D2.2.1 Specification of a common framework for characterizing alignment

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Abstract.
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Executive Summary

In a distributed and open system (like the semantic web), heterogeneity cannot be avoided. Some of the heterogeneity problems can be solved by aligning heterogeneous ontologies. This is illustrated through a number of use cases of ontology alignment (in deliverable D2.2.3).

In this document the problem of overcoming heterogeneity is equated to the problem of discovering, expressing and using ontology alignments. The goal of this document is to provide a common framework for future work in this domain. It first provides a definition of many of the terms used in the domain. In particular, aligning ontologies consists of providing the corresponding entities in these ontologies. These correspondences are called mappings.

We identify four levels at which heterogeneity occurs: syntactic, teminological, conceptual and semiotic. We focus on the terminological and conceptual levels and do not consider the other aspects in this document. So the ontologies are considered as expressed in the same (or at least comparable) languages.

Then we provide definitions for the nature of alignments through the approximation relations between the aligned ontologies and the structure and semantics of mappings.

An alignment is a set of mappings expressing the correspondence between two entities of different ontologies through their relation and a trust assessment. The relation can be equivalence as well as specialisation/generalisation or any other kind of relation. The trust assessment can be boolean as well as given by other measures (e.g., probabilistic or symbolic measures) .

A general framework is provided for expressing the semantics of these mappings in distributed systems. This framework is instanciated in model theoretic terms for crisp mappings and fuzzy mappings.

This semantics allows to fix the goal of the alignment process and to ground the use of the produced alignments in order to merge and transform ontologies or translate data flows. This is will be the goal of future work.

We then turn to the characterisation of the alignment process which takes two ontologies and produces such an alignment. It is characterised by a number of dimensions applying to the input ontologies, input alignments (when the task is alignment completion), method parameters, output alignment and the alignment process itself. Specifying each of these dimensions enable to consider particular applications or methods. It thus provide a basis for evaluating alignment methods described in deliverable D2.2.3 by defining what are input and output of the alignment process. Designing benchmarks will be the goal of our future work (deliverable D2.2.2).

Contents

Chapter 1

Introduction

1.1 Objectives of this document

The goal of this document is to provide a common framework for future work in the domain of semantic interoperability. In this document the problem of overcoming heterogeneity is equated to the problem of discovering, expressing and using mappings across ontologies.

The main contribution is a general characterization of what an alignment and an alignment process are in the context of the Semantic Web enterprise, and a specification of a formal semantics. The framework aims at the greatest possible generality, but will not cover approaches and models which fail to fulfill a high level requirement of any semantic web development, namely that mappings – the result of the alignment process – should have an explicit and formal semantics, as this is the minimal conditions for their usability in any semantic-based application.

This common framework is to be used by the partners of the Knowledge Web work package 2.2 and other Knowledge web groups as a reference document for models, languages and techniques related to the problem of aligning heterogeneous information. It is not a goal of this document to provide any detail or model of how a mapping between heterogeneous representations (e.g. ontologies) can be discovered, nor how mappings can be used in any specific application (e.g., data integration, query answering). The discovery and the usage of mappings is the object of other deliverables (*viz.* D2.2.3).

This is the first version of deliverable D2.2.1. It will be followed by an improved version once the framework has been used in practice.

1.2 Terminology

The framework presented in this document builds on top of a lot of recent work on the problem of semantic interoperability. In this area, different authors use different words to refer to similar concepts, and vice versa sometimes different concepts are referred to by the same name. In this section, we provide a tentative and partial glossary with the definition of terms as they will be used in the rest of the document and should be used within the Knowledge web work package 2.2.

Mapping: a formal expression that states the semantic relation between two entities belonging to different ontologies. When this relation is oriented, this corresponds to a restriction of the usual mathematical meaning of mapping: a function (whose domain is a singleton). Mappings are discussed at length in Chapter 4.

Ontology Alignment: a set of correspondences between two or more (in case of multi-alignment) ontologies (by analogy with DNA sequence alignment). These correspondences are expressed as mappings. Alignments are detailed in Chapter 3.

Ontology Coordination: broadest term that applies whenever knowledge from two or more ontologies must be used at the same time in a meaningful way (e.g. to achieve a single goal).

Ontology Transformation: a general term for referring to any process which leads to a new ontology o' from an ontology o by using a transformation function t. Transformations and the like are the subject of further work in this work package.

Ontology Translation: an ontology transformation function t for translating an ontology o written in some language L into another ontology o' written in a distinct language L'.

Ontology Merging: the creation of a new ontology o_m from two (possibly overlapping) source ontologies o' and o''. This concept is closely related to the that of *integration* in the database community.

Ontology Reconciliation: a process that harmonizes the content of two (or more) ontologies, typically requiring changes on one of the two sides or even on both sides [Hameed *et al.*, 2004].

Meaning Negotiation: the protocol through which two agents (either human or artificial) agree on the changes required to reconciliate their ontologies.

1.3 Structure of the document

This deliverable will first consider the types of heterogeneity that may occur in the semantic web and how to overcome them through alignment (Chapter 2). It will then propose a general structure (Chapter 3) and a semantic (Chapter 4) for these alignments. The framework ends with a characterization of the alignment process (Chapter 5).

Chapter 2

Semantic heterogeneity

In a distributed and open system (like the semantic web), heterogeneity cannot be avoided. Different actors have different interests and habits, use different tools, and use knowledge at different levels of detail. These various reasons for heterogeneity lead to different forms of heterogeneity that are considered below.

An ontology is a set of assertions that are meant to model some particular domain, in a consensual way. However, there is a huge body of evidence (in the literature of artificial intelligence, Cognitive Science, Linguistics, Epistemology, Sociology of Knowledge) that an ontology – as any other explicit representation of knowledge – always depends on a collection of implicit assumptions, no matter how hard its designers work to make it as "objective" as possible. These assumptions (including its designer's goals, background knowledge, biases, etc.) have the effect of creating several forms of heterogeneity between ontologies, even between ontologies on the same domain. We classify below (Section 2.1) the main forms of heterogeneity.

Heterogeneity affects the ontology used as well as the data exchanged. However, the actors of the semantic web have to communicate and to collaborate and thus need to overcome this kind of heterogeneity. We consider then how alignments can be used for overcoming these problems (Section 2.2).

2.1 Forms of heterogeneity

Heterogeneity may occur at different levels, and a detailed list of all forms of possible mismatches is beyond the scope of this document (see [Giunchiglia and Walsh, 1992; Benerecetti *et al.*, 2000; Klein, 2001; Euzenat, 2001; Corcho, 2004; Hameed *et al.*, 2004; Ghidini and Giunchiglia, 2004]). However, for the sake of the definition of a common framework, we suggest that they can be classified into four main levels: syntactic, terminological, conceptual, semiotic/pragmatic. Each of them is briefly described in the following sections.

2.1.1 The syntactic level

At the syntactic level, we encounter all forms of heterogeneity that depend on the choice of the representation format. Indeed, there are several proposed formats for ontology representation (e.g. OWL, KIF), and each of them is based on a different syntax.

Some of them are syntactic sugar (e.g., n3 and RDFS, DATALOG and a subset of Prolog), some of them are more complicated and involve expressing the same thing (having the same set of models) through totally different syntax.

