Swoogle: A Semantic Web Search and Metadata Engine [*]

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ABSTRACT

Swoogle is a crawler-based indexing and retrieval system for the Semantic Web, i.e., for Web documents in RDF or OWL. It extracts metadata for each discovered document, and computes relations between documents. Discovered documents are also indexed by an information retrieval system which can use either character N-Gram or URIrefs as keywords to find relevant documents and to compute the similarity among a set of documents. One of the interesting properties we compute is rank, a measure of the importance of a Semantic Web document.

1. INTRODUCTION

The Semantic Web, currently in the form of a web of Semantic Web documents (i.e. online documents written in RDF and OWL), is essentially a web universe parallel to the web of online documents. Semantic Web document (SWD) is well known for its semantic annotation and meaningful reference. Since no conventional search engines can take advantage of such features, a search engine customized for SWDs, especially for ontologies, is needed by human users as well as software agents and services. At this stage, human users are expected to be semantic web researchers and developers who are interested in accessing, exploring and querying the RDF and OWL documents found on the web.

We introduce a prototype Semantic Web search engine called *Swoogle* to facilitate the development of the Semantic Web, especially the following three activities:

Finding appropriate ontologies. Failing to find a proper ontology always leads to the creation of a new ontology, which is often too customized to be reused. Swoogle helps users to find ontologies containing specified terms, and users may even qualify the type (class or property) of a term. Moreover, the ranking mechanism sorts ontologies by their popularity. This feature, we believe, not only eases the burden of marking up data, but also contributes to the emergence of canonical ontologies.

Finding instance data. In order to help users to integrate Semantic Web data distributed on the Web, Swoogle enables querying SWDs with constraints on the classes and properties used by them.

Characterizing the Semantic Web. By collecting metadata, especially inter-document relations, about the Semantic Web, Swoogle reveals interesting structural properties such as "how the Semantic Web is connected", "how ontologies are referenced", and "how an ontology is modified externally".

To this end, our work involves many interesting research issues such as "what is the best way to index, digest and cache SWDs?", and "is it possible to create a meaningful *rank* measure that uses link semantics?".

Swoogle is designed as a system that automatically discovers SWDs, indexes their metadata and answers queries about it. This distinguishes it from other semantic web repositories and query systems in literature. *Ontology based annotation systems*, such as SHOE [15], Ontobroker [9], WebKB [16], QuizRDF [8] and CREAM [11], focus on annotating online documents. However, their document indexes are based on the annotations but not the entire document, and they use their own ontologies which may not suit for Semantic Web documents. It is notable that CREAM [11] had indexed 'proper reference' and 'relational metadata'. *Ontology repositories*, such as DAML Ontology Library [1], SemWebCentral [4] and Schema Web [2], do not automatically discover semantic web documents but rather require people to submit URLs. They only collect ontologies which constitute a small portion of the Semantic Web. In addition, they simply store the entire RDF documents. Recently, some *Semantic Web browsers* are introduced. Ontaria [5] is a searchable and browsable directory of RDF documents developed by the W3C; however, it also does not automatically discover SWDs and stores the full RDF graphs. Semantic Web Search [3] indexes individuals of well-known classes (e.g. foaf:Person, rss:Item). While the advantages of Swoogle's crawler-based discovery system are obvious, the decision to only store and reason over metadata is less obviously a good one. We made this choice since the key goal in building Swoogle is to design a system that will scale up to handle millions and even tens of millions of documents.

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Moreover, Swoogle also enables rich query constraints on semantic relations.

Swoogle architecture consists of a database that stores metadata about the SWDs, two distinct web crawlers that discover SWDs, components that compute useful document metadata, components to compute semantic relationships among the SWDs, an N-Gram based indexing and retrieval engine, a simple user interface for querying the system, and agent/web service APIs to provide useful services.

We describe an algorithm, *Ontology Rank*, inspired by the Page Rank algorithm [18, 14, 19], that is used to rank hits returned by the retrieval engine. This algorithm takes advantage of the fact that the graph formed by SWDs has a richer set of relations. In other word, the edges in this graph have explicit semantics. Some are defined or derivable from the RDF and OWL languages (e.g., imports, usesTerm, version, extends, etc.) and others by common ontologies (e.g., FOAF's knows [1]).

We will also present some preliminary results summarizing the characteristics of the portion of the semantic web that our system has crawled and analyzed.

