of relevant decisions and information, e.g. which matching algorithms have been used [8,18]. Meta-data documenting this lifecycle is needed to facilitate sharing and reuse of mappings. An ontology mapping representation should provide suitable placeholders to make this information retrievable in a structured and predictable way. Previously we have defined a mapping lifecycle [8] and based on that we identified metadata to document the source and target ontologies, the matching phase to identify mapping candidates, the mapping phase as well as the management phase. Table II gives an overview of all deduced criteria for this goal.

TABLE III GOAL 3: SHARING & REUSING OF EXISTING MAPPINGS

Criteria	Type	Examples
Question 1: How are the sources and target ontologies 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 [8]
Terms used	yes|no	link to relevant thesauri
Ontology measures	yes|no	count of classes
Question 2: How is the matching phase documented?		
Matching policies applied	yes|no	policy of organization A
Matching creation type	yes|no	automated or manual
Info on manual matching	yes|no	link to documentation
Identify 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 organization 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 [8]
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	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 of meta data	List	source code, publications
Documentation URI	yes|no	http://cs.tcd.ie/onto/docu
Ontology identifiers	yes|no	URL of ontology source

Another relevant issue for this evaluation framework is: which ontology mapping 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 [1]) languages used to express mappings [7]. 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 [7,8]. From a pragmatic point of view it is therefore not enough to evaluate a representation language like OWL in isolation. In fact, it is important to understand which specific instances of ontology mapping representations are supported by the individual mapping tools.

III. EVALUATION RESULTS

In this evaluation we analyzed 13 different mapping and matching applications (see appendix for a complete list). The selection include historically relevant and established tools but also examples of up-to-date matching applications [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/results.php*

A. Results for G1 Ability to Express a Mapping Relation

The first aspect we analyzed in our evaluation was the expressiveness of the application in terms of which operators and functions are supported to express mappings. We noticed that all analysed tools are limited to addressing individual ontology elements as subjects of mappings (Q1). Thus none of the evaluated applications is able to address ontology fragments which is quite odd because mappings of complex statements need to consider more than one concept and could easily be addressed with current querying languages (e.g. SPARQL) [7]. Considering the support for mapping correspondences, we ask which predefined types are supported (Q2). Our data showed that majority of analysed applications (61%) support only the equivalence relation. Other popular mapping types are subsumption and incompatible. The majority of applications (> 64%) don't support the extensibility of predefined mapping types (Q3). Only analyzed APIs (e.g. FOAM [25], Alignment API [26]) could (at least theoretically) be extended to support other mapping types. However, that isn't a flexible and user-friendly approach. Another aspect is the support of functions to express complex mapping. Our data showed that no mapping instance supports conversion functions (G3), e.g. numerical, string or date. An exception is RIMOM [27], which support basic numerical functions to manipulate attributes, e.g. <user> #addr+#zip=#ci</user>. Also most representation instances (> 76%) don't support functions for structural rearrangements. Only MAFRA [18], OMT, RIMOM [27] support adding of instances and attributes. Overall complex mappings can not be represented with the analyzed tools. Please note that Alignment API provides an export in XSLT, which supports complex transformations but in the current version none are supported.

B. Results of G2: Computationally Efficient to Process

On examination of the compatibility of the ontology mapping representation (Q1) we note that 68 % of the representations are implementation independent because they are based on common standard technologies like XML or RDF. Only 27 % of the applications use a proprietary format (text files) . The majority of representations (> 36.5 %) are based on RDF. In particular 5 of these 8 mapping representation instances are based n the RDF based INRIA format [26]. This shows that INRIA is still not a de-facto standard but a most popular method for representing mappings. However, this popularity is supported by the fact that the Ontology Alignment Contest demands that all results are delivers in the INRIA format [24]. Considering the tool support (Q2), to the best of our knowledge the majority of mapping representations can only be edited and visualized in their original tools. The only exception is the INRIA format which can be processed by different mapping tools, e.g. Lily, FOAM, RiMOM. Also, as far as we know none of the analyzed applications provide any sophisticated management or sharing tools for mapping information. One exception is COMA++ which provides functions for the manipulation of previous confirmed mapping results, e.g. invert domain or difference analysis [19]. Also worth mentioning is the OMT which supports the automatic testing of mappings to ensure that a given set of source instances translate into the expected set of target instances. However, many tools are based on standard languages like XML or RDF and these can be processed by other common applications.