Example 1 (Translating from DLR to CPDL) *In order to decide query containment in the DLR description logics, [Calvanese* et al.*, 1998a] defines a mapping from the DLR logic (which introduces n-ary relations) to the CPDL logic (Propositional Dynamic Logic with Converse). These relations are represented by concepts with exactly n features to the components of the relation.*

This transformation is a consequence preserving transformation.

In this document, and more generally in the work package 2.2 of Knowledge web, we are not strongly concerned about this syntactic level, which is well understood in computer science in general. Therefore, in what follows, we will assume that the different formats can be interoperated at a syntactic level. This is typically achieved through a translation function (see Section 1.2).

As a working assumption, from now on we assume that ontologies are represented using a common syntax (e.g., OWL). However, the framework presented in this document does not depend in any essential way on this assumption.

2.1.2 The terminological level

At the terminological level, we encounter all forms of mismatches that are related to the process of naming the entities (e.g. individuals, classes, properties, relations) that occur in an ontology. Naming is the process of associating a linguistic object from a public language (namely a language that is then use to exchange information with other parties) to entities described in an ontology. This level should not be confused with the conceptual level (see below); indeed, tricky terminological mismatches may occur in situations where the involved ontologies are conceptually equivalent.

Typical examples of mismatches at the terminological level are:

- different words are used to name the same entity (*synonymy*);
- the same word is used to name different entities (*polysemy*);
- words from different languages (English, French, Italian, Spanish, German, Greek, etc.) are used to name entities;
- syntactic variations of the same word (different acceptable spellings, abbreviations, use of optional prefixes or suffixes, etc.).

In a sense, mismatches at the terminological level are not as deep as those occurring at the conceptual level (see below). However, we should notice that most real cases have to do with the terminological level (e.g., with the way different people name the same entities), and therefore this level is at least as crucial as the other one.

2.1.3 The conceptual level

At the conceptual level, we encounter mismatches which have to do with the content of an ontology. Discrepancies at this level can be analyzed in two main classes:

- *metaphysical* differences, which have to do with how the world is “broken into pieces” (i.e., what entities, properties and relations are represented in an ontology);
- *epistemic* differences, which have to do with the assertions that are made about the selected entities.

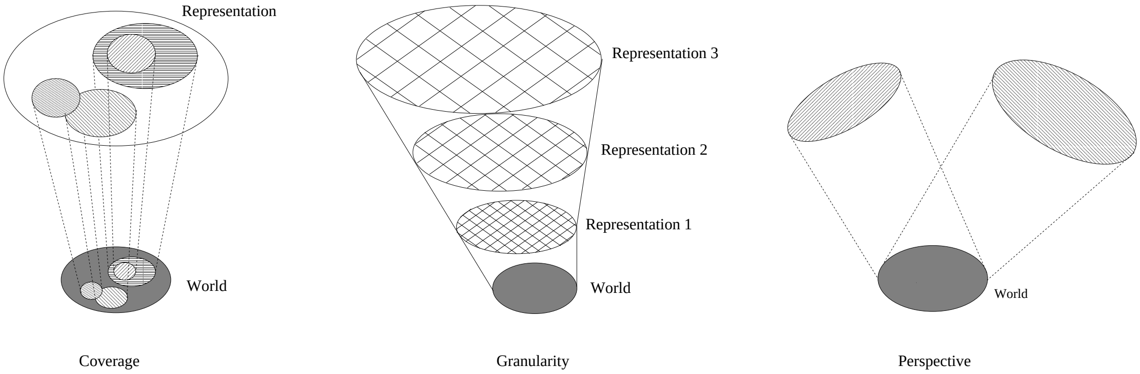


Figure 2.1: The three dimensions of heterogeneity at the conceptual level

These two kinds of differences explain, for example, why different ontologies of the same domain may start from different primitive classes, or why different ontologies may contain different (possibly contradictory) assertions about the same entities. As epistemic differences cannot be dealt with exclusively through mappings, in the rest of the document we will ignore this kind of difference, but we'll comment a bit later on the relation between the two forms of heterogeneity.

The practical forms in which metaphysical differences can arise are countless. However, following the artificial intelligence literature in this topic (in particular [Benerecetti *et al.*, 2000]), we suggest to cluster them into three abstract types:

Coverage: an ontology may differ from another as they cover different portions – possibly overlapping – of the world (or even of a single domain). For example, an ontology on sport may include car racing, whereas another may decide to ignore it as part of the sport domain; an ontology may contains properties of car racing that another disregards; and so on.

Granularity: an ontology may differ from another as the first provides a more (or less) detailed description of the same entities. For example, an ontology concerned with accounting and taxes, or delivery, would only consider the generic concept of document, while an ontology for libraries or scholars would distinguish between types of documents, e.g. books, biographies or autobiographies. Likewise, in the ontology of a Finnish, or a nivologist, there are many concepts of snow depending on how it is, while the ontology of a Tahitian or computer scientist would include significantly fewer snow related concepts.

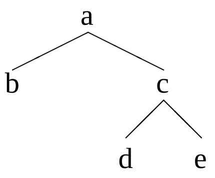
Perspective: an ontology may provide a viewpoint on some domain which is different from the viewpoint adopted in another ontology. For example, two ontologies may represent the same domain at the same level of coverage and granularity, but at different points in time (which means that the same property can hold at the time when the first ontology was designed and do not hold at the time when the oter was designed, without a real epistemic disgreement), or from a different spatial perspective (what is on the right hand side from one agent's perspective may be to the left hand side for another agent facing the opposite direction).

Figure 2.1 provides a graphical representations of these three dimensions along which ontology may differ at the conceptual level.

2.1.4 The semiotic/pragmatic level

Finally, at the semiotic/pragmatic level, we encounter all the discrepancies that have to do with the fact that different individuals/communities may interpret the same ontology in different ways in different contexts.

For instance, in a context related to knowledge formalisation, a user can express knowledge under the form of class hierarchies and first order clauses and then communicate it by using an interoperability language. But if this last language expresses all the knowledge with clauses (though preserving the semantics of the assertions), the initial user will hardly recognise (and hardly understand) the semantically equivalent result (see figure 2.2). Hence, when a transformation translates between formal languages, good understanding cannot be ensured by meaning preservation (which can indeed be preserved in this case) [Euzenat, 2000; Bechhofer *et al.*, 2001]. In this case, there is no syntactic heterogeneity (because clauses are allowed in the initial model) and no conceptual nor terminological heterogeneity: only a failure to interpret the (equivalent) representation by its designer.



$$\begin{aligned}\forall x, b(x) &\implies a(x)\\ \forall x, c(x) &\implies a(x)\\ \forall x, d(x) &\implies c(x)\\ \forall x, e(x) &\implies c(x)\end{aligned}$$

Figure 2.2: Do these representations mean the same?

The intended usage has a great impact on alignment, as it can be quite risky to map entities onto each other only because they are semantically related. For example, if the concept `Europe` appears in the classification schema of a multimedia repository along a path such as `Images/B&W/Europe`, we should not conclude that it is equivalent to the concept of Europe in a geographic ontology, as the pragmatically determined meaning of the first is to be a container of black and white images of Europe, whereas the intended meaning of the second is the continent itself (this is not to say that the two things are not connected, but to warn that mappings should take intended use of each structure into account).

