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A Review on ontology alignment and its application to the geospatial domain

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ABSTRACT

The techniques for the alignment of ontologies have evolved from techniques to treat common ontologies to specific techniques for a specific domain, such as geographic, to the point of defining the term geo-ontology. As has been seen, the investigations carried out in the field of geo-ontology alignments are far from being completed. There is still no well-defined metodology to perform alignment. In these few years, the algorithms developed have been based on different strategies. In this paper, we survey some of the most relevant techniques for geospatial ontology aligment.

Key words :geospatial applications, intelligent computing, ontology alignment.

1. INTRODUCTION

In Philosophy, ontology is the theory of "the nature of things or types of existence." The foundation of the first ideas on ontologies is due to Socrates and Aristotle, who described the world through an efficient and significant model, with the contributions of both philosophers. The abstract ideas are due to the first of them, while the second generated associations of a logical type to the class-instance relations of Socrates.

Traditionally, the concept of ontology in the hard sciences, in mathematics, has had a remarkable relevance. Professionals in mathematics are prone to think in massive descriptions of things, facts and events in the universe, in the world. The axiomatic-deductive method plays a central role in the motivations that lead mathematicians to think of ontologies as representations of men's knowledge, based on complex graphs. The inferences make their appearance and the axiomatic model allows making inferences in the field of knowledge, through ontologies.

Currently, there are different definitions in the literature of what thing must be an ontology. Some of these are discussed by Guarino [1], where stands the definition of Gruber[2] "An ontology is an explicit specification of conceptualization" [3]. Guarino[4] later defines ontologies as “A logical theory that justifies the desired meaning of a formal vocabulary, that is, its ontological purpose for a particular conceptualization of the world”. In this context, an ontology can only specify a conceptualization in a weak way.

An ontology will get closer to conceptualization by adding more axioms or adding more concepts and conceptualizations[5-7]. As a result, a distinction is made between unrefined ontologies and refined ontologies. Typically, refined (more detailed) ontologies will be used as references while raw (more generic) ontologies can be shared. According to the level of generalization, Guarino distinguished four types of ontologies: top-level ontology, domain ontology, task ontology, and application ontology[8-14]. The four types of ontologies are shown in Fig. 1.

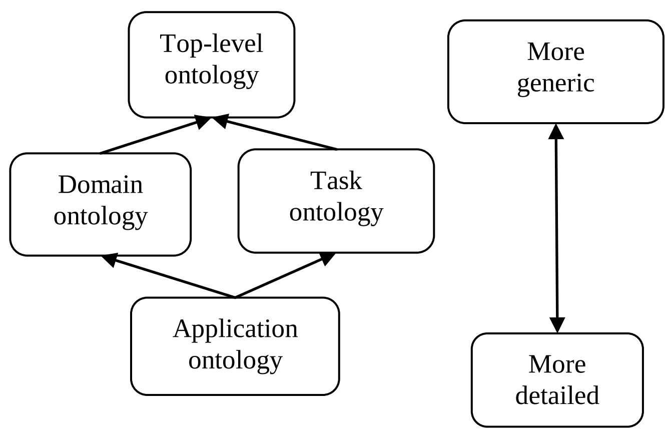

Figure 1: Types of ontology according to Guarino

The domain and task ontologies describe, respectively, the vocabulary related to a generic domain. These concepts usually correspond to a role played by domain entities while carrying out an activity[15-20]. A less elaborate definition but with a more practical sense is the one proposed by Hess et al. [21]. These authors propose that the data type property can be seen as a database attribute, while the object type property can be seen as a database relation[22-24].
An instance $i \in I$ is an occurrence of a concept c, with a value for each property p associated with the concept and a unique identifier[25-31].

2. ONTOLOGY ALIGNEMENT

Aligning something means "putting it online" This is a brief definition that emphasizes that alignment is an activity in which, after being performed, the objects involved are in mutual relationship. For ontologies, several institutions have been, for example, to collect and display data in a region space by ontologies, but each can be using different names to identify the same object, among other heterogeneities that prevent the realization of a direct integration of the ontologies.