2. SEMANTIC WEB DOCUMENTS

Semantic web languages based on RDF (e.g., RDFS [2], DAML+OIL [3], and OWL [4]) allow one to make statements that define general terms (classes and properties), extend the definition of terms, create individuals, and to make assertions about terms and individuals already defined or created.

We define a *Semantic Web Document* (SWD) to be a document in a semantic web language that is online and accessible to web users and software agents. . Similar to a document in IR, a SWD is an atomic information exchange object in the Semantic Web.

Current practice favors the use of two kinds of documents which we will refer to as semantic web ontologies (SWOs) and semantic web databases (SWDBs). These correspond to what are called T-Boxes and A-Boxes in the description logic literature [6, 13]. Since a document may consist of both T-Boxes and A-Boxes, we adopt threshold based measure. We consider a document to be a SWO when a significant proportion of the statements it makes define new terms (e.g., new classes and properties) or extends the definition of terms defined in other SWDs by adding new properties or constraints. A document is considered as a SWDB when it does not define or extend a significant number of terms. A SWDB can introduce individuals and make assertions about them or make assertions about individuals defined in other SWDs.

For example, the SWD http://xmlns.com/foaf/0.1/index.rdf is considered a SWO in that its 466 statements (i.e. triples) define 12 classes and 51 properties but introduces no individuals. The SWD http://umbc.edu/˜finin/foaf.rdf is considered to be a SWDB since it defines or extends no terms but defines three individuals and makes statements about them.

Between these two extremes, some SWDs are intended to be both an ontology that defines a set of terms to be used by others, as well as a useful database of information about a set of individuals. Even a document that is intended as an ontology (e.g., it defines a set of terms that can be used by others) might define individuals as part of the ontology. Similarly, a document that is intended as defining a set of individuals might introduce some new terms in order to make it easier to describe the individuals rather than to make them available for others to use, [5] (e.g. http://www.daml.ri.cmu.edu/ont/USCity.daml, http://reliant.teknowledge.com/DAML/Government.owl).

[1]http://xmlns.com/foaf/0.1/
[2]http://www.w3.org/TR/rdf-schema/
[3]http://www.w3.org/TR/daml+oil-reference
[4]http://www.w3.org/TR/owl-semantics/

3. SWOOGLE ARCHITECTURE

As shown in figure 1, Swoogle's architecture can be broken into four major components: SWD discovery, metadata creation, data analysis, and interface. This architecture is data centric and extensible: components work independently and interact with one another through a database.

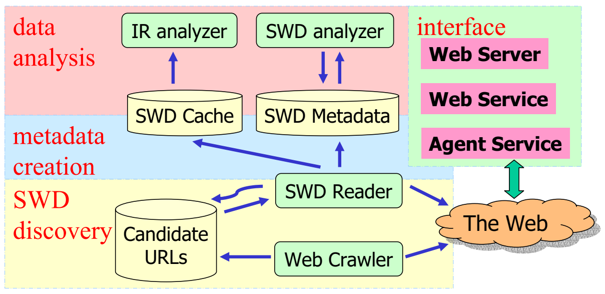


Figure 1: The architecture of Swoogle

The *SWD discovery* component discovers potential SWDs throughout the Web and keeps up-to-date information about SWDs.

The *metadata creation* component caches a snapshot of a SWD and generates objective metadata about SWDs at both the syntax level and the semantic level.

The *data analysis* component uses the cached SWDs and the created metadata to derive analytical reports, such as classification of SWOs and SWDBs, rank of SWDs, and the IR index of SWDs.

The *interface* component focuses on providing data service to the Semantic Web community. We have implemented a Web interface at http://www.swoogle.org, and we are working on making Swoogle a Web Service for software agents.

We elaborate on each component in the following sections.

4. FINDING SWDS

Finding URLs of SWDs is by itself an interesting engineering challenge. A straightforward approach is to search through a conventional search engine. By May 25, 2004, Google has indexed 4,285,199,774 web documents. It is not possible for Swoogle to parse all documents on the web to see if thery are SWDs. (Even if it were computationally feasible, most search engines returns at most 1,000 results per query). We developed a set of crawlers employing a number of heuristics for finding SWDs.