2.2 Overcoming heterogeneity

One common approach to the problems of heterogeneity is the definition of relations across the heterogeneous representations, in particular across ontologies. These correspondence can be used for various tasks such as merging ontologies, generating mediators, translating messages, etc. These relations can be used for transforming expression of one ontology into a form compatible with that of the other. This may happen at any level:

syntactic: through transducers preserving the semantics of expressions;
terminological: through functions mapping lexical information;
conceptual: through general transformation of the representations (sometimes requiring a complete prover for some languages);

pragmatic: through transformation taking care of the context. This path is hardly explored though ([Bouquet *et al.*, 2003; Goguen, 1999] are exceptions).

This means that any mapping across ontologies has four distinct components:

1. a *syntactic component*: the syntactic transformations needed to transform one representation format into another. As we said, this aspect is not central in this document, and therefore we will ignore it;

2. a *terminological component*: the part of a mapping that expresses terminological relation between the expressions used to name the entities to be mapped. Simple examples are: the name of two entities is the same; the two entities are named with expressions that are one the translation of the other in a different language; the name of an entity is an abbreviation of the name of the other;

3. a *conceptual component*: the part of a mapping that expresses the relation between entities in different ontologies. Simple examples are: concept c_1 in ontology O_1 is equivalent to concept c_2 in ontology O_2; concept c_1 in ontology O_1 is similar to concept c_2 in ontology O_2; individual i_1 in ontology O_1 is the same as individual i_2 in ontology O_2...

4. a *semiotic/pragmatic component*: the part of a mapping that bridges the use of entities in different ontologies. For example, that the concept c_1 used in a schema O_1 to classify a collection of documents is used in a sense defined by c_2 in ontology O_2; that the name used for a concept in a schema is taken from a lexicon L.

In work package 2.2, we restrict our attention to terminological and conceptual heterogeneity. Indeed, syntactic heterogeneity is well understood in computer science and is generally solved by proving the semantic-preserving correspondence between two languages; pragmatic heterogeneity is currently a relatively poorly structured research domain (in which we contribute anyway). The techniques for finding, expressing and using alignments at the terminological and conceptual level are relatively integrated. Finally, the conceptual part is the most studied component of a mapping, and is probably the most important one for its role in the development of the semantic web.

The use of a mappings across heterogeneous ontologies requires a clear definition of their meaning. Similarly, for generating useful alignments, it is better to know what is expected from them. This is the reason why the current framework will provide a syntax and semantics for the mappings which make correspondences.

Because, we are concerned here with finding alignments, this framework provides two main elements:

- a general characterization of ontology alignments (§ 3) and a formal semantic for mappings (§ 4) that is to be used when using them as well as when finding them;
- a general definition of the alignment process (§ 5) and its potential dimensions (in particular more specific constraints applying to the resulting mapping).

These issues are covered in the next chapters.

Chapter 3

Ontology alignment and mapping

For our purposees, aligning two (or more) ontologies is a process that produces a set of mappings across ontologies which allow ontology coordination (see Glossary); said differently, mappings are tools that may enable the “flow” of information across heterogeneous ontologies by describing the relations existing between entities of different ontologies.

Following the analysis we proposed in Section 2.1, here we present a very abstract characterization of mappings (Section 3.1), and then show how this characterization can then be used to solve interesting problems, in particular the problem of creating ontologies that mediates between other ontologies (Section 3.2).

3.1 General characterization of alignments

Let o and o' be two ontologies. Then, following the analysis we provided in Section 2.1, the three basic relations between ontologies can be characterized as follows:

Coverage: the two ontologies describe different (possibly overlapping) regions of the world at the same level of detail and from a unique perspective (see left hand side of Figure 2.1);

Granularity: the two ontologies describe the same region of the world from the same perspective but at different levels of detail (see central part of Figure 2.1);

Perspective: the two ontologies describe the same region of the world, at the same level of detail, but from a different perspective (see right hand side of Figure 2.1).

With respect to this description, an alignment can be viewed as an operator $\alpha(o, o')$ that:

- given two ontologies o and o' with different coverage, tells us how the two ontologies can be used together to achieve a (less partial) description of the world;
- given two ontologies o and o' with different granularity, tells us how facts in o can be systematically translated into facts of o' (for example, how a fact f belonging to o can be rewritten as a logically equivalent fact f' in o');
- given two ontologies o and o' with different perspective, tells us how a fact f in o would be seen from the perspective of o'.

Let us briefly discuss the three categories and consider a few simple examples.

3.1.1 Aligning ontologies with different coverage

Two ontologies which differ only for the portion of the world they describe can be disjoint or may overlap. In the first case, as we excluded epistemic discrepancies (in particular, inconsistencies), they can easily be viewed as a partitioned theory, which can be jointly used to provide knowledge about the world. A simple example is an ontology o about soccer and an ontology o' about cricket. If we assume that there is no intersection between the two, an alignment will tell us that the two ontologies have no relation at all, and thus operations like inclusion, merge, and so on can be performed with no harm.

The situation is slightly different when the two theories (partially or completely) overlap. A simple example is an ontology o describing team sports and another describing indoor sports, where some sports (like volleyball) may belong to both ontologies. In this case, we must be able to recognize the common part and solve possible syntactic and terminological problems. Indeed, if we exclude inconsistencies, the only potential heterogeneity between the two ontologies may concern the syntactic format (e.g., RDF Schemas and OWL) and the choice of names used to identify the common entities (e.g., individuals, classes, and so on).

3.1.2 Aligning ontologies with different granularity

Let us now consider the case of two ontologies o and o' that describe the same portion of the world, but at different level of granularity. Simple examples are: when o characterizes the position of physical objects only by two coordinates (latitude and longitude), whereas o' takes into account also a third coordinate (height above the sea level); when o expresses measures in centimeters and o' in millimiters; and so on.

For granularity, the alignment should provide a way to move from one the level of representation of an ontology to the level of representation of another ontology. Model-theoretically, this operation is more complex than the operation required in the previous case (coverage), as it requires to put in relation models which are intrinsically heterogeneous (e.g., facts of the form $loc(x, y)$ in o with facts of the form $loc(x, y, t)$ in o', where x and y may be expressed in different units of measure).

3.1.3 Aligning ontologies with different perspective

Finally, let us imagine that two ontologies o and o' describe the same region of the world, at the same level of granularity but from a different perspective. A very intuitive example is a representation using indexical expressions (like “here”, “I”, “now”, “yesterday”), as the content of such an expression essentially depends on where, when, from whom it is uttered, and their correct interpretation often requires the ability of *shifting* one’s perspective. But of course there are less direct examples. For example, the fans of two different political parties will apply opposed descriptions to the same politicians; “cold” will be applied to different climatic conditions in Finland and in Greece; and so on.

