Using Explicit Informationto To Map Between Two Ontologies*

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1. ABSTRACT

Understanding the meaning of messages exchanged between software agents has long been realized as one of the key problems to realizing multi-agent systems. Forcing all agents to use a common vocabulary defined in a shared ontology is an oversimplified solution, especially when these agents are designed and deployed independently of each other. An alternative, and more realistic, solution would be to provide mapping services between different ontologies (Weisman, Roos and Vogt[1], Pinto[6]). In this paper, we present our work along this direction. This work combines the recently emerging semantic markup language DAML+OIL (for ontology specification), the information retrieval technique (for similarity information collection), and Bayesian reasoning (for similarity synthesis and final mapping selection), to provide ontology mapping between two classification hierarchies.

2. INTRODUCTION

Agent technology is one of the most promising ways of distributing and gathering information. In a multi-agent system, an ontology is the basis for communication. The way an agent internally stores information is not known to the environment. Each agent may have its own ontology to organize its data. Mapping one ontology onto another basically means that for each concept in ontology A, a corresponding concept node in ontology B with the same or similar semantics has to be found. Therefore, there is a need to find a mapping between the concepts of two ontologies, using either explicit or implicit information. In our work, we have used explict information in the form of documents assigned to each concept in an ontology. We consider classification information for each document and suggest two approaches that use this information to propose a set of possible mappings between the given ontologies. The classification information is in the form of either similarity measures or probability values for single concept nodes.

This system is intended to be used as part of the ITTalks[4] system to allow multiple topic ontologies to be used to describe subjects of talks of different users. ITTalks is a web-based system for automatic and intelligent notification of information technology talks. If both ITTalks and the user agree on a common semantics, the web portal can provide not only the talks that correspond to the user's profile in terms of interest, time, and location constraints, but can further filter the IT events based on information about the user's personal schedule, inferred location at the time of the talk, distance and current traffic patterns, etc. All the information is denoted in a sematically machine-understandable format, using DAML.

3. PREVIOUS RELATED WORK

A great number of proposals have been made in the general area of ontology mapping with different approaches [2, 7, 3, 10]. One such work that is very similar to ours is that of Lacher and Groh [3]. This work also uses documents as explicit information associated with each concept and uses the *Bow* toolkit for the classification task. It also treats the scores returned by the text classifier as probabilities. The difference between this approach and ours is in how these scores are used in determine the final mappings. In their work, only the two most probable nodes that could match a node in the ontology are considered, and the process proceeds to look at their parents if they do not share a common parent.

Another related work is Anchor-PROMPT (Noy, Musen [7]). It takes as input a set of anchors – pairs of related terms defined by the user or automatically identified by lexical matching. The algorithm treats an ontology as a graph with classes as nodes and slots as links. It analyzes the paths in the subgraph limited by the anchors and determines which classes frequently appear in similar positions on similar paths. These classes are likely to represent semantically similar concepts.

Some more recent work includes OntoMerge, an ontology translation service, developed at Yale University (McDermott et al [8]). This service performs the merge of concepts and relations of two ontologies built for the same domain. The service takes the union of the axioms defining them. Then bridging axioms are added that relate the terms in one ontology to the terms in the other. XML namespaces are used to avoid name clashes. OntoMerge accepts a dataset as a DAML file in the source ontology, and responds with the dataset represented in the target ontology also as a DAML file.

Another service for mapping between two source ontologies is the Articulation service [9], developed at GRCI. The mapping is asymmetric, from the subject ontology to the object ontology. Articulations are identified by a UUID URN scheme. A one-to-one mapping is obtained between the articulation's URN and a resolveable URL. A seed articulation can be provided as a starting point. The mapping is expressed using the CODIP articulation ontology. Both OntoMerge and the Articulation service can be tried online via the World Wide Web. Their URLs are included in the references.

In [16], the authors address the problem of integrating documents from different sources into a master catalog. They enhance a Naive Bayes classification to incorporate the similarity information present in source catalogs. This work makes use of implicit information in the source categorizations (documents in the same category are similar), while ours uses explicit information. The two works are similar in that they both use text classification techniques, training data for the classifiers, and construct models from the training data to predict categories (in our case, concepts) of unknown documents.