First, we developed a *Google crawler* to search URLs using the Google Web Service. We start with type extensions,

[5]Programming languages introduce the notion of a modules, importing and exporting to make these intentions explicit

such as ".rdf", ".owl", ".daml", and ".n3". Although they are not perfect SWD indicators, table 1 shows that they have fair precision. To overcome Googleś limit of returning only the first 1000 results for any query, we append some constraints (keywords) to construct more specific queries, and then combine their results (see table 2). Such query expansion techniques have enabled us to collect as many as 20K candidate URLs of SWDs at a time. Since Google changes its PageRanks daily, we also expect to discover new SWDs by running the same query weekly (in fact, Swoogle already have 200k urls discovered by Google Crawler).

extension	# discovered(100%)	# SWD
rdf	184,992	111,350(60%)
rss	8,359	7,712(92%)
owl	4,669	3,138(67%)
n3	4,326	1,523(35%)
daml	3,699	2,256(61%)
no extension	154,591	7,258(5%)

Table 1: Extensions of SWD (Aug 30, 2004)

query string	number of pages
rdf	5,230,000
filetype:rdf rdf	246,000
filetype:rss rdf	13,800
filetype:daml rdf	4,360
filetype:n3 rdf	2,630
filetype:owl rdf	1,310
filetype:rdfs rdf	304

Table 2: Google search results (May 25,2004)

We have also developed the *Focused Crawler*, which crawls documents within a given website. In order to reduce search complexity and improve precision, simple heuristics, like extension constraint (e.g. documents with ".jpg" or ".html" extensions are seldom SWDs) and focus constraint (i.e. only crawl URLs relative to the given base URL), are used to filter out those documents likely to be irrelevant. Swoogle provides a web interface where registered users can submit a URL of either a SWD or a web directory under which many SWDs may be present, e.g. http://daml.umbc.edu/ontologies/. We have initiated focused crawls from many Semantic Web URLs know to us, and actively invite the SW community to submit further URLs for focused crawling.

Since SWDs can be discovered by semantic links while parsing SWDs, we developed the JENA2 [6] based *Swoogle Crawler*. It both analyzes the content of a SWD and discovers new SWDs. First, it verifies if a document is a SWD or not, and it also revisits discovered URLs to check updates. Secondly, several heuristics are used to discover new SWDs through semantic relations: (1)the semantics of URIref shows that the namespace of a URIref is highly likely to be the URL of an SWD; (2)the semantics of OWL shows that owl:imports links to an external ontology, which is a SWD; (3) the semantics of FOAF ontology, shows that rdfs:seeAlso property of an instance of foaf:Person often links to another FOAF document, which often is a SWD.

[6]http://jena.sourceforge.net/

5. SWD METADATA

SWD metadata is collected to make SWD search more efficient and effective. It is derived from the content of SWD as well as the relations among SWDs. Swoogle identifies three categories of metadata: (i) basic metadata, which considers the syntactic and semantic features of a SWD, (ii) relations, which consider the explicit semantics between individual SWDs, and (iii) analytical results such as SWO/SWDB classification, and SWD ranking. The first two categories are objective information about SWDs, and we will discuss them in the rest of this section. The third category is subjective and will be discussed in section 6.

In order to simplify notations, we use qualified names (QNames [7]) in the following context. E.g. "rdf:" stands for RDF namespace, "daml:" stands for DAML namespace (i.e. http://www.w3.org/2001/03/daml+oil#)

5.1 Basic metadata

The basic metadata about a SWD falls in three categories: language feature, RDF statistics and ontology annotation.

Language feature refers to the properties describing the syntactic or semantic features of a SWD. Swoogle captures the following features:

1. *Encoding.* It shows the syntactic encoding of a SWD. There are three existing encodings, namely "RDF/XML", "N-TRIPLE" and "N3".

2. *Language.* It shows the language used by a SWD. Swoogle considers the usage of four meta level languages, namely "OWL", "DAML+OIL", "RDFS", and "RDF".

3. *OWL Species.* It shows the language species of a SWD written in OWL. There are three possible species, namely "OWL-LITE", "OWL-DL", and "OWL-FULL".

RDF statistics refers to the properties summarizing node distribution of the RDF graph of a SWD. We focus on how SWDs define new classes, properties and individuals. In an RDF graph, a node is recognized as a *class* iff it is not an anonymous node and it is an instance of rdfs:Class; similarly, a node is a *property* iff it is not an anonymous node and it is an instance of rdf:Property; an *individual* is a node which is an instance of any user defined class.

