A Layered approach for Similarity Measurement between Ontologies

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Abstract: With the vision of Semantic Web, the ontology operations such as aligning, merging and mapping have gained much importance. The measuring of similarity between concepts of source ontologies is preprocessing of all these operations. Several techniques have been proposed for measuring similarity between concepts based on their lexical, taxonomic and elementary characteristics but a very little attention has been given on their non-taxonomic relations. We have observed that lexically similarity between concepts is mandatory in order to their taxonomic similarity. Furthermore, the taxonomic similarity between two concepts is pre-requisite of their non-taxonomic similarity. This motivates that if the similarity measurement process is made in layered fashion then it will become more efficient. In this paper, a new technique is proposed that includes non-taxonomic relations of concepts along with their lexical and taxonomic characteristics while measuring their similarities. The proposed technique works in a layered fashion that enables the measuring process more efficient. [Journal of American Science. 2010;6(12):69-77]. (ISSN: 1545-1003).

Keywords: Ontology Matching, Lexical Similarity, Taxonomic Similarity, non-taxonomic similarity

1. Introduction

Nowadays the web has become the main source of information but the semantic heterogeneity is its main bottleneck in the retrieval of relevant information. The semantic web proposed its solutions but still the problem is not fully solved. Semantic web is mainly based on ontologies whereas ontologies themselves suffer from heterogeneity when simultaneously used in some integrating processes such as merging, aligning and mapping. Those ontologies may contain some lexically similar concepts belonging to different context and likewise some contextually similar concepts may have different roles or granularities in their respective ontologies (Farooq and Shah, 2010). When such ontologies are required to reuse simultaneously in some operations for sharing and acquiring of information, the heterogeneity usually arises and then it is required to find the similarity between their concepts to handle the situation.

With respect to ontology, a concept is defined as a class of objects or individuals with some common elementary, taxonomic and non-taxonomic characteristics. A concept has a certain name with some synonyms. Usually, it is known by its taxonomic characteristics (parents, children and siblings), and the non-taxonomic characteristics it keeps in a certain domain in addition to its name or synonyms.

Motivations

- Usually a concept is known by the role it keeps in its respective domain rather than by its parent, sub and/or sibling concepts, therefore the similarity of concepts based on their roles should be properly measured.

- Some pairs of similar concepts are discarded during the measuring of their taxonomic similarity because they have un-similar immediate parent, sub or sibling concepts. This motivates that there is a need of change in the measuring process of taxonomic similarity.

- Some pairs of similar concepts are discarded during the measuring of their lexical similarity because the terms used to name them are not similar. This motivates that there is a need of change in the measuring process of lexical similarity.

- There may some concept those are lexically similar but taxonomically they are not similar but vive versa is not true. Similarly taxonomically similar concepts may be un-similar with respect to their roles but again the vice versa is not true. This motivates that the measuring process should be in some layered fashioned to make it efficient.

- There should be an integrated language-independent technique for measuring lexical, taxonomic and role-based similarities between concepts of ontologies whereas the measuring process should be at conceptual levels of ontologies to make it language independent.

In this paper we propose an integrated language-independent technique, for measuring similarity between concepts of two ontologies by taking into consideration the above motivations to achieve the following objectives: (a) None of similar pair of concepts should remain undetected or eliminated. (b) The role-based similar concepts between ontologies should be determined. (c) The measure process should be more efficient, complete and realistic.

The paper is structured as follows. The related work is briefly overviewed in Section 2. The proposed technique is given in Section 3 and it is validated through a case study in Section 4. Finally the paper is concluded with future directions in Section 5.