4. OVERVIEW

The two hierarchies we used as examples are the ACM topic ontology, and a small ITTopic topic ontology which organizes classes of IT related talks differently from the ACM classification. These two ontologies are extended by attaching to each concept/class a set of *exemplar*s, which are URLs pointing to the locations of text documents thought to belong to that class. Both ontologies, as well as the output mappings, are marked up in DAML+OIL[1].

A *model* is built for each ontology, which primarily contains statistical information about the exemplar documents associated with each concept in that ontology, using the Rainbow text classifier[2]. Then, each concept of one ontology is mapped into one or more concepts of the other ontology by comparing its exemplars against the other ontology's model, again using Rainbow classifier. The raw similarity scores returned by the classifier are used by the mapper to produce a set of possible mappings between the two ontologies. Fig. 1 shows the system components and the flow of inputs to the components.

The initial step in this process involves the user specifying a set of mappings between concepts of the two ontologies, calledemphlandmarks. When specifying *landmarks*, a property can be assigned to the link - Broader, Similar, or Narrower. These properties, if used properly, can significantly improve both accuracy and efficiency of the concept mapping. Once the user has finished specifying landmarks, he can select one of the two approaches for classification. From then on, the automated mapper takes over, considering these mappings to be absolute.

Based on the subsumption operation in description logics, two algorithms have been developed to synthesize the raw similarity scores toward the final mappings. One is based on a heuristic rule that if a foreign concept (partially) matched with a *majority* of children of a concept, then this concept is a better mapping than (and thus subsumes) its children. The other takes the Bayesian approach that considers the best mapping being the concept that is the lowest in the hierarchy and with the posterior probability greater than 0.5. Details of these two algorithms are given in the next section.

[1]http://www.daml.org/dl/

[2]http://www-2.cs.cmu.edu/~mccallum/bow/rainbow/

Over the next few sections, we describe our proposed algorithms. We briefly describe our preliminary experiments, which combine computer simulation and human verification, and conclude by discussing issues and future research.

5. ALGORITHMS

Let us call the two topic ontologies A and B. Each ontology is a classification hierarchy, with each concept represented as a node in the corresponding tree. Each node in each hierarchy $(A_1, A_2, \ldots, A_m)$, $(B_1, B_2, \ldots, B_n)$ has a set of exemplar documents (a training set to build its model) that have already been classified as being associated with that node.

The Rainbow classifier is used to compute two raw topic similarity matrices $SMab(A_i, B_j)$ and $SMba(A_i, B_j)$, for each pair of nodes, one from ontology A and one from ontology B. So, $SMab$ is a matrix obtained by classifying the text of A using the model built using the text of B, and vice versa for $SMba$. Let $text(i)$ be the string of all text associated with node i.

$$SMab(A_i, B_j) = Sb(text(A_i), B_j) \quad (1)$$
$$SMba(A_i, B_j) = Sa(text(B_j), A_i). \quad (2)$$

5.1 *Simple heuristic approach*

This approach realizes the subsumption based on the majority rule. It considers the percentage of children of a node that agree on a mapping to a particular node in the other hierarchy. This percentage, called propagation threshold, can be varied. For each node in the tree, the mappings indicated by the children of the node are examined. The percentage of children that indicate mappings (with non-zero values) to a particular node in the second tree is calculated. If this percentage is greater than or equal to the threshold specified by the user, these mappings and the values associated with them are propagated up to (and thus subsumed by) their parent node. Otherwise, no decision can be made about the parent node, and nothing is propagated. For example, consider a node A with children $(A_1, A_2, \ldots, A_{10})$. Suppose the propagation threshold is set to 60%. So, if children A_1, A_2 andA_3 map to B_1, A_4andA_5 map to B_2, and the other children map to different nodes in B, then no decision can be made for the node A. If, instead, at least 6 children mapped to B_1 with non- zero values, then it could be concluded that A also maps to B_1.