In this case, alignment should provide a way of “rotating” the perspective of an ontology, or – as we said above – to shift its viewpoint. For some forms of heterogeneity, this can be done systematically and in a relatively simple way (e.g. for indexical descriptions); however, in general the change of perspective is a very hard task for any ontology alignment method.

$$\begin{tikzcd}
 & & & & & & \cdots \\
 & & & & & m \arrow[ur] & \\
 & & o' \arrow[rr] & & \mu(o,o') \arrow[ur] & & \\
 & \alpha(o,o') \arrow[ur] \arrow[rr] & & o \arrow[ur] & & & \\
a \arrow[ur] & & & & & &
\end{tikzcd}$$

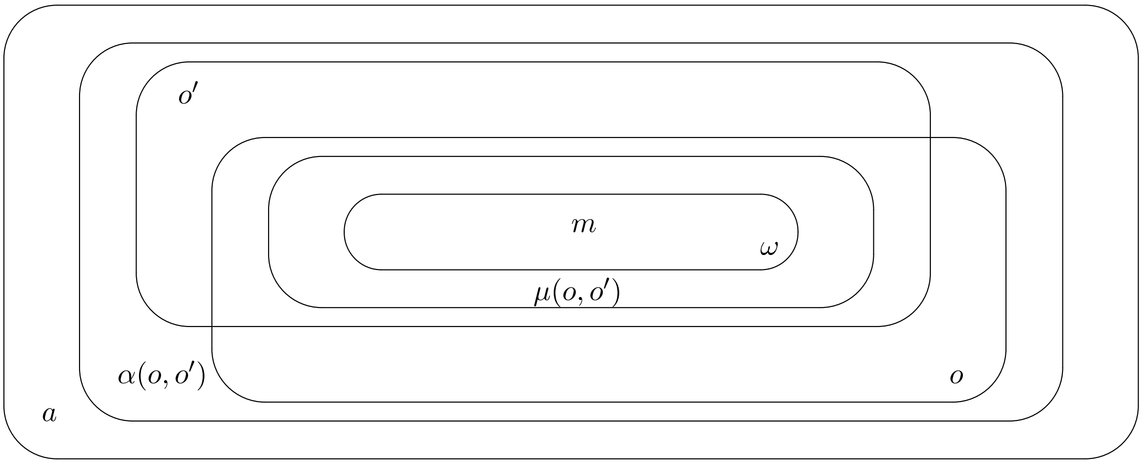


Figure 3.1: Relations between ontologies and alignment ($\alpha(o,o')$) and the corresponding model-theoretic interpretation (each ontology is represented by its set of models).

3.2 Categorical presentation

In this section we propose a special case of what we said above and an application to the problem of generating an ontology o_m which mediates between two heterogeneous ontologies o and o' (the description is similar to that of [Kalfoglou and Schorlemmer, 2003]).

Let us call approximation a relation between ontologies which expresses that one ontology (a) is a representation of at least the same modeled domains as another ($\alpha(o,o')$). In logic, this relation corresponds to entailment. This formulation will be completed below, but one can define other relations between ontologies such as having at least one common approximated ontology. Syntactically, it it possible to provide a set of generators that will complete an ontology (e.g., adding a constraint on a class, classifying an individual), providing an approximated ontology.

Model-theoretic semantics assigns to any ontology the set of its models. If the ontology is correctly designed, the modeled domain is part of these. Model-theoretic semantics provides a formal meaning to the intuitions behind notions such as approximation: an ontology approximates another if its models contains all the models of the other (this is the standard interpretation of entailment). So, the more approximated an ontology, the less models it has.

In these very general terms, aligning two ontologies (o and o') consists of finding a most specific ontology ($\alpha(o, o')$) that approximates both ontologies. In model-theoretic terms, it amounts to finding an ontology whose set of models is maximal for inclusion and is included in the intersection of the set of models of the two aligned ontologies. If one ontology is approximated by another, the result of alignment should be the latter ($\alpha(o, o') = o$).

Finding the alignments between two ontologies is very useful if ones wants to merge two ontologies ($\mu(o, o')$) for instance because it is then sufficient to stick to the non aligned part to the aligned subpart of the ontology.

$\alpha(o, o') = \emptyset$ ($\emptyset$ being the empty ontology);

Ontologies are syntactic expressions defined in an ontology language. This language defines some discrete entities (e.g., formulas, terms, classes, individuals) and relations or constraints between them. In this context a *morphism* can be defined as a structure-preserving map from one ontology to another.

At the conceptual level, aligning two ontologies amounts to finding the entities to put in correspondence and to express this correspondence by a new ontology ($\alpha(o, o')$) and a pair of morphisms. Not any such ontology can be said an alignment. The constraint of exactly what structure is preserved is what defines a method for ontology alignments. Some requires that the labels are preserved, some others require this modulo synonymy, some requires that the set of instances be preserved, some others do not, etc.

However, the reality is not that simple: beside these strict correspondences, there is partial correspondences between these elements that do not exactly corresponds ($\sqsubseteq$).

3.3 Structure of a mapping

The general characterization above requires more information about what is in a morphism. Such a morphism can be seen as a set of oriented mappings (or mapping rules). The general form of these mappings are presented below.

In this document, we propose to see alignment as a process that starts from two representations o and o' and produces a set of mappings between pairs of (simple or complex) entities $\langle e, e' \rangle$ belonging to O and O' respectively.

Intuitively, we will assume that in general a mapping can be described as a quadruple:

$$\langle e, e', n, R \rangle$$

where:

1. e and e' are the entities between which a relation is asserted by the mapping (e.g., formulas, terms, classes, individuals);

2. n is a degree of trust (confidence) in that mapping (notice, this degree does not refer to the relation R, it is rather a measure of the trust in the fact that the mapping is appropriate ("I trust 70% the fact that the mapping is correct/reliable/…"). The trust degree can be computed in many ways, including users' feedback or log analysis;

3. R is the relation associated to a mapping, where R identifies the relation holding between e and e'. Nothing is said about the relation but that it must apply to the pair of entities.

> For instance, this relation can be a simple set-theoretic relation (applied to entities seens as sets or their interpretation seen as sets), a fuzzy relation (see Section 4.4), a probabilistic distribution over a complete set of relations, a similarity measure, etc.

The degree of confidence must satisfy some minimum requirements, due to the model-theoretic semantics of the basic representation language like OWL. First of all, we require that the degrees are part of a structure $\langle D, \leq, \perp, \top \rangle$ such that D is the set of degrees, $\leq$ is an order on $D \times D$ such that whatever $d \in D$, $\perp \leq d \leq \top$. This structure is applicable to a wide number of measures (e.g., boolean lattice, fuzzy degrees, probabilities, any lattice). Moreover, whatever method is associated to the computation of the degree of confidence associated to some mapping, whenever such degree is $\perp$, then this must be interpreted as if the relation is logically false, and whenever such degree is $\top$, then this must be interpreted as if the relation be logically true. Last, we require some sort of smoothness, continuity and monotonicity of the degree of confidence function from zero to one; this requires that some argument should be made about the satisfaction of the (crisp) semantic-based meanings of the basic representation even in the cases when the degree of confidence is neither zero nor one. In this deliverable, we will concentrate on the mapping construct of the representation language, which is the crucial construct involved in the alignment procedure.