In order to work with the information provided by various ontologies, it is necessary to establish a link, a correspondence between their entities, in order to share information between both. This is where the field of study of ontology alignment comes from, which is the process of determining a set of correspondences between the concepts belonging to different ontologies.

Ehrig[32]suggests that aligning one ontology with another means that, for each entity (concept, relationship, or instance) in the first ontology, it is a question of looking for a corresponding entity, which pretends to have the same meaning in the second ontology.

It is denoted $align_{O\ 1,2}$ (e) for $align$ $(e,\ O1,\ O2)$. Once a (partial) align has been established between two ontologies $O1$ and $O2$, the entity e is said to be aligned with the entity f when $align(e) = f$.

For Ehrig[32], the similarities between two ontologies are organized in two orthogonal dimensions . It can be viewed as horizontal and vertical dimensions as shown in Fig. 2.

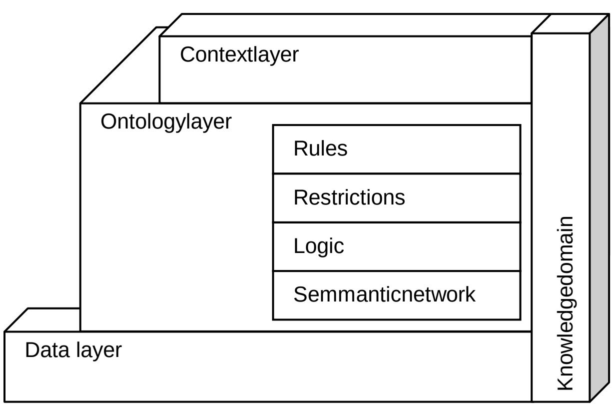

Figure 2: Layers of similarity according to Ehring's classification

The horizontal dimension includes three layers, one built on top of another. The different layers are described below.

2.1 Data layer

In this layer, complex data types are created from simple data types, so it requires complex measures, which can be simple measures effectively compiled[33-36].

2.2 Ontology layer

The semantic relationships between the entities are considered. In fact, this layer can be separated again depending on the semantic complexity. At the lowest level, ontologies are treated only as a graph with concepts and relationships (semantic networks). This level is improved by the logic description (*Description Logic*), and semantics [37], for example, a taxonomy is created on concepts in a concept which inherits all relationships of their super concepts.

2.3 Context layer

In this layer, the most important is the context of the application, for example, a specific entity of an ontology has been used in the context of a given application.

The vertical dimension represents the specific knowledge domain that can be located in any layer of the horizontal dimension. Here, the advantage of a domain-specific external resource can provide valuable information for establishing similarities. Ehrig[32] describes a general procedure for aligning two ontologies. Fig. 3 illustrates the input, output and the six main steps of the general alignment process.

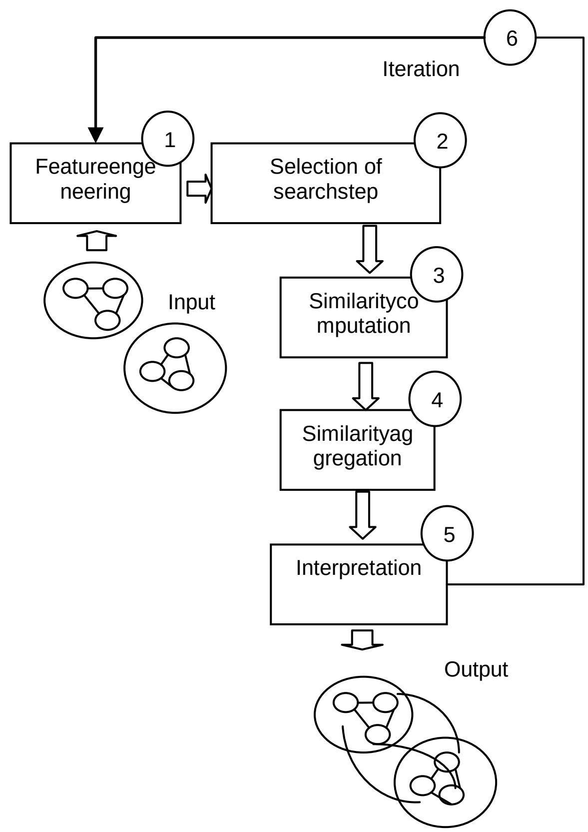

Figure 3: Alignment process according to Ehring's classification

The general process is specified below by explaining its individual steps in detail.