2. Background and Related Work

In lexical similarity, the terms used to represent concepts, are compared. Different techniques such as (i) edit-distance (ii) prefix (iii) suffix and (iv) n-gram as surveyed in (Lee et al., 2001) are used to measure the degree of similarities between terms. A method (Muller et al., 2006) known as edit distance is mostly used for measuring the similarity between two terms. In this method, the similarity is measured based on the number of insertions, deletions and substitutions to transform one term into other. The degree of similarity between two concepts based on their terms can be measured using a metric as proposed in (Madhavan et al., 2001), based on (Muller et al., 2006) and that metric is:

DoS_{Lex}=

$$Max\left(0, \frac{Min(LengthOf(a), LengthOf(b)) - NoOfIDS(a,b)}{Min(LengthOf(a), LengthOf(b))}\right) \in [0,1] \quad (1)$$

In above Equation, the *NoOfIDS* is a function that returns integer-value equal to the number of insertion, deletion or substitutions to transform term ***a*** into ***b*** or vice versa. In some scenarios, the Equation 1 *does not give accurate results* e.g. the degree of similarity between terms *Deptt* and *Department* of respective ontologies *A and B* is 0.25 i.e. these are partially similar according to this equation, although both terms represent the same concept.

The two concepts are rendered similar taxonomically (Miller, 1995; Noy and Musen, 2001; Giunchiglia et al., 2007; Aleksovski et al., 2006) if i) their direct super-concepts are similar; ii) their sibling-concepts are similar; iii) their direct sub-concepts are similar; iv) their descendant-concepts are similar; v) their leaf-concepts are similar and vi) concepts in the paths from the root to those concepts are similar. Irrespective of the structural aligning technique used, we have observed that *certain pairs of similar concepts are categorized dissimilar* because of bias of above mentioned criteria towards those concepts whose siblings-concepts, sub-concepts or direct super-concepts are not similar. Secondly, the roles of concepts represented via non-taxonomic relations are not properly incorporated in the similarity measuring process.

The non-taxonomic relations of a concept represent its roles and in most of domains, a concept is known by the role it keeps. However, in some domains the concepts have no intellectual properties e.g. in ontology of a furniture domain, the concepts like chair, table and desk have only taxonomic (i.e. parent, child, sibling) and elementary (i.e. color, type, etc.) characteristics. For such situation the granularities of concepts should be used for measuring semantic relations.

In (Erhard and Philip, 2001; Lambrix and Tan, 2006; Shvaiko and Euzenat, 2005; Hariri et al.,, 2006), the similarities between concepts are measured based on their taxonomic properties (parents, siblings and children concepts) and the degree of similarity between two ontologies may decrease because of over-looking of some pairs of similar concepts in these approaches. The measuring of similarities of concepts based on different criteria is discussed in (Lambrix and Tan, 2006) where a software package WordNet (Miller, 1995) has been used to measure the semantic similarity between a pair of concepts through their synonyms (Giunchiglia et al., 2007). If the similarity score is above a given threshold then the concepts are considered to be similar. In order to identify semantic equivalence between concepts of different ontologies, only SubClassOf, Generalize, partOf and InstanceOf relationships with predefined semantics have been considered. Several ontology alignment tools are reviewed and a new tool for ontology alignment is described in (Isabel et al., 2007). Mostly these tools have XML-schema orientation. That is, the ontologies are represented into XML trees. XML nodes are taken as concepts. Their similarities are computed on the bases of similarities of their respective parents and sub-nodes.

In (Maedche and Staab, 2002), a set of similarity measures for ontologies at lexical and conceptual levels of their concepts have been proposed. Similarity measures at lexical level compare the terms used for concepts in ontology but at conceptual level the similarity is computed from hierarchical relations existing between those terms. Schema-based matching techniques and systems have been surveyed in (Erhard and Philip, 2001), in which techniques are grouped into terminological, structural and semantic categories. The terminological techniques are further divided into string-based and language-based categories. Structural category includes all taxonomy-based and graph-based techniques whereas the semantic category includes all model-based techniques such as propositional satisfiability and description logics reasoning techniques. In (Aleksovski et al., 2006), the background knowledge of domain has been used via ontology to determine similarity between concepts of two ontologies, especially for those concepts which are not lexically and structurally similar. A similar work was presented in (Aleksovski et al., 2006), and it has been evaluated by matching a medical ontology to another, while using comprehensive medical domain ontology as background knowledge. The key consideration of this technique is if source ontologies are missing some non-taxonomic or logical relations between concepts, then for those logical relations, the third ontology i.e. the comprehensive domain ontology can be consulted while measuring similarity for those concepts. This technique is well suited for those ontologies having very poor taxonomic and non-taxonomic relations between concepts.