Let foo be a SWD. By parsing foo into an RDF graph, we may get RDF statistics about foo. Let $C(foo), P(foo), I(foo)$ be the set of classes, properties and individuals defined in the SWD foo respectively. The *ontology-ratio* $R(foo)$ is calculated by equation (1). The value of ontology-ratio ranges from 0 to 1, where "0" implies that foo is a pure SWDB and "1" implies that foo is a pure SWO.

$$R(foo) = \frac{|C(foo)| + |P(foo)|}{|C(foo)| + |P(foo)| + |I(foo)|} \quad (1)$$

Ontology annotation refers to the properties that describe a SWD as an ontology. In practice, when a SWD has an instance of OWL:Ontology, Swoogle records its properties as the following:

1. *label.* i.e. rdfs:label

2. *comment.* i.e. rdfs:comment

[7]http://www.w3.org/TR/1999/REC-xml-names-19990114/#NT-QName

3. *versionInfo.* i.e. owl:versionInfo and daml:versionInfo

5.2 Relations among SWDs

Looking at the entire semantic web, it is hard to capture and analyze relations at the RDF node level. Therefore, Swoogle focuses on SWD level relations which generalize RDF node level relations. Swoogle captures the following SWD level relations:

TM/IN captures *term reference* relations between two SWDs, i.e. a SWD is using terms defined by some other SWDs. By retrieving and processing the reference SWD, the type of term (class, property or individual) can be determined. The referenced SWDs are collected by recording the namespaces of all valid URIrefs in the given SWD.

IM shows that an ontology *imports* another ontology. The URLs of referenced ontolgoies are collected by recording the objects in triples whose predicate is owl:imports or daml:imports.

EX shows that an ontology *extends* another. Such a relation may be produced by many properties as shown in table 3. For example, if ontology A defines class AC which has the "rdfs:subClassOf" relation with class BC defined in ontology B, Swoogle will record the EX relation from A to B.

PV shows that an ontology *is a prior version of* another.

CPV shows that an ontology *is a prior version of and is compatible with* another.

IPV shows that an ontology *is a prior version of but is incompatible with* another.

The last five relations are types of *inter-ontology relation.* They are extracted from a SWD by analyzing triples containing "indicators", which is listed in table 3.

Type	Classes and Properties
IM	owl:imports, daml:imports
EX	rdfs:subClassOf, rdfs:subPropertyOf, owl:disjointWith, owl:equivalentClass, owl:equivalentProperty, owl:complementOf, owl:inverseOf, owl:intersectionOf, owl:unionOf daml:sameClassAs, daml:samePropertyAs, daml:inverseOf, daml:disjoinWith daml:complementOf, daml:unionOf daml:disjointUnionOf, daml:intersectionOf
PV	owl:priorVersion
CPV	owl:DeprecatedProperty, owl:DeprecatedClass, owl:backwardCompatibleWith
IPV	owl:incompatibleWith

Table 3: Indicators of inter-ontology relation

6. RANKING SWDS

PageRank, introduced by Google [18, 12], evaluates the relative importance of web documents. Given a document A, A's PageRank is computed by equation 2:

$$\begin{aligned} &PR(A) = PR_{direct}(A) + PR_{link}(A) \\ &PR_{direct}(A) = (1-d) \\ &PR_{link}(A) = \mathrm{d}\left(\frac{\mathrm{PR(T_1)}}{\mathrm{C(T_1)}} + ... + \frac{\mathrm{PR(T_n)}}{\mathrm{C(T_n)}}\right) \end{aligned} \tag{2}$$

where $T_1, \ldots, T_n$ are web documents that link to A; $C(T_i)$ is the total outlinks of T_i; and d is a damping factor, which is typically set to 0.85. The intuition of PageRank is to measure the probability that a random surfer will visit a page. Equation 2 captures the probability that a user will arrive at a given page either by directly addressing it (via $PR_{direct}(A)$), or by following one of the links pointing to it (via $PR_{link}(A)$).

Unfortunately, this random surfing model is not appropriate for the Semantic Web. The semantics of links lead to a non-uniform probability of following a particular outgoing link. Therefore, Swoogle uses a *rational random surfing model* which accounts for the various types of links that can exist between SWDs.

Given SWDs A and B, Swoogle classifies inter-SWD links into four categories: (i) imports(A,B), A imports all content of B; (ii) uses-term(A,B), A uses some of terms defined by B without importing B; (iii) extends(A,B), A extends the definitions of terms defined by B; and (iv) asserts(A,B), A makes assertions about the individuals defined by B.

These relations should be treated differently. For instance, when a surfer observes imports(A,B) while visiting A, it is natural for it to follow this link because B is semantically part of A. Similarly, the surfer may follow extends(A,B) relation because it can understand the defined term completely (which depends on the definition of external class/property) only when it browses both A and B. Therefore, we assign different weight, which shows the probability of following that kind of link, to the four categories of inter-SWD relations.