2.3.1 Entry

The inputs for the process are two or more ontologies that need to be aligned. Additionally, previously known alignments can be entered manually which can aid in searching for the other alignments. Formally, given a set of ontologies O, the input function or process *input*: → 𝔓 (O), selects two or more ontologies from it.

2.3.2 Feature Engineering

Small fragments of the global definition of the ontology are selected to describe a specific entity. To compare two entities from two different ontologies $O1$ and $O2$, we consider n their characteristics, their features F.

In a formal way, Risk Engineering consists of starting from two ontologies, a list of features F is determined through *feat*:O×O→𝔓(F).

Examples of traits are[38-43]:

- Identifiers: they include strings with specific formats, such as URIs (unified source identifiers) or ontology labels. Tags are the most common traits used when considering related methods.
- RDF-Schema primitives: provide a wide range of features, for example properties or the defined subclass / superclass relationships (≤ , ≤ R). This also includes inferred subclass/subproperty relationships.
- OWL primitives extends the features of RDF primitives.
- Added traits: it is necessary to compare more than a simple primitive, for example, a sibling is each instance of the parent concept of the original instance. It is also not modeled directly in the ontology.
- Usually, the alignment of ontologies has to be executed for a specific application of a domain, which is expressed within the definition of ontology[44].
- External features: they are a type of information that has not been directly encoded in the ontology, such as a collection of words (bag-of-words) of a document.

2.3.3 Search Step Selection

Ontology alignment takes place in a search space for candidate alignments[45-48]. This step can choose, to calculate the similarity between certain candidates, a pair of concepts {(e ,) | e∈O 1, f∈O 2} and ignore others (for example, only compare o1: car with o2: car and not with o2: hasMotor.

More formally, given tuples two ontologies to align, we define*selec* : × O → 𝔓(E × E), resulting in a set of pairs of entities where E are those previously entities defined.

The most common methods for candidate alignments are:

1. Compare all entities;
2. Compare only those entities of the same type (concept, relations and instances) (,) ∈ (C 1 × C 2) ∪ (R 1 × R 2) ∪ (I 1 × I 2).

These strategies are known as complete agendas.

2.3.4 Similarity Aggregation

It is possible to align ontologies by comparing similarities[49-56].Even though there are several methods for alignments, an article focused on the combination and integration of these methods for ontologies has not been found. Do and Rahm [10] expressed the aggregation of similarity can be through: sim_agg(e,f)=agg(sim1(e, f),…, sim k (e , f)) , with (e , f) an alignment candidate and agg a function on individual similarity measures $s$im1 through $s$im$k$. Usually, this function carries the equation:

$$sim_{agg}(e,f) = \frac{\sum_{k=1...n} w_k * adj_k(sim_k(e,f))}{\sum_{k=1...n} w_k)} \quad (1)$$

wherewk is the weight for each individual similarity measure and $a$dj$k$ is a fitting function to transform the original value ($a$dj : [0,1] → [0,1]).

2.3.5Interpretation

For aggregated similarity values, it is necessary to deduce whether or not there is an alignment. More formally, an added similarity value can lead to an inter *alignment*:[0,1]→{aligment} where aligment is a constant[57-65].

2.3.6 Output

The output of the process are tuples from two ontologies output alignments is created through the output:×O→E×E×[0..1]×{aligment}. As the alignment has been calculated based on the similarity, the similarity value added in this table is also added, if necessary the individual similarity of each trait can be stored. For this representation, it is necessary to mark the pairs that represent valid alignments[66-69].

4. GEO-ONTOLOGY ALIGNEMENT

Previously, the topic of ontologies was addressed in a general way. However, to handle the particularities of a geographic phenomenon, a conventional ontology may not be expressive enough. Due to the level of specialization of ontologies in the geospatial domain, a concept called geographic ontology or geo-ontology arises.