3. Proposed Technique

As stated earlier:

(i) Usually a concept is also known by the non-taxonomic relations it keeps in its respective domain in addition to its other characteristics; therefore the non-taxonomic relation based similarity of concepts should be measured.

(ii) To make result more complete and accurate, the taxonomic similarity of two concepts should be based on the similarity of their respective parents only whereas the similarity of sub and sibling concepts should be relaxed to determine all pairs of similar concepts.

(iii) The lexical similarity should be measured via domain-vocabulary of respective system instead of using existing techniques such as edit-distance, prefix, suffix and n-gram to make result more complete and accurate.

(iv) To make measuring process more efficient, the similarity should be measured in a layered fashion because there is no need to measure the contextual similarity for primarily un-similar concepts. Furthermore, there is no need to measure role-based similarity for those concepts which are contextually un-similar.

(v) There should be an integrated technique for measuring primarily, contextual and role-based similarities between concepts of ontologies whereas the measuring process should be at conceptual levels of ontologies to make it language independent.

The proposed technique fulfills these requirements as said above. It works in three phases as shown in Figure 1. First of all we describe the main terms used in the proposed technique:

Primary similarity may be called as conceptual similarity or 1st level of similarity and it is updated form of lexical similarity. Since in ontologies, the concepts are represented via terms, therefore while measuring primarily similarity we identify the corresponding terms between source ontologies, representing the exactly-same or similar concepts in addition to representing entirely different concepts.

Taxonomic similarity: Two concepts are contextually similar if and only if they possess primarily similarity and there are one or more common concepts in their respective parent-concepts. It may also be called 2nd level of similarity and it is updated form of taxonomic similarity.

Non-taxonomic similarity: This is a 3rd level of similarity between concepts. Two concepts possess 3rd level of similarity if and only they have second level similarity and they have similar roles i.e. their interaction with concepts other than parent, children and sibling concepts, in their respective domains.

The input ontologies are taken in triple-forms where each triple consists of three parts i.e. subject, predicate and object. There are some preprocessing activities of acquiring concepts, their super-concepts and their roles. The details of preprocessing are omitted here just for sake of simplicity. The concepts of source ontologies *A* and *B* are taken into sets CS_A and CS_B as mathematically represented in Equations 1 and 2 respectively.

$$CS_A = \{a_i \mid \forall\ a_i \in A\} \qquad (1)$$

$$CS_B = \{b_j \mid \forall\ b_j \in B\} \qquad (2)$$

Since contextual similarity of two concepts is based on the similarity of their respective parent concepts, therefore in order to it we need the parent-concepts of each concept. The parents of each concept of *A* and *B* ontologies are separately acquired in two sets i.e. C^PS_A and C^PS_B, formally defined as:

$$C^PS_A = \{(a_i,\ p_i)\ |\ \forall\ a_i,\ p_i \in A \wedge p_i\ \text{isParentOf}(a_i)\} \quad (3)$$

$$C^PS_B = \{(b_j,\ p_j)\ |\ \forall\ b_j,\ p_i \in B \wedge p_j\ \text{isParentOf}(b_j)\} \quad (4)$$

Similarly, to measure the role-based similarity we need to acquire the roles of concepts. The roles of each concept of *A* and *B* ontologies are separately acquired in two vectors i.e. C^RS_A and C^RS_B, formally defined as:

$$C^RS_A = \{(a_i,\ r_i)\ |\ \forall\ a_i,\ r_i \in A \wedge r_i\ \text{isRoleOf}(a_i)\} \quad (5)$$

$$C^RS_B = \{(b_j,\ r_j)\ |\ \forall\ b_j,\ r_j \in B \wedge r_j\ \text{isRoleOf}(b_j)\} \quad (6)$$

Phase-1: Measurement of Primary Similarity

The primarily similarity as defined earlier, is not the same as terminological similarity as reported in literature because we focus is on concepts rather than terms used to represent them.

We measure the first-level similarity between concepts via a domain-specific vocabulary that contains the terms-names, abbreviated-names, synonyms and hyponyms of those concepts. While populating synonyms and hyponyms of a concept the WordNet can be used as helping aid.