C. Results of G3: Enable Sharing and Reuse of Existing Mappings

The third goal analyzed was: how mapping representations instances support the sharing and reuse of previous mappings [7,8]. In particular we analyzed how the ontology mapping life cycle is documented. The first question was: what meta-data is supported to document the source and target ontologies (Q1). The first finding is that all mapping representations contain an ontology identifier, e.g. URI, file paths or labels. This is not surprising because a basic requirement for any mappings is the ability to identify the source and target ontology. Furthermore, none of the analyzed representations provide any information on the version of the processed ontologies. This is quite odd because ontologies can be very dynamic (reviews, updates) and the validity of mappings must be checked for any new version of the ontology. For the processing and especially the applicability of automated matching algorithms it is important to know the ontology format. However, only 64 % of the representations provide such information and in the majority the format can only be deduced by the file extension. This is ambiguous because ".owl" could indicate an OWL DL or OWL Full ontology, e.g. which is essential for a reasoning based matcher. Only the INRIA format [12] and the XML format used by OMT explicitly specify the format which is more appropriate for users and applications. None of the analyzed mapping representations contained information on the used canonical format, the terms usage as well as ontology measurements.

The second question is: how is the mapping phase documented (Q2)? It is important to understand how matching candidates were created to decide if a mapping can be reused. Most applications don't provide any information on the applied matching policies. Only in FOAM [25], an individual classifier can be defined to model simple matching policies. Considering information on the applied type of matcher we must note that only FOAM explicitly specifies if an automated or manual matching was applied. This is quite odd given the fundamental difference between automatic and manual matching relating to quality and quantity [11,17]. In addition no representations provided details on the manual matching process (e.g. who, when) which makes a validation almost impossible. On the other side at least 23 % of the mapping formats specified the applied matching algorithm but commonly by a unambiguous labels, e.g. "Value Algorithm" in Ontobuilder. In common quite different parameters are used to configure automated matchers [11] and it is surprising that only 9 % of the representations specify the applied matcher configuration. Also none of the formats contain information on the specific type of automated matching algorithm, e.g. string or structure based.

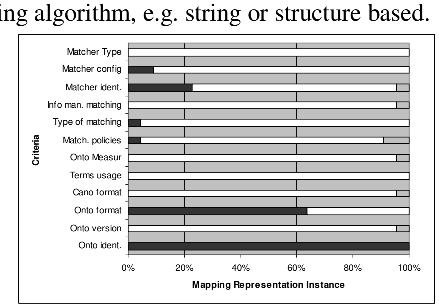

Fig. 1. Results for the Documentation of the Source and the Target Ontologies Phase and the Mapping Phase

The next question was: how is the mapping phase documented in the mapping representation? (Q3). Our results showed that most mapping representation instances don't provide information on applied mapping policies. Only in MAFRA is it possible to define simple mapping conditions. In addition, most formats don't provide information on pre-validated user mappings. Only the representation used by FOAM provides an explicit link to pre-validated user mappings. Also no information is available on the context in which the mapping was created. This is especially problematic because many decisions made in the mapping life cycle are based on external factors and therefore the context is essential for a validation of mappings. The majority of representations (59 %) provide a confidence level for each mapping pair. In common this is a normalized measure of the strength of the relation provided by the applied matching methods [11]. However, it is problematic that no information is available about, how these individual ratios are calculated and should be interpreted. Also the documentation of the applied mapping strategy is very limited. Only FOAM and RIMOM provide a placeholder for a mapping strategy.

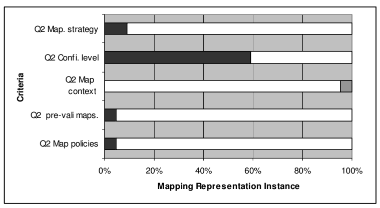

Fig. 2. Results for Q2 Documentation of Mapping Phase

In conclusion we asked: how is the management phase documented in the mapping representation? (Q4). None of the analyzed mapping representations provided any information on the distribution system and therefore it is difficult to find the newest version of the mappings. Also no information on the version of the mapping itself is provided as well as no information on possible conflicts. Really surprising was that no representation contained information on the author or the date of creation. The only exception is RIMOM which at least stores a creation date but it is unclear how the value should be interpreted. To know which specific mapping format used is essential for processing, but only 50 % of the mapping representations instances explicitly specify their format. In addition none of the formats provide any information on the authority for changes, relevant dependencies or the method for change propagation. Overall this is a major problem because it makes the management and sharing of mappings over time or in a different context challenging especially if the source and target ontologies evolve over time. As a result, current mapping phase relies on external change management and consistency systems.