5.2 *Bayesian approach*

First, consider any non-leaf node, say, N in a hierarchy. Exemplars associated with N are documents that belong to this class but cannot be classified into any one of its subclasses. Therefore, we create one leaf node, called "N-other", as a child of N, and move all exemplars of N to N-other. With this arrangement, raw scores given by Rainbow classifier now become similarity scores between leaves of these two ontologies. Two assumptions are then made:

Assumption 1: all leaves of a hierarchy form a mutually exclusive and exhaustive set.

Assumption 2: the raw score returned by Rainbow classifier $SMba(A_j, B_i)$ is interpreted as $P(A_j \mid B_i)$.

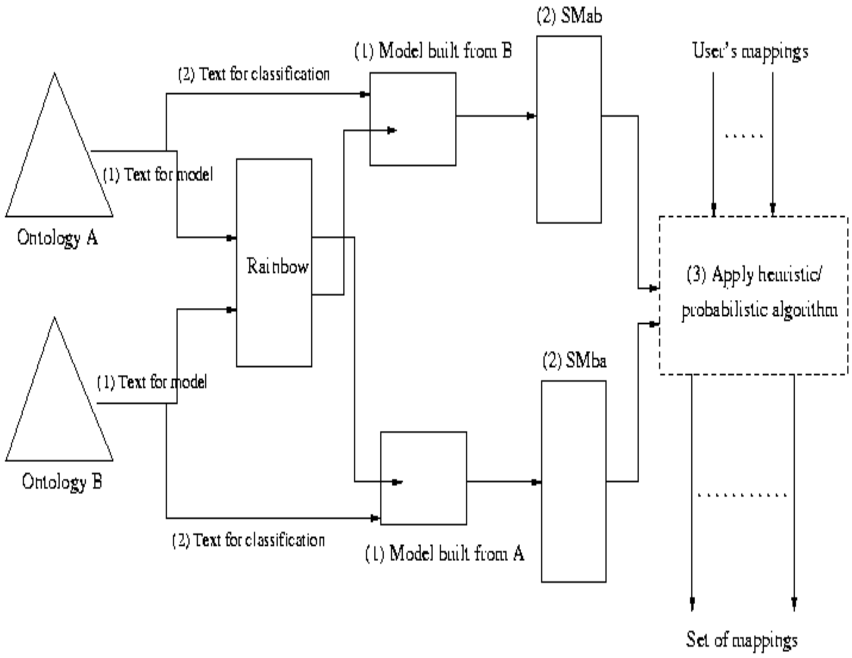

Figure 1: System components and flow

Assumption 1 implies that all children of a node are also mutually exclusive. Assumption 2 allows us to obtain $P(A_j \mid B_i)$ if B_i is a leaf in hierarchy B[3]. When B_i is a non-leaf node, as a superclass, its exemplar documents should include all exemplars associated with all of its subclasses. Therefore, the probability of a leaf node A_j, given a non-leaf node B_i, is

$$\begin{aligned} P(A_j \mid B_i) &= P(A_j \mid \vee_k B_k) \; \forall \; B_k \in children(B_i) \\ &= \sum_{B_k \in B_i} P(A_j \mid B_k).\frac{P(B_k)}{P(B_i)}. \end{aligned} \quad (3)$$

When specific $P(B_k)/P(B_i)$ is not available, we use a heuristic approximation:

$$P(A_j \mid B_i) \approx \frac{1}{|child(B_i)|}.\sum_{B_k \in B_i} P(A_j \mid B_k) \quad (4)$$

Definition: The concept $A*$ in A said to be the best mapping of a concept B_i in B if
1) $P(A*|B_i) > 0.5$, and
2) none of $A*$'s children A_k has $P(A_k|B_i) > 0.5$.

Condition 1 is used to circumvent the problem of mappings to overly general concepts by going too high on the target hierarchy. This would occur if only relying on $P(A_j|B_i)$ because the posterior probability of any node is the sum of its children's (and the probability of A_{root} is always 1). The value 0.5 is somewhat arbitrary, but it at least indicates that $A*$ is more similar to B_i than not. Condition 2 ensures $A*$ is the most specific concept satisfying condition 1. They together give $A*$ the flavor of the most specific subsumption in description logics. It can be easily shown that there is one and only one $A*$ for a given B_i.