Chapter 4

The representation of mappings

The previous chapter provided a very general view of what is to be found in mappings. However, it did not gave a precise semantics of the mapping that are expected from alignment and reconciliation processes. This chapter provides the semantics of these mappings.

The chapter begins with an example which purpose is providing the reader with the intuition behind the introduced formalism. In the following sections syntax and semantics of the mappings are introduced. While in the last part of this chapter we briefly show that well known approaches to information integration fit into the described framework.

4.1 Motivating Example

Let's consider an example emphasising the difference between the rule-based semantics of integration and the classical semantics given to data integration systems, in the case of crisp mappings. Suppose we have three distributed information nodes. The first one (Σ_1) is the municipality's internal database, which has a binary table `Citizen-1` which contains the name of the citizen and the marital status (with values *single* or *married*). The second one (Σ_2) is a public database, obtained from the municipality's database, with two unary tables `Male-2` and `Female-2`. The third information node (Σ_3) is the Pension Agency database, obtained from a public database, with the unary table `Citizen-3` and a binary table `Marriage-3` (stating that two people are married). The three information nodes are interconnected by means of the following mappings:

$1 : \texttt{Citizen-1}(x, y) \rightsquigarrow_\alpha 2 : (\texttt{Male-2}(x) \vee \texttt{Female-2}(x))$
(this mapping connects Σ_1 with Σ_2)

$2 : \texttt{Male-2}(x) \rightsquigarrow_\alpha 3 : \texttt{Citizen-3}(x)$
$2 : \texttt{Female-2}(x) \rightsquigarrow_\alpha 3 : \texttt{Citizen-3}(x)$
(these mappings connect Σ_2 with Σ_3)

In the classical model, the `Citizen-3` table in Σ_3 should be filled with all of the individuals in the `Citizen-1` table in Σ_1, since the following mapping is logically implied:

$1 : \texttt{Citizen-1}(x) \rightsquigarrow_\alpha 3 : \texttt{Citizen-3}(x)$

However, in a rule-based integrated system – which can be compared to a peer-to-peer system – this is not a desirable conclusion. In fact, mappings should be interpreted only for fetching data, and not for deduction. In this example, the tables `Female-2` and `Male-2` in Σ_2 will be empty, since the data is fetched from Σ_1, where the gender of any specific entry in `Citizen-1` is not known. From the perspective of Σ_2, the only thing that is known is that each citizen is in the view $(\texttt{Female-2} \vee \texttt{Male-2})$. Therefore, when Σ_3 asks for data from Σ_2, the result will be empty. In other words, the mappings

$$2 : \texttt{Male-2}(x) \rightsquigarrow_\alpha 3 : \texttt{Citizen-3}(x)$$
$$2 : \texttt{Female-2}(x) \rightsquigarrow_\alpha 3 : \texttt{Citizen-3}(x)$$

will transfer no data from Σ_2 to Σ_3, since no individual is known in Σ_2 to be either definitely a male (in which case the first mapping would apply) or definitely a female (in which case the second mapping would apply). We only know that any citizen in Σ_1 is either male or female in Σ_2, and no reasoning about the mappings should be allowed.

Suppose now to have an additional cyclic pair of mappings connecting Σ_1 and Σ_3 as follows:

$$\begin{aligned} &1 : \texttt{Citizen-1}(x, \text{“married”}) \rightsquigarrow_\alpha 3 : \texttt{Marriage-3}(x, y) \\ &3 : \texttt{Marriage-3}(x, y) \rightsquigarrow_\alpha 1 : (\texttt{Citizen-1}(x, \text{“married”}) \ \wedge \\ &\qquad\qquad\qquad\qquad\qquad\quad \texttt{Citizen-1}(y, \text{“married”})) \end{aligned}$$

These cyclic mappings serve the purpose to *synchronise* the people who are known to be married from within the information node Σ_1 (by means of the `Citizen-1` table) with the people who are known to be married from within the information node Σ_3 (by means of the `Marriage-3` table).

Suppose that it is known in Σ_1 that only John is married, and nothing in known in Σ_3 about marriages. The cyclic mappings will propagate this information to Σ_3. However, there is still a subtle difference between the mappings interpreted in a classical way an the mappings interpreted as rules. In the classical model, a query to Σ_3 asking for the non existence of some married person different from John will get a negative answer. In a rule-based setting, we actually expect a positive answer, since the only information that is fetched is about John.

4.2 Syntax

Mappings are means to align knowledge among entities providing information. For this reason, the first concept to be introduced is a formal representation of these entities. These entities are called *information nodes*, and can be considered as first order theories on (possibly) distinct signatures.

However, the purpose of semantic alignment is to share knowledge among the nodes. Therefore, it is assumed a shared set of constant names which provides a sort of common vocabulary for the objects in the information system. One example of such shared constants are the URN in the world wide web.

Definition 1 (Information node) *Let I be a nonempty finite set of indexes $\{1, 2, \ldots, n\}$, and C be a set of constants. For each pair of distinct i, $j \in I$, let L_i be a first order function-free language with signature disjoint from L_j but for the shared constants C. An* information node Σ_i *is a theory on the first order language L_i.*

Given the starting blocks provided by the information nodes, the *mappings* are defined as relationships connecting formulae from different information nodes. As highlighted by the example, there are two different types of mappings according to the semantics of the integration among the nodes.

The mapping are distinguished into *classical* and *rule-based*. As their names suggest, their semantics differ in order to take into account the main two approaches in information integration. Only the syntax is described in this section, the formal semantics is introduced in the following section.

Definition 2 (Mapping) *A* mapping *is an expression of either of the form:*

$$\begin{array}{ll} i:\phi(\mathbf{x}) \Rightarrow_\alpha j:\psi(\mathbf{x}) & \textit{(classical mapping)} \\ i:\phi(\mathbf{x}) \rightsquigarrow_\alpha j:\psi(\mathbf{x}) & \textit{(rule-based mapping)} \end{array}$$

where i, j *are distinct indices,* $\alpha \in [\bot, \top]$ *is a degree of confidence and* ϕ *is an open formula of* L_i*, and* $\psi(\mathbf{x})$ *is an open formula of* L_j*, both with free variables* $\mathbf{x} = \{x_1, \ldots, x_\ell\}$*. A* crisp mapping *is a mapping with a degree of confidence* $\alpha = \top$*.*

In addition to generic formula mappings, a special kind of mappings is included to allows the alignment of arbitrary constants.

Definition 3 (Constant Mapping) *A* constant mapping *is an expression of the form* $c_i \mapsto_\alpha c_j$ *where* i, j *are distinct indices,* $\alpha \in [\bot, \top]$ *is a degree of confidence,* c_i *is a constant of* Σ_i*,* c_j *is a constant of* Σ_j*.*

To any mapping is associated a degree of confidence to allow the representation of uncertainty into the framework. This aspect is described in Section 4.4.

An integrated system is defined as the information nodes themselves, together with the mappings connecting them.

Definition 4 (Integrated system) *An* integrated system *is composed by a set MDB of information nodes and a set MAP of mappings.*

The purpose of an information system is to provide knowledge; therefore querying is an essential aspect of this framework. A query is always considered w.r.t. a given node, the alignment provides the mechanism in which different nodes can contribute to the answer of a given query. For this reason, queries are defined as formulae written with a language from an (arbitrary) single node.