Since we generalized RDF node level relations to SWD level relations, we also count the number of references. The more terms in B referenced by A, the more likely a surfer will follow the link from A to B.

Based on the above considerations, given SWD a, Swoogle computes its raw rank using equation 3.

$$\begin{aligned} &rawPR(a) = (1-d) + d \sum_{x \in L(a)} rawPR(x)\frac{f(x,a)}{f(x)} \\ &f(x,a) = \sum_{l \in links(x,a)} weight(l) \\ &f(x) = \sum_{a \in T(x)} f(x,a) \end{aligned} \tag{3}$$

where $L(a)$ is the set of SWDs that link to a, $T(x)$ is the set of SWDs that x links to.

Then Swoogle computes the rank for SWDB and SWO using equation 4 and 5 respectively.

$$PR_{SWDB}(a) = rawPR(a) \tag{4}$$

$$PR_{SWO}(a) = \sum_{x \in TC(a)} rawPR(x) \tag{5}$$

where TC(a) is the transitive closure of SWOs imported by a.

Our hypothetical *Rational Random Surfer*(RRS) retain PageRank's direct visit component; the rational surfer can jump to SWDs directly with a certain probability d. However, in the link-following component, the link is chosen with unequal probability – $\frac{f(x,a)}{f(x)}$, where x is the current SWDB, a is the SWD that x links to, $f(x,a)$ is the sum of all link weights from x to a, and $f(x)$ is the sum of the weights of all outlinks from x. The control flow of such a surfer is is shown in figure 2.

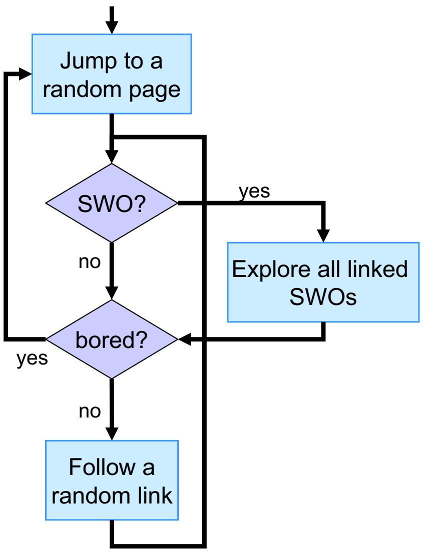


Figure 2: Rational Random Surfer

Figure 3 illustrate how the rank of a SWO is computed. Let A, B, C, D, E and F be SWOs, and assume that the probability for a RRS to visit any of these SWOs from a SWDB is 0.0001. The probability that she visits B is $PR_{SWO}(B) + (PR_{SWO}(E) + PR_{SWO}(D)) = 0.0003$. The probability that she visits F is $PR_{SWO}(F) + (PR_{SWO}(C) = 0.0002$.The probability that she visits A is 0.0006 since A will be visited when any of

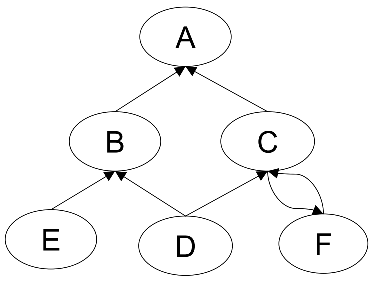


Figure 3: Combine ranks of SWO

Table 4 shows the top ranked SWDs discovered by Swoogle.

7. INDEXING AND RETRIEVAL OF SWDS

Central to a Semantic Web search engine is the problem of indexing and searching SWDs. While there is significant semantic information encoded in marked documents, reasoning over large collections of documents can be expensive. Traditional information retrieval techniques have the advantage of being faster, while taking a somewhat more coarse view of the text. They can thus quickly retrieve a set of SWDs that deal with a topic based on similarity of the source text alone.

In addition to the efficiency, there are a number of reasons why one would want to apply IR techniques to this problem. For one thing, documents are not entirely markup. We would like to be able to apply search to both the structured and unstructured components of a document. Related to this point, it is conceivable that there will be some text documents that contain embedded markup. In addition, we may want to make our documents available to commonly used search engines, such as Google. This implies that the documents must be transformed into a form that a standard information retrieval engine can understand and manipulate. Information retrieval techniques also have some value characteristics, including well researched methods for ranking matches, computing similarity between documents, and employing relevance feedback. These compliment and extend the retrieval functions inherent in Swoogle.

There has been work [20, 17, 10] demonstrating that such techniques can be made to work with both RDF dcuments as well as text documents with embedded RDF markup, and that they can be made to leverage some of the semantic information encoded.