The procedure of finding $A*$ consists of a bottom-up step (to compute probabilities of non-leaves) and a top-down step (to identify $A*$).

Bottom-Up:

1. For each leaf node A_j, obtain $P(A_j|B_i)$, either directly from $SMba$ if B_i is a leaf or computed from $SMba$ by Eq. 4 if not.
2. For each non-leaf node A_j, compute
$$P(A_j \mid B_i) = \sum_{A_k \in child(A_j)} P(A_k \mid B_i) \quad (5)$$

Top-Down:

1. set *current* to A_{root}.
2. **while** *current* has a child with $P > 0.5$
   set *current* to its most probable child
3. **return** *current*.

6. EXPERIMENTS AND RESULTS

We have conducted some preliminary experiments in which the automated mapping procedure was performed on the

[3]If needed, we normalize these $P(A_j \mid B_i)$ for all j so that they add up to 1.

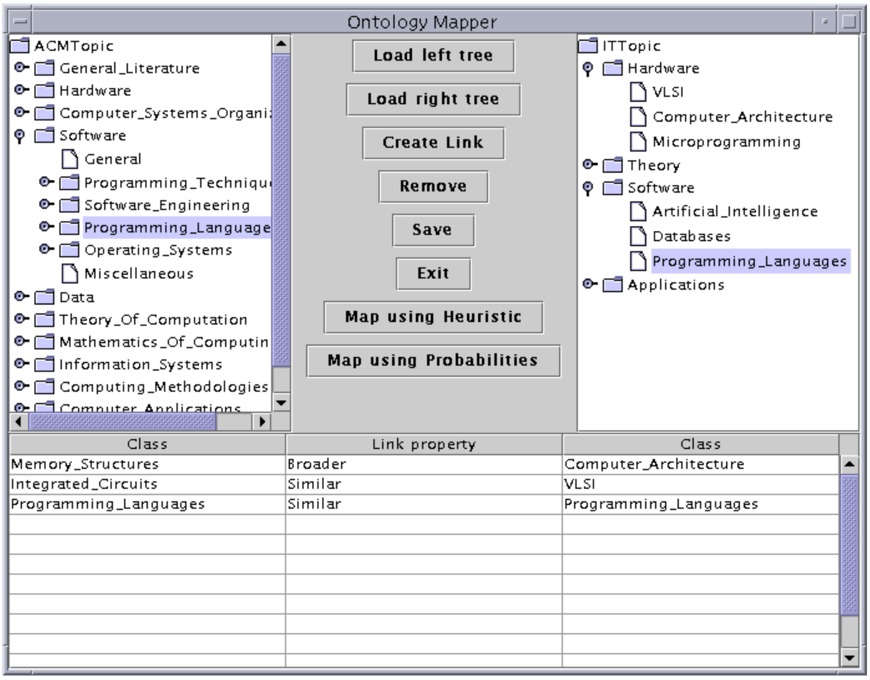

Figure 2: GUI for specifying manual mappings

two topic ontologies for a set of selected concepts. Three propagation thresholds (40%, 60%, and 80%) were experimented with the heuristic algorithm. For both algorithms, the resulting mappings were ranked by their respective final scores or probabilities, and were given to five people knowledgeable about computer science for evaluation. Each person was asked to indicate which of the mappings he/she considered to be appropriate. Those mappings that 4 out of 5 survey participants agreed upon were taken to be acceptable. The results were manually analyzed to get an idea of how different people view topics to be related, and thereby judge how accurate the automatically generated mappings are.

Running the heuristic algorithm with a threshold of 80% gives the best results of the three thresholds used in the testing. For the top 5%, 10%, 15%, and 20% ranked mappings, the acceptable rates (according to human evaluators) for the heuristic algorithm are 0.8, 0.55, 0.4, 0.4, respectively. The probabilistic algorithm gives better results than the simple heuristic. The corresponding acceptable rates were 0.8, 0.7, 0.68, 0.65, respectively. The better performance of the probabilistic algorithm is probably due to the fact that it has a much stricter constraint on which mappings the system should consider to be good. Fig. 3 shows the results obtained for the probabilistic algorithm.