The measuring process of first-level of similarity is given in algorithmic form in Figure 1. Let DV be the domain-specific vocabulary of source ontologies A and B whose similarity is to be determined. Each element of *DV* has four components: (i) *name* (term that is exactly the same spelled as concept); (ii) ***aName*** - the abbreviated-names, (iii) ***sName*** - the synonyms and (iv) ***hName*** - the hyponyms of a concept. The output of this phase is a vector containing pairs of similar concepts with semantic relations exist concepts of each pair separately.

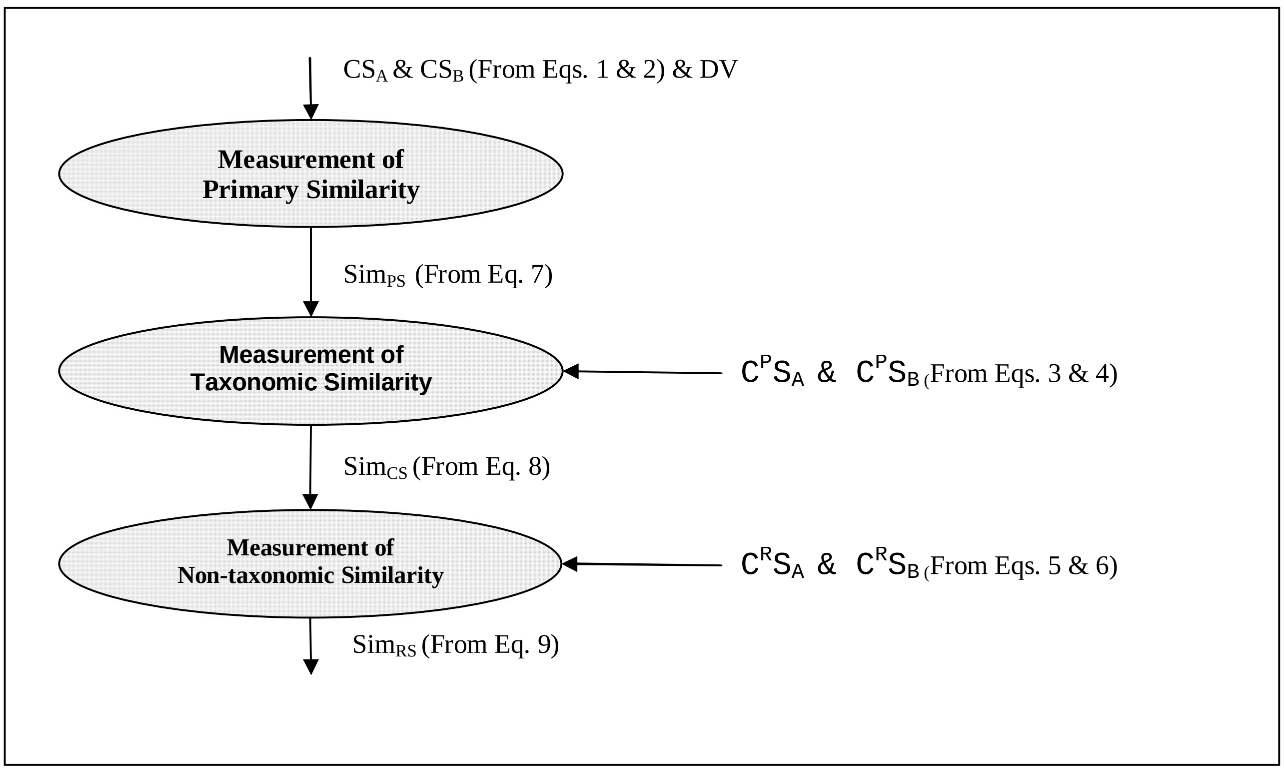

Figure 1: Outline of proposed technique

The terms used for concepts in both source ontologies A and B, as obtained in sets CS_A, CS_B (from Eqs. 1 & 2) is input and a set as formally defined in Equation. 7, containing pairs of primarily similar concepts is obtained as output of this phase. A slice of pseudo code of this phase is given in Figure 3.