A geo-ontology can be seen as an extension of a conventional ontology. Taking the definition of ontology given previously by Hess et al. [6] a geographical ontology or geo-ontology is defined as an extension of an ontology being a 4-tuple O=<C,P,I,A>, where:

- C is the set of concepts.
- P is the set of properties.
- I is the set of instances.
- A is the set of axioms.

Unlike the concepts of a conventional ontology, a concept *c* can be classified in a domain concept, such as River, Park, Building, or in a geometric concept, such as Point, Line, or in a time concept such as Instant or Period. Furthermore, a geographic domain concept *g* is a specialization of a domain concept that represents a geographic phenomenon. In a geo-ontology, a property $p \in P$ can be of the following types:

- Conventional property. A property is a component that is associated with a concept c in order to characterize it. It can be a property of type (integer, real, string) or a property of type object that allow various types of values. A data type property can be seen as a database attribute, while an object type property can be seen as a relationship in a database. A property of type object represents an association between a concept of domain, geographic or not.
- Spatial property (topological, directional or metric).It is always a property of type object and represents an association between two geographical concepts. Spatial relationships have predefined semantics and are standardized by the OGC consortium, (*Open Geospatial Consortium*).
- Geometric property.It is an association between a geographic domain with a geometric concept. It is a property of type object. Conventional relations, on the other hand, can assume different semantics depending on the associated concept.
  - Positional property. It is a data type property that must be associated with a geometric concept to give it its location (set of coordinates).
- Time property. It is an association between a domain concept and a time concept.

A geographic instance $gi \in I$ is an extension of the instance *i*. Like a geographic instance, it must be associated with at least one instance of a geometric concept. The value of a positional property returns the spatial position (coordinates) of that geographic instance. On the basis of this reference model it is possible to point out at least three differences between geo-ontologies and conventional ontologies.

- Spatial relationships have predefined semantics and are standardized in the literature [11], while conventional relationships can assume different semantics depending on the associated concepts.
- Each geographic concept has at least one associated geometry that represents it. Geometry plays a fundamental role in defining the possible spatial relationships that the concept may have.
- A geographic instance has a number of coordinate pairs that represents its spatial position on the surface. The secoordinates are expressed in a given coordinate system.

Any conventional ontology alignment method can be used to align geographic ontologies. Non-geographic properties (attributes and relationships) can be aligned by a conventional method mentioned above. However, the properties that represent spatial relationships cannot be aligned because these conventional methods do not know their specific semantics. Geo-ontology alignment methods are mainly based on the instances of the objects that contain the spatial information of these objects.

Then, it is allusion made to the evolution of methods that exploit the information geographic provided by the authorities.

Rodríguez et al. [70] proposed an approach for calculating the similarities between the geospatial features of the class definitions using an asymmetric similarity measure. The evaluation of the similarity is basically carried out on the semantic interrelationships between the classes. In that sense, they consider not only the is-a and part - of relationships but also the distinctive features (parts, functions and attributes). In addition to semantic relationships and distinctive features, two linguistic concepts are taken into account for the definition of classes of entities: words and meanings, synonymy and polysemy (homonymy). Later work, using ontologies and set theory [71]determined the semantic similarity between classes of entities of different ontologies. This approach focuses on aligning large vocabularies with a hierarchical organization.

Geographic information systems are not always homogeneous. Sometimes semantic objects are heterogeneous, which causes semantic conflicts. Therefore, it is necessary to resolve these semantic heterogeneities. Considering in a very special way geographic information systems, Hakimpour and Timpf[72] proposed the use of ontologies in solving semantic heterogeneities.

Hakimpour and Geppert[73] also proposed a database integration approach that employs the mixture of formal ontologies. The source ontologies (one for each database) are mixed by a reasoning system that finds relationships of semantic similarities between the various definitions used for each concept. A schema integrator builds a global schema of the database using the source schemas and associations found in the merge process.