Queries can have free variables, and in this case they retrieve set of tuples corresponding to the variables. When queries have no free variables, they are called boolean, since they can be either true or false.

Definition 5 (Query) *A* query *is a (possibly open) first order formula in the language of one of the information node* Σ_i*.*

4.3 Semantics of crisp mappings

In order to simplify the exposition in this section only crisp mappings are considered. The following section will take into account the degree of confidence as well.

To describe the semantics of the integrated system, the semantics of each node must be accounted for. Then the interconnection among the single nodes are considered, together with the restrictions imposed by the mappings.

It has been assumed that each node is a first order theory, therefore interpretations for each node are given in terms of a domain and first order interpretations. An interpretation for the integrated system consists in the set of interpretations for the single nodes. However, this is not sufficient because the node interpretation are not required to share the same domain.

Domains of different node interpretations are related by means of *match* relations, mapping elements of a domain to elements of the domain of a different node.

Definition 6 (Interpretation) *Let $\langle MDB, MAP\rangle$ be an integrated system with crisp mappings only, and for each information node Σ_i let Δ_i be a non empty set of objects. For each pair of distinct indices in MDB, we define a* match *relation $R_{i,j} \subseteq \Delta_i \times \Delta_j$.*

An integrated interpretation *for the integrated system is a collection of information node models $\mathbf{m} = \{m_1, m_2, \dots m_n\}$. For each information node Σ_i in MDB, an information node model m_i is a first order model of Σ_i on the domain Δ_i that interpret constants in C as themselves; i.e.,*

$$m_i \models \Sigma_i.$$

Models of an integration system are the interpretations which satisfy the mappings among the nodes.

Definition 7 (Models) *Let's define an assignment α_i for the information node Σ_i in the usual way as a function from variable symbols in L_i to elements in Δ_i. In addition, we restrict the assignments to satisfy the match relations, i.e., $R_{i,j}(\alpha_i(x), \alpha_j(x))$ for each variable symbol x and each pair of distinct indices i, j in the integrated system.*

A model $\mathbf{M}$ *of an integrated system – written $\mathbf{M} \models \langle MDB, MAP\rangle$ – is a nonempty set of integrated interpretations satisfying every mapping, i.e, for each pair of assignments α_i and α_j the following holds:*

- *if the mapping is classical – $(i : \phi(\mathbf{x}) \Rightarrow_\alpha j : \psi(\mathbf{x}))$ – then*

$$\forall \mathbf{m} \in \mathbf{M}.\, ((\mathbf{m}|_i, \alpha_i \models \phi(\mathbf{x})) \rightarrow (\mathbf{m}|_j, \alpha_j \models \psi(\mathbf{x})))$$

- *if the mapping is rule-based – $(i : \phi(\mathbf{x}) \rightsquigarrow_\alpha j : \psi(\mathbf{x}))$ – then*

$$(\forall \mathbf{m} \in \mathbf{M}.(\mathbf{m}|_i, \alpha_i \models \phi(\mathbf{x}))) \rightarrow (\forall \mathbf{m} \in \mathbf{M}.(\mathbf{m}|_j, \alpha_j \models \psi(\mathbf{x})))$$

- *if the mapping is between constants – $c_i \mapsto_\alpha c_j$ – then*

$$\forall \mathbf{m} \in \mathbf{M}.\, ((\mathbf{m}|_i, \alpha_i \models (x = c_i)) \rightarrow (\mathbf{m}|_j, \alpha_j \models (x = c_j)))$$

where we intend $\mathbf{m}|_i$ to be the element m_i of $\mathbf{m}$.

Although the mappings are restricted to three kinds, the freedom in their combination allows to represent a variety of commonly used mappings. In fact, even the constant mapping can be represented by means of a classical mapping; as shown in the semantics above.

Among the widely used mappings, two common examples are equivalence and disjointness. The first one stating the equivalence between two formulae, and the second their disjointness. Given the nature of these two constraints they are better represented by means of classical mappings.

An equivalence mapping can be represented by means of two symmetric mappings. For example, to say that $Car(\cdot)$ in the node 1 is equivalent to $Voiture(\cdot)$ in node 2, the following two mappings can be used:

$$1 : Car(x) \Rightarrow_\alpha 2 : Voiture(x)$$
$$2 : Voiture(x) \Rightarrow_\alpha 1 : Car(x)$$

Disjointness mappings can be represented using negation in one of the formulae. For example, to say that two nodes, although they use the same predicate $Person(\cdot)$, contain informations about two different group of people the following mapping can be employed:

$$1 : Person(x) \Rightarrow_\alpha 2 : \neg Person(x)$$

Complex mappings can be represented using rule-based mappings as well; but the nature of their semantics makes their combination less intuitive.

Semantics for the queries is provided in the usual way, by means of the models of an integrated system. Note that answers to a query are given in terms of the shared constants.

Definition 8 (Query answer) *Let $Q_i(\mathbf{x})$ be a query with free variables $\mathbf{x}$ (possibly empty). The* answer set *of Q_i is the set of substitutions of $\mathbf{x}$ with constants $\mathbf{c}$, such that any model $\mathbf{M}$ of an integrated system satisfies the query, i.e.,*

$$\{\mathbf{c} \in C \times \cdots \times C \mid \forall \mathbf{M}.\ (\mathbf{M} \models \langle \mathit{MDB}, \mathit{MAP} \rangle) \rightarrow \forall \mathbf{m} \in \mathbf{M}.\ (m_i \models Q_i(\mathbf{c}))\}$$

4.4 Semantics of fuzzy mappings

In real-life applications, the conceptualisation of the specific domain may result to a represented knowledge that has deficiencies. In general, the information represented can be imprecise, incomplete, vague, fragmentary, contradictory, random, etc. Moreover, the mappings between different information nodes are also caused by uncertainty.

Modelling this can take advantage of relationships between formulas which are not crisp (like $\Longrightarrow$), but have an α component which is different from $\top$ and $\bot$. We present here the semantics of the fuzzy one. In the framework presented here, we try to face this uncertainty, by using degrees (between 0 and 1) that represent the confidence of a specific hypothesis. Three types of uncertainty are introduced in the knowledge representation and alignment process:

- Fuzzy interpretations, i.e. a degree of membership to each interpretation (different semantics for the constructors of the representation language).
- Fuzzy mappings, i.e. a degree of confidence associated to each mapping.
- Fuzzy alignment, i.e. a degree of trust associated to the alignment system.

In this section, we concentrate on the first and the second types of uncertainty. We assume that we have mappings (crisp or not) between information nodes constructed with the aid of a fuzzy extension of its representation language. This means that the syntactic constructors of the language have different semantics based on the notion of a fuzzy interpretation. It is important to notice that all the above constructors should satisfy some minimal requirements that ensure the validity of the extension. In Deliverable 2.5.1 (Specification of Coordination of Rule and Ontology Languages), and more specifically in Section 5 (A Fuzzy Extension), a fuzzy DL extension is presented and the above requirements are summarised in the definition of *valid fuzzy assertional extensions*. The use of the extended language L_i (with extended semantics) results to formulas that have truth values between 0 and 1 (and not only 0 or 1), under a fuzzy model m_i of Σ_i (on the domain Δ_i) and an assignment α.