$$Sim_{PS} = \{(a_i, b_j, SR) \mid \forall a_i \in CS_A \wedge b_j \in CS_B\} \quad (7)$$

The terms a_i and b_j holds a semantic relation *SR* and this may be equal (=), more generic ($\supseteq$) or more specific ($\subseteq$), i.e. ai = bi or ai $\supseteq$ bj or ai $\subseteq$ bj.

$$DoS_{PS} = LexSim(A{:}ai, B) \;\; return \;\; P$$

The ***P***, in above expression, is a vector containing pairs of terms a_i and b_j with semantic relation ***SR*** i.e., $P = (a_i, b_j, SR)$

There may be no b_j exactly similar to a_i, and there may be multiple b_js that are more specific that a_i and/or multiple b_js that are more generic than b_js. In that cases, we have opted two strategies i.e. up-ward and down-ward strategies. In up-word strategy, we choose a pair (a_i, b_j) with ***SR*** such that b_j is least granular in all b_js. Similarly in down-ward strategy we choose a pair with b_j having the maximum granularity. If there is no b_j similar to a_i then a_i is declared entirely different term. In that case p = (a_i, null, null) will be returned and this pair is not included in the resultant vector and it is simply discarded. For mapping, aligning and merging of ontologies, the correspondence between their similar concepts are required. It is required to find exactly equivalent, and the semantic relations between similar concepts

Phase-2: Measurement of Taxonomic Similarity

This phase takes C^PS_A, C^PS_B (from Eqs. 3 & 4) and Sim_{Lex} (from Eq. 7) as input and returns a set Sim_{CS}, formally defined in Eq. 8, containing pairs of taxonomically similar concepts as output.

$$Sim_{CS} = \{(a_i, b_j, SR) \mid \forall a_i, b_j \in Sim_{PS} \wedge \exists \; isSameParent(C^PS_A(a_i), C^PS_B(b_j))\} \quad (8)$$

Taxonomic similarity is based on taxonomic positions of a_i and b_j. To measure this similarity, we need to measure the similarity between their respective parents. A slice of pseudo code of measuring process of taxonomic similarity is given in Figure 4.

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Algorithm: Measurement of primary similarity

Input:  two vectors CS_A, CS_B (from Eqs. 1 & 2), DV (Domain Vocabulary)
Output: Sim_PS (From Eq. 7); a vector containing pairs of primarily similar concepts
Begin
For each a in CS_A
  For each d in DV
   IF d.name.equal(a)OR d.aName.found(a)OR d.sName.found(a)
   THEN {tempA.add(d.rowId, a, 1); break;}
   Else IF a.hName.found(a)
   THEN {tempA.add(d.rowId, a, 2); break;}
  Next
Next
For each b in CS_B
For each a in tempA
IF (a.level=1) AND ( DV[a.rowId].name.equal(a) OR
    DV[a.rowId].aName.found(b) OR DV[a.rowId].sName.found(b)
THEN { Sim_PS.add(a, b, '='); break;}
ELSEIF (a.level=1) AND  DV[a.rowId].hName.found(b)
THEN     { Sim_PS.add(a, b, '⊇'); break;}
ELSEIF (a.level=2) AND (DV[a.rowId].name.equal(a) OR
       DV[a.rowId].aName.found(b)  OR  DV[a.rowId].sName.found(b)
THEN { Sim_PS.add(a, b, '⊆'); break;}
ELSE      // a and b are dissimilar
Next
Next
End
```

Figure 2: A slice of pseudo code for measuring primary similarity

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Algorithm: Measurement of taxonomic similarity
Input:(i) Two vectors   CpSA, CpSB (From Eqs. 3 & 4);
      (ii) SimPS vector (From Eq. 7)
Output: SimCS (From Eq. 8); a vector containing pairs of taxonomically
similar concepts
Begin
      For each p in LexSim
            parentCa = CpSA.getParents(p.Ca)
            parentCb = CpSB.getParents(p.Cb)
            same = isSameParent(parentCa, parentCb)
            If same Then SimCS.add(p)
      Next
         -  - -
         -  - -
         -  - -
      End.
```