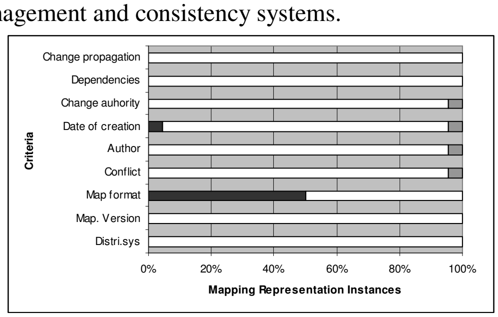

Fig. 3. Results for Q3 Documentation of Management Phase

The last question was: how is the interpretation of the meta-data supported? (Q4). Our data showed that the majority of representations (> 73%) use URIs to identify elements in the mapping representation. However, URIs are commonly established but they are not consistently used in all implementations. Thus not always an unambiguous identification is provided, e.g. only 68 % of the source and target ontologies are identified by a URI, the rest only by file paths and simple labels. In addition, in all mapping representations human-readable labels can be found which helps users to interpret the mapping representations. However, only 59 % of the applications provide a documentation which is commonly very rudimentary. Also none of the URI's refer to a explaining web resource.

IV. SUMMARY AND FUTURE WORK

In this paper we have presented an evaluation of ontology mapping representations. In summary, our evaluation revealed three insights. Firstly, when the heterogeneity of mapping use-cases [28] is considered, the level of supported expressiveness in mapping applications and representations is still too low and can not be extended flexibly. The majority of representations support only equivalence relation and no complex mappings. This result is not surprising because most applications are designed as matching tools and their main purpose is the identification of equivalence relations. However, this study is limited to actual implementations but other more generic and expressive mapping languages have been designed, e.g. C-OWL [29]. Such languages may be more powerful but they are not currently used or supported by tools.

Secondly, our evaluation showed that all phases of the ontology mapping lifecycle are very poorly documented and as a result management and reuse of mappings is insufficiently supported by current mapping representations. The lack of meta-data makes it impossible to identify the provenance of the mappings, the latest version of the mappings or the context in which they were created or used. Also disappointing is the common lack of sufficient documentation which makes correct and consistent interpretation of the representations difficult or impossible. Another disadvantage is that currently all meta-data is stored in single attributes only. However, most meta-data elements have a complex knowledge structure and a simplified model is not enough for a practical reuse, e.g. an authors name is not enough to contact him. Recently, sophisticated technologies have been evolved to model complex meta-data, e.g. FOAF for contact details. Such common and established technologies are currently not used in mapping representations but could support the creation of richer knowledge models and interoperability of lifecycle meta-data.

Thirdly, the evaluation showed that the majority of mapping representations can be processed efficiently because they build on standard technologies. RDF is the most common language to express mappings and the RDF based INRIA format has the highest chance of establishment as a de facto standard. However, the majority of the representations can only be reused efficiently in the original application which makes reuse in a broader scale challenging. Hence, ontology mapping representations are still very limited and heterogeneous in terms of expressiveness and meta-data support. No standardised ontology mapping representation has yet emerged or is generally accepted.

The reasons for this are the multitude of mapping/matching approaches available, e.g. different matching algorithms, matching types etc. Each approach has unique requirements for mapping representation, simply because different information and structures need to be represented to express a correspondence. The design of a mapping representation which fulfils all those requirements might be too complex or could lead to a format which represents only the smallest common denominator. For example INRIA is generic but, compared to proprietary formats (e.g. FOAM) less detailed. Multiple mapping representations may be unavoidable because for different mapping scenarios, different representations of the mapping correlations are suitable. In contrast, meta-data which documents the mapping lifecycle is more uniform and for most correlation representations are available. As a result we propose that it is more beneficial to develop the concept of a flexible enrichment of existing and future ontology mapping representations in order to augment their usage, reuse and management. In particular, in an ontology based meta-layer a common vocabulary for modelling life-cycle meta-data could be established and linked to the individual formats representing mapping correlations [20]. Established mapping formats and tools don't need to be changed but available meta-data can still be stored and retrieved in a structured, documented and predictable way.

In conclusion, the remarkable efforts to support the creation of ontology mappings are just the first step. Further research is needed to develop more powerful concepts for the management, sharing and reuse of ontology mappings to even begin to support the flexible communication of a common understanding of a domain at a scale large enough to control the overall information glut [1].

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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
Context Matching Algorithm (CtxMatch)	http://dit.unitn.it/~zanobini/downloads.html
CROSI Mapping System	http://www.aktors.org/crosi/
Falcon-AO	http://iws.seu.edu.cn/projects/matching/projects.jsp
Framework for Ontology Alignment & 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 s	http://www.wsmx.org/
Risk Minimization Ontol-	http://keg.cs.tsinghua.edu.cn/project/Ri

ogy Mapping (RiMOM)	MOM/