Traditional IR techniques look at a document as either a collection of tokens, typically words, or N-Gram. An N-Gram is an n-character segment of the text which spans inter-word boundaries. The N-Gram approach is typically employed by sliding a window of n-characters along the text, and taking a sample at each one character step. The use of N-Grams can result in a larger vocabulary, as single words can contain multiple N-Grams. One advantage to this approach is that inter-word relationships are preserved, where they are typically not in word based approaches. N-Grams are also known to be somewhat resistant to certain kinds of errors, such as mis-spellings.

The use of N-Gram is particularly important to this approach because of the treatment of URIrefs as terms. Given a set of keywords defining a search, we may want to match documents that have URIrefs containing those keywords. For example, consider a search for ontologies for "time". The search keywords might be *time temporal interval point before after during day month year eventually calendar clock durations end begin zone*. Candidate matches might include documents containing URIrefs such as:

```
http://foo.com/timeont.owl#timeInterval
http://foo.com/timeont.owl#CalendarClockInterval
http://purl.org/upper/temporal/t13.owl#timeThing
```

Clearly, exact matching based on words only would miss these documents (based on the URIrefs given). However, N-Grams would find a number of matches.

It is also possible, however, to use a word based approach. Bear in mind that ontologies define vocabularies. In OWL, URIrefs of classes, properties and individuals correspond play the role of words in a natural language. We can take an SWD, reduce it to triples, extract the URIrefs (with duplicates), discard URIrefs for blank nodes, hash each URIref to a token, and index the document. Whereas a conventional information retrieval system treats a text document as a *bag of words*, we could treat a SWD as a *bag of URIrefs*. This would support retrieval using queries which are also sets of URIrefs as well as other functions, such as document similarity metrics.

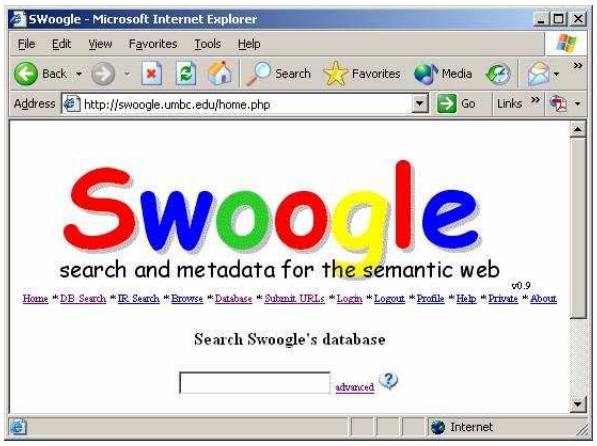
Rank	URL	Value
1	http://www.w3.org/1999/02/22-rdf-syntax-ns	2845.97
2	http://www.w3.org/2000/01/rdf-schema	2814.21
3	http://www.daml.org/2001/03/daml+oil	311.65
4	http://www.w3.org/2002/07/owl	192.18
5	http://www.w3.org/2000/10/rdf-tests/rdfcore/testSchema	59.82
6	http://www.w3.org/2002/03owlt/testOntology	22.50
7	http://ontology.ihmc.us/Entity.owl	21.28
8	http://www.w3.org/2001/XMLSchema	17.45
9	http://www.daml.org/2000/12/daml+oil	10.44
10	http://www.daml.org/2000/10/daml-ont	8.88
11	http://ontology.ihmc.us/Group.owl	7.67
12	http://ontology.ihmc.us/Actor.owl	6.83

Table 4: Top 12 ranked SWDs (May 25,2004)

We are currently adapting the Sire, a custom indexing and retrieval engine we built for the Carrot2 distributed IR system [7], to augment Swoogle. Sire can be made to use either n-grams or words, and employs a TF/IDF model with a standard cosine similarity metric. Sire is being enhansed to process RDF docouments using either character level n-grams computed over the RDF source or to process the URIrefs in the document as indexible tokens.

8. CURRENT STATUS

Swoogle is an ongoing project undergoing constant development. This paper describes the features in version 1. Figure 4 shows the Swoogle start page.



SWoogle - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Search Favorites Media
Address http://swoogle.umbc.edu/home.php
Go Links
Swoogle
search and metadata for the semantic web
v0.9
Home DB Search IR Search Browse Database Submit URLs Login Logout Profile Help Private About
Search Swoogle's database
advanced
Internet

Figure 4: Swoogle interface

A general user can query with keywords, and the SWDs matching those keywords will be returned in ranked order.