Figure 4: A slice of pseudo code for measuring taxonomic similarity

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Algorithm: Measurement of non-taxonomic similarity
Input:(i) CRSA, CRSB (From Eqs. 5 & 6);
      (ii) SimTax (From Eq. 8)
Output: SimNonTax (From Eq. 9); a vector containing pairs of non-
taxonomically similar concepts.
Begin
For each p in SimTax
      NTRCa= CRSA.getNTRs(p.Ca)
      NTRCb= CRSB.getNTRs(p.Cb)
      same = isSame(NTRCa, NTRCb)
      If same Then  SimNonTax.add(p)
Next
         -  - -
         -  - -
         -  - -

End.
```

Figure 5: A slice of pseudo code for measurement of non-taxonomic similarity

Phase-3: Measurement of Non-taxonomic Similarity

It is based on roles of concepts. In a domain, usually a concept is known by the roles it keeps, in addition to its parents, children, siblings and attributes. The non-taxonomic relations represent roles of concepts and their parts as well. If some pairs of concepts have no intellectual characteristics then they may have no roles. In that case those pairs of concepts possess third level of similarity implicitly. Figure 5, depicts a slice of pseudo code of measuring process of non-taxonomic similarity.

The C^RS_A, C^RS_B (from Eqs. 5 & 6) and Sim_{CS} (from Eq. 8) is the input and a set Sim_{RS}, formally defined in Eq. 9, containing pairs of similar concepts based on their roles, is output of this phase.

$$Sim_{RS} = \{(a_i, b_j, SR) \mid \forall\ a_i, b_j \in Sim_{CS} \wedge \exists\ isSameRole(C^{R}S_A(a_i), {}^{R}S_B(b_j))\} \quad (9)$$

4. Case study

Using various ontologies we validated our proposed technique for its both cases i.e. some ontologies may have only taxonomic relations whereas some other ontologies may have both taxonomic and non-taxonomic relations at the same time. Two ontologies about university domain developed by different groups were used. Concepts along with non-taxonomic relations of O_1 and O_2 are listed in Tables 2 and 3 respectively. A set of sample concepts selected from both ontologies is shown in Figure 6. For sake of simplicity, we have just show the similarity status in terms or true of false rather than semantic relation in Table 3.

Table 1: A slice of non-taxonomic relations from ontology O_1 of a university domain

	Subject	Predicate (InverseOf)	Object
a1.	Faculty	teacherOf (hasTeacher)	Student
a2.	Faculty	demonstratorOf (hasDemostrator)	LabExperiment
a3.	Faculty	developerOf (hasDeveloper)	DevProject
a4.	Faculty	ResearcherOf (hasResearcher)	ResProject
a5.	SoftwareEngineer	developerOf (hasDeveloper)	DevProject
a6.	SoftwareEngineer	demonstratorOf (hasDemostrator)	LabExperiment
a7.	Consultant	consutantOf (hasConsultant)	DevProject
a8.	Consultant	consultantOf (hasConsultant	ResProject
a9.	Consultant	consultantOf (hasConsultant)	Education
a10.	Consultant	consultantOf (hasConsultant)	Network
a11.	Consultant	consultantOf (hasConsultant)	HumanResource
a12.	Director	directorOf (hasDirector)	DevProject
a13.	Director	directorOf (hasDirector	ResProject
a14.	Director	directorOf (hasDirector)	Sport
a15.	Director	directorOf (hasDirector)	Transport
a16.	Manager	managerOf (hasManager)	Network
a17.	Manager	managerOf (hasManager)	HumanResource
a18.	Manager	managerOf (hasManager)	Transport
a19.	Manager	managerOf (hasManager)	DevProject
a20.	Manger	managerOf (hasManager)	ResProject
a21.	Convener	convenerOf (hasConvener)	AdmissionCommittee
a22.	Convener	convernerOf (hasConvener)	LibraryCommittee
a23.	Convener	convernerOf (hasConvener)	DisciplinaryCommittee
a24.	Course	hasInstructor	Faculty