When it comes to a simple domain, there is no doubt what you have to do, because you work with that domain, period. But what happens when you need to work with two or more data sets that belong to the same domain? For example, suppose we have multiple disease-related datasets. We could work the datasets one by one, but it is also possible to work them together. Those in charge of creating a framework to semantically integrate various datasets of the same domain wasUitermark[74], who generated ontologies that are in charge of datast applications, and on the other hand, they generated ontologies that are in charge of references to concepts of type general. Obviously, as in any framework that is useful in applications, there must be operating rules. In this case, the rules proposed by Uitermark allow to determine the way in which it is possible to transform a terrain, for example, into a set of geographic data, which is represented by a set of instances of objects.

Geographical applications could not be lacking, since ontologies lend themselves in a very clear way to the management of geographical data and the relationships between geographical concepts. Fonseca et al. [75, 76] were the researchers in charge of presenting the framework for the development of applications in the geographic and geospatial fields. In any geographic application process there must be a stage that allows the integration of the information. Fonseca et al. proposed ontologies as the elements that are useful for the integration of all the information of the geographic problem under study.. Fonseca created a mechanism that allows geographic information to be integrated into a geographic information system based mainly on its meaning. Fonseca opened a new generation for the development of GIS, to which ontologies are added and this approach was called ODGIS (*Ontology Driven GIS*). The use of an ontology, translated into a component of an information system, is the basis of the ODGIS.

The essential mix of ontologies is addressed by Kavouras and Kokla[77], who presents the definition of a technique that uses formal concepts. Then, from these formal concepts, an analysis is performed (Formal Concept Analysis, FCA). The grids is the pictorial tool that FCA uses to formally define the concepts associated with common human activities. The environment of the universe is represented by concepts which are formalized in the context of the FCA. Through the proposal of Kavouras and Kokla it is possible to represent the concepts by means of a lattice of thematic concepts. Experts should participate, without a doubt, in order to identify the categories and attributes involved in the problem under study. In addition, the relationships between the domains involved must be perfectly defined.

Sotnykova et al. [78]present in their research work three stages that form a model to integrate data and information that links space with time. The order is given in the sense that a diagram is presented first and then the corresponding data. The first stage is that syntactic problems must be solved without any doubt. There must be no contradictions or conflicts. This first stage is called pre-integration. The second stage has to do with the schemes and the way or ways in which these schemes correspond. This second stage can be interpreted as trying to resolve semantic conflicts or contradictions. Finally, the third stage has to generate a schema like everything else, which represents integration. This is closely linked to the structures and their contradictions, the structural conflicts, which are resolved in this third stage. But there is more: using descriptive logic as a valuable tool, the researchers propose a language in the whole form. With this language they try to resolve semantic conflicts. And, of course, it is required to verify the degree of satisfaction of the two source schemas and the set of correspondences between schemas. For this they use a descriptive logical reasoning service. With this, it is possible to validate the set of correspondences between schemas with the source schemas.

Schwering and Raubal[79] define measures of similarities between geospatial concepts, which estimate the similarity between instances using the points represented in a vector space, which is the data set. Convexity is very useful in many contexts. In this particular case, the spatial convex regions are of great interest, because the authors have chosen this idea and definition with the purpose of representing the distances between the different concepts involved in the problem under study. This allows in a clear way the process of measuring the similarity of the instances, considering that the convex regions in space represent the distances between the concepts.

Duckham and Worboys[80] adopt an extensional method (based on instances or individuals) to align ontologies. The authors took an extensional method based on the fact that geographic information is well structured and is a voluminous source of instances on which an inductive reasoning process will be carried out.The instances in geo-ontologies are a rich source of information on them can be found significant data as the geographical position of an entity, which now provide the main information in the alignment process.

Inductive reasoning finds, from specific cases, general rules.Inductive inference, as its name implies and its semantics makes it clear, is useful in the case where one prefers to work on semantic relations during the inference process. This case occurs when there are very general rules which are called category of entities, which determine in certain sets of entities the existence of spatial relationships. This work allowed to see the data from another point of view, based on the instances. Estatécnica y algunassimilares se hanaplicadoenáreas tan diversascomo ontology-linked selectional preferences [81, 82], opinion analysis in social networks [83], augmenting word space models [84], urban green space analysis [85], and semantic relatedness through common spatial patterns [86], among others.