Several factors may affect the mapping results. The first is the quality and amount of descriptive text associated with the concepts in each ontology. Most documents associated with our ontologies are abstracts of technical papers taken from ACM's digital library[4] and Citeseer[5]. The

[4]http://www.acm.org/dl/

[5]http://citeseer.nj.nec.com/

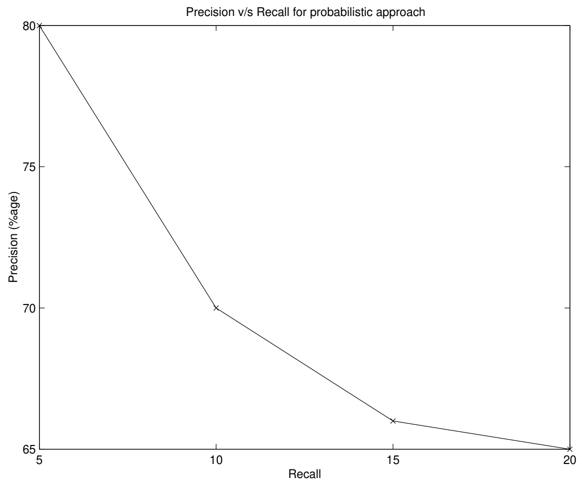

Figure 3: Probabilistic algorithm results

problem arises when a document related to databases also talks about other topics. Since the classifier only has knowledge of statistics obtained from the training documents, it may classify this document into concepts of the other ontology which may reference database issues, but are primarily about hardware or computer system implementation. This leads to some inaccuracy when Rainbow builds the models for the ontologies and while calculating raw similarity scores. The accuracy may be improved by including a greater number of abstracts associated wit each concept, or including full-length papers rather than short abstracts.

The second factor is the text classifier used. Each classifier has a different accuracy and implements various methods of text classification. We have used Rainbow, and it is possible that using a different classifier may give different, maybe better, results.

Thirdly, different human evaluators may have different views of the subject, based a different level of knowledge and experience in the field. For example, some persons may agree to a mapping between "ACMTopic/Software/Programming_Techniques" and "IT-Topic/Software/Databases", while others may not. This problem may be eased to a degree by including more evaluators.

The last issue to consider is the mutually exclusive assumption we made for the Bayesian approach. This may not hold for all leaf nodes, thus contributing to possible misclassification.

7. DISCUSSION AND FUTURE WORK

The problem we have worked on is similar to that of database schema integration, which is required to provide database interoperability and involves the resolution of naming, structural, and semantic conflicts. Some references to work in this area are given in the bibliography[13, 14, 15].

An attempt has been made to provide solutions for mapping between concepts belonging to two ontologies, using exemplar texts associated with each concept. Our approach is a combination of IR based text classification and Bayesian inference. The values returned by the text classifier are raw numbers. The algorithms we have proposed attempt to make sense of these numbers, and try to produce possible mappings for the user's perusal. Our experiments, though limited in scope, produced encouraging results.

We have developed an interface that allows a user to manually select a class from each hierarchy (a *landmark*) and specify a relation between these two classes (e.g. broader, narrower, similar, etc.) thus creating a mapping with special semantics. Similar to anchors [7], the mappings between landmarks, if properly used, can significantly improve both accuracy and efficiency of concept mapping. Another potentially valuable information source is the set of properties one class may have, because similar concepts not only share similar texts but also similar properties. How to incorporate these and other additional information sources into our automatic mapping framework is one important direction of future research. This would require re-examination of the probabilistic assumptions we have made and development of new algorithms.

Other research directions under active consideration include experimenting with and assessing different text classifiers; exploring possible application of our approach in other applications; adaptation of existing mappings when new evidence (e.g., new exemplars) is collected; improving the GUI and developing additional tools, to mention just a few.

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