a25.	Course	hasBook	Book
a26.	Course	hasContent	Content
a27.	University	hasDepartment	Department
a28.	University	hasResearchCentre	ResearchCentre
a29.	ResearchPaper	publishIn	Book
a30.	Conference	isA	Event

Table 2: A slice of non-taxonomic relations from ontology O_2 of a university domain

	Subject	Predicate (InverseOf)	Object
b1.	Faculty	teacherOf (hasTeacher)	Student
b2.	Faculty	demonstratorOf (hasDemostrator)	LabExperiment
b3.	Faculty	developerOf (hasDeveloper)	DevProject
b4.	Faculty	ResearcherOf (hasResearcher)	ResProject
b5.	SoftwareEngineer	developerOf (hasDeveloper)	DevProject
b6.	SoftwareEngineer	demonstratorOf (hasDemostrator)	LabExperiment
b7.	Consultant	consutantOf (hasConsultant)	DevProject
b8.	Consultant	consultantOf (hasConsultant	ResProject
b9.	Consultant	consultantOf (hasConsultant)	Education
b10.	Consultant	consultantOf (hasConsultant)	Network
b11.	Consultant	consultantOf (hasConsultant)	HumanResource
b12.	Director	directorOf (hasDirector)	DevProject
b13.	Director	directorOf (hasDirector	ResProject
b14.	Director	directorOf (hasDirector)	Sport
b15.	Director	directorOf (hasDirector)	StundentAffair
b16.	Manager	managerOf (hasManager)	Network
b17.	Manager	managerOf (hasManager)	HumanResource
b18.	Manager	managerOf (hasManager)	Transport
b19.	Manager	managerOf (hasManager)	DevProject
b20.	Manger	managerOf (hasManager)	ResProject
b21.	Convener	convenerOf (hasConvener)	AdmissionCommittee
b22.	Convener	convernerOf (hasConvener)	LibraryCommittee
b23.	Convener	convernerOf (hasConvener)	DisciplinaryCommittee
b24.	Course	hasInstructor	Faculty
b25.	Course	HasBook	Book
b26.	Course	hasContent	Content
b27.	Department	hasResearchCentre	ResearchCentre
b28.	University	hasDepartment	Department
b29.	ResearchPaper	publishIn	Book
b30.	ResearchPaper	publishIn	Journal
b31.	ResearchPaper	publishIn	Conference

a7) Consultant	b10) Consultant
a14) Director	b15) Director
a16) Manager	b18) Manager
a21) Convener	b23) Convener
a1) Faculty	b1) Faculty
a26) Course	b26) BS-Course
a25) Book	b29) Book
a30) Conference	b31) Conference
a28) ResearchCentre	b27) ResearchCentre

Figure 6: A sample set of concepts from O1 and O2

Table 3: Similarity of pairs of concepts with different criteria

Pair\Criteria	Primarily Similar	Taxonomically Similar	Non-taxonomically Similar
(a7,b10)	Y	Y	N
(a14,b15)	Y	Y	N
(a16,b18)	Y	Y	N
(a21,b23)	Y	Y	N
(a1,b1)	Y	Y	Y
(a26,b26)	Y	Y	Y
(a25,b29)	Y	N	N
(a30,b31)	Y	N	N
(a28,b27)	Y	N	N
(a14, b29)	N	N	N

5. Conclusion and Future Work

The proposed technique measures similarity in a layered fashion. The conceptual schemas of two ontologies are taken as input (technique is language-independent). Concepts with their super-concepts and non-taxonomically relating concepts along with synonyms of concepts are acquired in phase-1. Concepts are short-listed in phase-2, based on their primarily similarity so-called lexical similarity. Only those concepts, short-listed in phase-2, are tried to find their taxonomic similarity i.e. Concepts are short-listed based on their taxonomic similarity in phase-3. Only those concepts, short-listed in phase-3, are tried to find their non-taxonomic similarity in phase-4. We validated the technique by a case study. The current test case study includes small ontologies. Although the similarities between concepts of large realistic ontologies are difficult to obtain however, they are necessary for better evaluation of proposed technique. A framework is needed to realize its full potential and completeness.

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