As shown in table 4, Swoogle ranks SWOs higher than SWDBs; thus, SWOs will be returned as query results before SWDBs. The highest ranked SWDs typically are the base ontologies that define the Semantic Web languages, such as the RDF and OWL language definitions, which are used by almost all SWDs and are always imported by SWOs.

For advanced users, an "advanced" search interface is provided (figure 5), which essentially allows them to fill in the constraints to a general SQL query on the underlying database.

The user can query using keywords, content based constraints (e.g. type of SWD, OWL syntax, number of defined classes/properties/individuals), language and encoding based constraints (N3 vs XML), and/or the Rank of the document. Sample results are shown in figure 6.

At present, the metadata are stored in a mySQL database, and we have already indexed about 11,000 SWDs. We anticipate that in future versions, we will need to migrate to a commercial database in order to scale to indexing millions of SWDs.

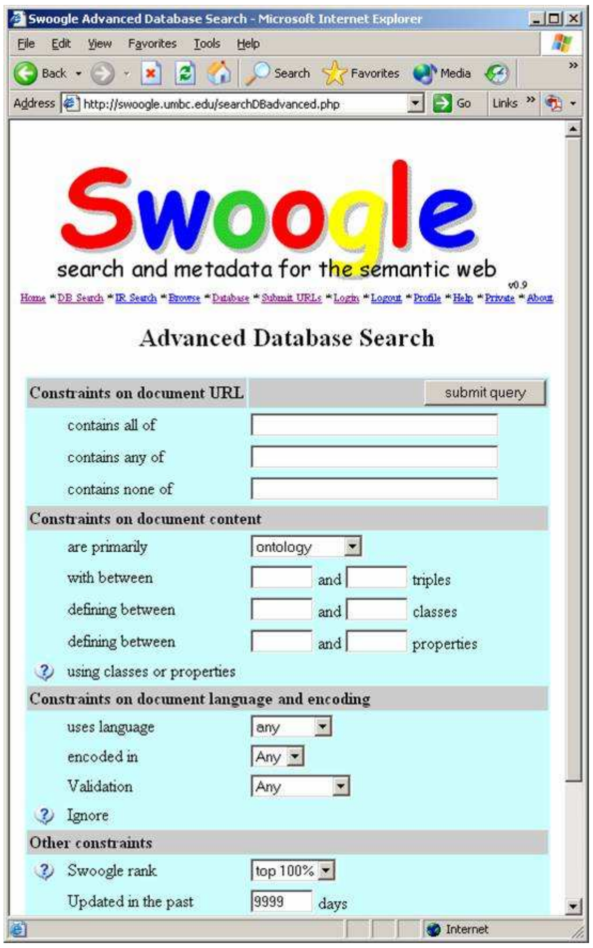
In our database, 13.29% SWDs are classified as SWOs, and others as SWDBs (with 0.8 as the threshold on ontology ratio). We find that about half of all SWDs have rank of 0.15, which means they are not referred to by any other SWDs. Also, the mean of ranks is 0.8376, which implies that the SWDs we have crawled are poorly connected.

Currently, Swoogle has evolved to Swoogle2 (version 2), which is featured by three components: Swoogle Search, Ontology Dictionary and statistical measures of the collection of SWDs. We invite the readers to visit Swoogle website at http://swoogle.umbc.edu.

9. CONCLUSIONS AND FUTURE WORK

Current web search engines such as Google and AlltheWeb do not work well with SWDs since they are designed to work with natural languages and expect documents to contain unstructured text composed of words. Failing to understand the structure and semantics of SWDs, they cant take advantage of the Semantic Web. Accompany with the growth of the Semantic Web, powerful search and indexing systems are highly needed by the Semantic Web researchers to help them find and analyze SWDs on the web. Such systems can be used to support the tools being developed by researchers – such as annotation editors – as well as software agents whose knowledge comes from the semantic web.