Definition 9 (Semantics of fuzzy mappings) *Let $\langle MDB, MAP\rangle$ be an integrated system with information nodes and mappings that are crisp or not. Let also R be a fuzzy match relation $R_{i,j} : \Delta_i \times \Delta_j \to [0,1]$.*
An integrated interpretation *for the integrated system is a collection of fuzzy models $\mathbf{m} = \{m_1, m_2, \ldots m_n\}$, where m_i is a fuzzy model of Σ_i.*
A model $\mathbf{M}$ *of an integrated system is a nonempty set of integrated interpretations satisfying every mapping, i.e, for each pair of assignments α_i and α_j that satisfy $R_{i,j}(\alpha_i(x), \alpha_j(x))$ (i.e., $R_{i,j}(\alpha_i(x), \alpha_j(x)) > 0$) the following holds:*

- *if the mapping is classical – $(i : \phi(\mathbf{x}) \Rightarrow_\alpha j : \psi(\mathbf{x}))$ – then*

$$\inf_{\mathbf{m}\in\mathbf{M}} \omega_t((\mathbf{m}|_i, \alpha_i \models \phi(\mathbf{x})), (\mathbf{m}|_j, \alpha_j \models \psi(\mathbf{x}))) \geqslant \alpha$$

- *if the mapping is rule-based – $(i : \phi(\mathbf{x}) \rightsquigarrow_\alpha j : \psi(\mathbf{x}))$ – then*

$$\omega_t[\inf_{\mathbf{m}\in\mathbf{M}}(\mathbf{m}|_i, \alpha_i \models \phi(\mathbf{x})), \inf_{\mathbf{m}\in\mathbf{M}}(\mathbf{m}|_j, \alpha_j \models \psi(\mathbf{x}))] \geqslant \alpha$$

where ω_t is a fuzzy implication, t is a triangular norm.

4.5 Comparison with other approaches

Classical logic-based Information Integration If we consider an integrated system where there is a unique common domain Δ for each information node, the match relation is the identity relation over Δ, and only classical mappings are present, then the logical framework exactly characterises (and generalises) the classical logic-based information integration approach [Franconi *et al.*, 2001; Catarci and Lenzerini, 1993; Calvanese *et al.*, 1998b; Jarke *et al.*, 1999; 2000; Calvanese *et al.*, 2002; Peim *et al.*, 2004].

Consider, as an example, the case of multiple databases to be integrated. Each database have its own conceptual schema and logical schema, where the logical schema can be seen a set of views over the conceptual schema (local-as-view approach). We assume that each symbol of each schema is identified by a unique global symbol; i.e., the various databases have disjoint signatures. Interdependencies between entities and relationships in different schemas are represented by means of integrity constraints involving symbols of the schemas. Such interdependencies are called *inter-model assertions*. The union of the various schemas with the inter-model assertions and the local views forms the global integrated schema, or the *mediator*. It is worth noting that the integration process is incremental – since the integrated schema can be monotonically refined as soon as there is new understanding of the different component schemas – and that the resulting unified schema is strongly dependent from (actually, it includes) the schemas of the single information sources.

This approach gives both a clear semantics to the integration process of ontologies, and a calculus for deriving inconsistencies and checking the validity of integrity constraints in the integrated schema. Most importantly, in this framework global queries can be defined as views over single ontologies, or they can be generalised to span over multiple ontologies. The view-based query processing mechanism will guarantee the correct answer to the global query from the local sources [Calì *et al.*, 2004].

In [Lenzerini, 2002] a comparison is given between the above local-as-view approach to processing global queries and the global-as-view approach, which is more common in current information integration architectures.

Only recently has knowledge representation research started to have an interest in query processing and information access. Recent work has come up with advanced reasoning techniques for query evaluation and rewriting using views under the constraints given by the ontology – also called view-based query processing [Ullman, 1997; Calvanese *et al.*, 2000b]. This means that the notion of accessing information through the navigation of an Ontology modelling the document's domain – which can be seen as a conceptual schema – has its formal foundations.

Two approaches to view-based query processing exist, namely query rewriting (see, e.g., [Beeri *et al.*, 1997]) and query answering (see, e.g., [Abiteboul and Duschka, 1998; Calvanese *et al.*, 2000a; Peim *et al.*, 2002]). In the former approach, we are given a query Q, a set of view definitions characterising the actual data, and a set of (conceptual) constraints – all over the conceptual vocabulary – and the goal is to reformulate the query into an expression, the rewriting, that refers only to the views, and provides the answer to Q. Typically, the rewriting is formulated in the same language used for the query and the views. In the latter approach, besides Q, the view definitions and the constraints, we are also given the extensions of the (materialised) views. The goal is to compute the set of tuples that are implied by these extensions, i.e., the set of tuples that are in the answer set of Q in all the databases that are consistent with the views and the constraints.

In both cases, view definitions can be characterised in the framework presented in this document. In fact, the mappings are general enough to be used to define queries over the different databases. Analysing the techniques for answering these queries is outside the scope of this document; however, with opportune restrictions the techniques presented in literature can be used in this framework.

Rule-based Information Integration If we consider an integrated system where there is a unique common domain Δ for each information node, the match relation is the identity relation over Δ, and only rule-based mappings are present, then the logical framework exactly characterises (and generalises) the peer-to-peer logic-based information integration approach. If we push further, by allowing arbitrary distinct domains for the information nodes as well as a general match relation, then the logical framework characterises the context based approach. In the following, we will briefly show how the most relevant approaches in the literature are actually within our proposed logical framework.

The autoepistemic approach, which is the basis for the rule-based semantics, was first introduced by [Donini *et al.*, 1998], with the goal of formalising the *constraint rules* implemented in many practical knowledge representation systems. These rules are also the basis of the recent formalisations of peer-to-peer systems [Franconi *et al.*, 2003a]. As shown in [Franconi *et al.*, 2003a], the autoepistemic semantics as defined above is equivalent to the context-based semantics of [Giunchiglia, 1993; Ghidini and Serafini, 1998; Ghidini and Giunchiglia, 2001], and to the use of the autoepistemic operator, as defined, e.g., in [Reiter, 1992].

The framework presented in this document shares the same spirit of the Piazza system [Halevy *et al.*, 2003; Tatarinov and Halevy, 2004]. The vision of the Piazza peer data management system (PDMS) project is to provide semantic mediation between an environment of peers, each with its own schema. Rather than requiring the use of a single, uniform, centralised mediated schema to share data between peers, Piazza allows peers to define semantic mappings between pairs of peers (or among small subsets of peers). In turn, transitive relationships among the schemas of the peers are exploited so the entire resources of the PDMS can be used. The Piazza system is limited in the fact that it does not allow full GLAV mapping rules (i.e., heads must be atomic queries), it does not allow for cyclic mapping rules, and it does not allow for dynamic networks.