Cruz et al. [87] consider that the ontologies are related in the same domain. Although this work proposes the application for alignments of ontologies of a geospatial domain, its use does not restrict it to that domain, but they can be applied to conventional ontologies. The method followed is to consider the ontologies as hierarchies, this being the essential aspect in the alignment process. An expert user initially identifies the levels of the hierarchies that are aligned. Next, this alignment is propagated by the hierarchy following a bottom- up strategy , known in English as *bottom -up* , that is, two concepts will be considered equivalent if they have equivalent children . The user is allowed to assist in the alignment process by allowing him to enter alignments manually. This approach is the basis of the visual tool AgreementMaker[82], which allows visualizing ontologies and showing the generated alignments.

AgreementMaker is a proposal that consists of four layers for calculating the similarity between the entities of the ontologies. The first layer replaces the initial alignments entered by an expert or by the use of linguistic methods with which the names of the entities will be compared and makes use of a dictionary to allow the analysis of synonyms. The alignments are then refined by propagating them through the hierarchy and allowing the user to incorporate the alignments identified by him. These tasks are performed in layers two and three. Finally, the last layer is in charge of consolidating the similarities to obtain the final result.

Sunna and Cruz [88] propose an improvement by introducing two measures of similarities based on structural methods, that is, considering the hierarchical structure of ontologies. These measures are applied after calculate a base similarity using linguistic methods, in order to achieve greater precision. These new measures take into account the ancestors of the concepts and the siblings of the concepts, respectively.

Based on the work of Duckham and Worboys[80], Navarrete and BLAT [89] performed the mixture of two data sets based on the spatial distribution of the values. This algorithm is based on the level of overlap between the spatial extensions (vector of spatial units) of the value sets of the data sets. A high overlap between two spatial extents of different data sets means that you are probably referring to equivalent topics.
Relations can behave as or subclasses according to their spatial extensions. If the spatial extent of the second value contains the spatial extent of the first value, it is not remote to think that a subclass relationship between the classes is involved. It is a relationship of subsets. To work on these types of concepts and achieve results related to the intended goals in their studies, the definitions of two measures of asymmetric similarity emerged. The asymmetry occurs because these two measures reflect the degree of belonging of a spatial extension to the other and, on the contrary, they also measure the degree of belonging of the second spatial extension to the first considered. If there is overlap, the phenomenon of equivalence between spatial extensions occurs. With the authors' proposal, it is possible to classify the elements of two data sets, with the use of membership relations or equivalence relations of the data sets.

5. CONCLUSION

Structural methods use similarity measures that consider the taxonomic structure of ontologies. Terminological methods use similarities between entity name tags and can use external resources such as thesauri and consider relationships such as synonymy. The extensional methods are based on the similarity between the individuals (instances) of the ontologies.

Heterogeneities at the concept level and at the taxonomic level can be handled by any conventional alignment tool. At these levels, the characteristics of geographic information do not influence the calculation of similarities. These comparators do not perform the comparison at the instance level. The instances in the geographic data are those that contain the specific information of a geographic object (river, mountain, city). To handle heterogeneity at the instance level, it is necessary to consider tools that use algorithms that work with instances.

Of the revised alignment method proposals, no one has been found that establishes a way to associate the similarities obtained using conventional ontology alignment techniques with geo-ontology alignment techniques, in particular, the techniques that take into account the instances, which consider the information and characteristics of this domain.

Another aspect that has not been found is the use of spatial relationships between concepts. Concepts can come from areas as diverse as medical applications, the social realm, or engineering concepts related to control or expert systems. There is an ocean of possibilities [90-103]. These general alignment methods have been restricted to the use of few relations because they cannot know the semantics of other types of relations in a specific domain.However, the implicit semantics in spatial relationships provide information that can be exploited in the process of aligning geo-ontologies that help improve results.

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