We have described a prototype crawler-based indexing and retrieval system for the Semantic Web Documents, i.e., web documents written in RDF or OWL. It runs multiple crawler to discover SWDs through meta-search and following links, analyzes SWDs and produce metadata about SWDs as well as the relations among SWDs, computes ranks of SWDs using a "rational random surfing model", and indexs SWDs using an information retrieval system by treating URIrefs are terms. One of the interesting properties


Swoogle Advanced Database Search - Microsoft Internet Explorer

Address http://swoogle.umbc.edu/searchDBadvanced.php

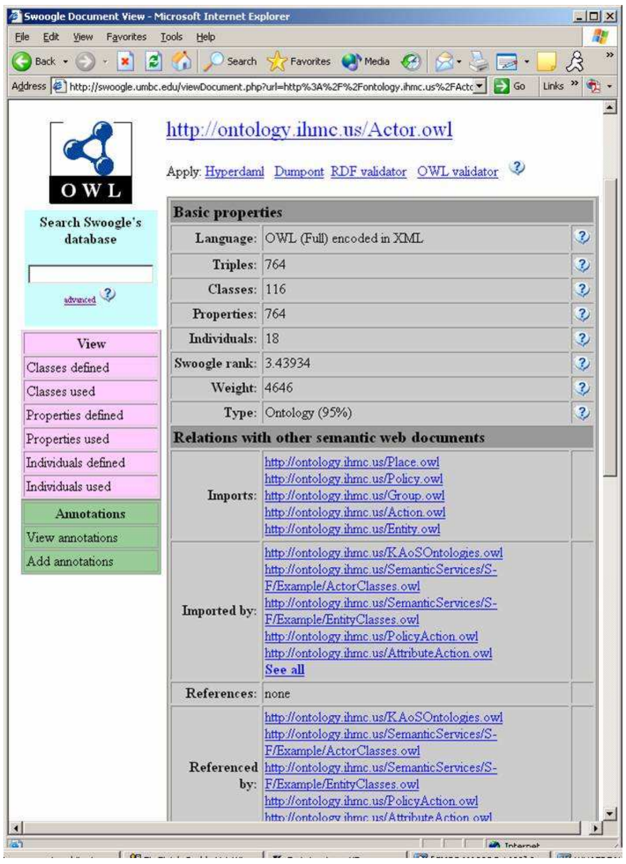
Swoogle
search and metadata for the semantic web v0.9

Home * DB Search * IR Search * Browse * Database * Submit URLs * Login * Logout * Profile * Help * Private * About

Advanced Database Search

Constraints on document URL	submit query
contains all of	
contains any of	
contains none of	
Constraints on document content	
are primarily	ontology
with between	and triples
defining between	and classes
defining between	and properties
using classes or properties	
Constraints on document language and encoding	
uses language	any
encoded in	Any
Validation	Any
Ignore	
Other constraints	
Swoogle rank	top 100%
Updated in the past	9999 days

Figure 5: Swoogle advanced query


Swoogle Document View - Microsoft Internet Explorer

Address http://swoogle.umbc.edu/viewDocument.php?url=http%3A%2F%2Fontology.ihmc.us%2FActc

Search Swoogle's database

advanced

View: Classes defined, Classes used, Properties defined, Properties used, Individuals defined, Individuals used

Annotations: View annotations, Add annotations

http://ontology.ihmc.us/Actor.owl

Apply: Hyperdaml Dumpont RDF validator OWL validator

Basic properties	
Language:	OWL (Full) encoded in XML
Triples:	764
Classes:	116
Properties:	764
Individuals:	18
Swoogle rank:	3.43934
Weight:	4646
Type:	Ontology (95%)
Relations with other semantic web documents	
Imports:	http://ontology.ihmc.us/Place.owl http://ontology.ihmc.us/Policy.owl http://ontology.ihmc.us/Group.owl http://ontology.ihmc.us/Action.owl http://ontology.ihmc.us/Entity.owl
Imported by:	http://ontology.ihmc.us/KAoSOntologies.owl http://ontology.ihmc.us/SemanticServices/S-F/Example/ActorClasses.owl http://ontology.ihmc.us/SemanticServices/S-F/Example/EntityClasses.owl http://ontology.ihmc.us/PolicyAction.owl http://ontology.ihmc.us/AttributeAction.owl See all
References:	none
Referenced by:	http://ontology.ihmc.us/KAoSOntologies.owl http://ontology.ihmc.us/SemanticServices/S-F/Example/ActorClasses.owl http://ontology.ihmc.us/SemanticServices/S-F/Example/EntityClasses.owl http://ontology.ihmc.us/PolicyAction.owl http://ontology.ihmc.us/AttributeAction.owl

Figure 6: Swoogle query result

computed for each semantic web document is its rank – a measure of the documents importance on the Semantic Web.

The current version of our system has discovered and analyzed over 11,000 semantic web documents. A second version has been designed and partially implemented that will also capture more metadata on classes and properties and is designed to support millions of documents. We are also considering building an ontology dictionary based on the ontologies discovered by Swoogle.

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