In the field of PDMS as defined above – which includes [Bernstein *et al.*, 2002; Serafini *et al.*, 2003; Halevy *et al.*, 2003; Tatarinov and Halevy, 2004; Calvanese *et al.*, 2003; 2004; Fagin *et al.*, 2003] – there are only two other approaches which deal in a well founded way with cycles in the mapping rules [Serafini and Ghidini, 2000; Calvanese *et al.*, 2003]. The acyclic case is relatively simple – a query is propagated through the network until it reaches the leaves of the network. The work in [Calvanese *et al.*, 2003] uses a notion of semantics similar to the semantics introduced in [Franconi *et al.*, 2003b], but it describes a partially distributed algorithm, that assumes that nodes may exchange mappings and data, so that a unique node will eventually evaluate in one shot the query answer – there is no distributed computation and the network may be flooded with data. The paper [Serafini and Ghidini, 2000] describes a local algorithm to compute query answers, but it does not allow real GLAV mapping rules (with existential variables in the head).

Chapter 5

Ontology alignment process

Mappings are the basic building blocks of ontology alignment. The goal of this section is to provide a precise definition of what the alignment process is in general, and what are its main dimensions.

Determining these dimensions is very important for characterizing what known or yet to invent alignment algorithm does and then in which situation it is adapted. It should also be very useful in designing benchmark tests and comparing similar algorithms.

5.1 Characterization of the alignment process

The alignment process simply consists of generating an alignment (A') from a pair of ontologies (o and o'). However, there are various other parameters which can extend the definition of the alignment process. These are namely, the use of an input alignment (A) which is to be completed by the process, the alignment methods parameters (which can be weigths for instance) and some external resources used by the alignment process (which can be general-purpose resources not made for the case under consideration, e.g., lexicons, databases). This process can be defined as follow:

Definition 10 (Alignment process) *The alignment process can be seen as a function f which, from a pair of ontologies o and o' to align, an input alignment A, a set of parameters p, a set oracles and resources r, returns a new alignment A' between these ontologies:*

$$A' = f(o, o', A, p, r)$$

This can be represented as in Figure 5.1.

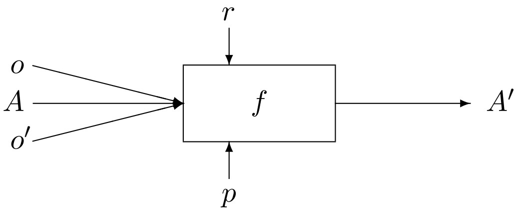


Figure 5.1: The alignment process.

Moreover, it can be useful to specifically consider the alignment of many ontologies within the same process. We call this multi-alignment.

Definition 11 (multi-alignment process) *The multi-alignment process can be seen as a function* f *which, from a set of ontologies to align* $\{o_1, \dots o_n\}$*, an input multi-alignment* A*, a set of parameters* p*, a set oracles and resources* r*, returns a new alignment* A' *between these ontologies:*

$$A' = f(o_1, \dots o_n, A, p, r)$$

5.2 Dimensions of an alignment process

Beside the general scheme presented above, there are many restrictions that can be put on this alignment process. These restrictions are useful for either constraining the alignment algorithm to deliver a particular kind of alignment (e.g., 1-1 preserving consequences) or to choose an algorithm adapted to the required constraints.

These dimensions affect most of the components of the above alignment definition:

Input ontologies (o**,** o'**)** Input ontologies can be applied various constraints:

- **heterogeneity** of the input languages: are they described in the same knowledge representation languages? This corresponds to asking for the non emptyness of the syntactic component of the resulting alignment.
- **languages:** what are the languages of the ontologies (especially in case of homogeneous languages)? Example of languages are KIF, OWL, RDFS, UML, F-Logic, etc.
- **number:** is this an alignment or a multi-alignment?

Input alignment (A**)** The input alignment:

- **complete/update:** Is the alignment process required to complete an existing alignment? (i.e., is A non empty).
- **multiplicity** : How many entities of one ontology can correspond to one entity of the others? Usual notations are 1:1, 1:m, n:1 or n:m. We prefer to note if the mapping is injective, surjective and total or partial on both side. We then end up with more alignment arities (noted with, 1 for injective and total, ? for injective, + for total and * for none and each sign concerning one mapping and its converse): ?:?, ?:1, 1:?, 1:1, ?:+, +:?, 1:+, +:1, +:+, ?:*, *:?, 1:*, *:1, +:*, *:+, *:*. These assertions could be provided as input (or constraint) for the alignment algorithm or be provided as a result by the same algorithm.

Parameters (p**,** r**)**

- **Oracles/resources** Are oracle authorized? If so, which ones (the answer can be any)? Is human input authorized?
- **Training** Can training be performed on a sample?
- **Proper parameters** Are some parameter necessary? And what are they? This point is quite important when a method is very sensitive the variation of parameters. A good tuning of these must be available.

Output alignment (A')

multiplicity The multiplicity of the output alignment is similar to that of the input alignment (see above).

justification Is a justification of the results provided?

strictness Can the result be expressed with trust-degrees different than $\top$ and $\bot$ or should they be strictified before?

Alignment process (f) The alignment process itself can be constrained:

resource constraints Is there a maximal amount of time or space available for computing the alignment?

Language restrictions Is the mapping scope limited to some kind of entities (e.g., only T-box, only classes)?

Property Must some property be true of the alignment? For instance, one might want that the alignment (as defined in the previous chapter be a conseqeunce of the combination of the ontologies (i.e., $o, o' \models A'$) or that alignments preserve consequences (e.g., $\forall \phi, \phi' \in L, \phi \models \phi' \implies A'(\phi) \models A'(\phi')$) or that the initial alignment is preserved (i.e., $o, o', A' \models A$).

The purpose of the dimensions is the definition of the parameters and characteristics of expected behavior in benchmark and the comparison of algorithms and systems in deliverable D2.2.3.

5.3 Data alignment and integration as a variation of this framework

Data alignment and integration consists in merging data (and sometimes data streams, d and d') expressed in different ontologies (o and o'). For that purpose, the ontologies have to be aligned beforehand and the data integration can use this alignment. This is an example of combined off-line and on-line alignment.

It can be thought of as:

1. a first ontology alignment phase (f), possibly with an instance training set,
2. a data alignment phase (f') using the first alignment (A').

This is presented in Figure 5.2.

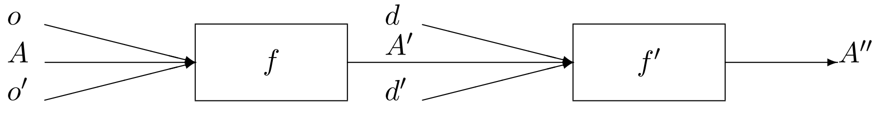


Figure 5.2: Data integration as another alignment process.

In this setting, the second phase benefits from the precompiling of the first alignment. Indeed, the second alignment process f' can be thought of as a compilation of the first alignment. This covers enough applications to deserve a separate threatment (e.g., for benchmarking).

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Related deliverables

A number of Knowledge web deliverable are clearly related to this one:

Project	Number	**Title** and relationship
KW	D2.2.3	**State of the art on ontology alignment** presents the various ways to find alignments as they are described here.
KW	D2.1.1	study the use of modularity for the purpose of scalability. The composition of modules can raise heterogeneity problems that are naturally solved by using alignment results. The techniques for this are found in the present deliverable.