1. INTRODUCTION

Faceted search is a technique for accessing document collections that combines text search and faceted navigation applied to the documents’ metadata. With the latter users can narrow down search results by incrementally applying multiple filters, called facets [18]. Though faceted search has become a mainstream commercial technology, traditional models impose severe constraints on the way faceted metadata is represented, and queries are formulated.

In particular, conventional faceted search models assume that documents are not “linked” to each other. E.g., in travel websites like TripAdvisor.com, one can do faceted search for hotels and restaurants, but there are no facets linking specific hotel and restaurant documents. Thus, values of facets for different kinds of documents cannot be joined in a single query. E.g., one cannot formulate a query (in TripAdvisor) that returns hotels with restaurants serving local food: even if we can query for hotels or restaurants independently, when we “switch view” from hotels to restaurants, the constraints imposed on hotels are lost. Data sparsity is another important issue in faceted search applications: document annotations are intrinsically incomplete, which leads to missing expected answers and facets. The meaning of queries in faceted search front-ends is also an issue: users are allowed to make a multiple choice within facets and the meaning of the corresponding queries is resolved in the back-end when queries are translated into operations over inverted indices. This is application dependent and not grounded on a formal query model that can be studied independently.

In this paper we demonstrate SemFacet, a proof-of-concept prototype implementing faceted search enhanced with Semantic Web technologies. RDF provides the required flexibility to semantically link documents in arbitrary ways, thus overcoming the limitations of conventional metadata models for faceted search. Furthermore, RDF is powerful enough to capture existing metadata models for faceted search. OWL 2 can be used to provide rich domain knowl-

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Faceted Queries. A conventional faceted query can be seen as a filter over a set of documents: it specifies what facet names should be used to annotate a target document and what facet values should be used for each of these names. The answer for such a query is the subset of the given documents satisfying the filter. In the semantic faceted search approach, we go further: a semantic faceted query can relate sets $S_1, \ldots, S_n$ of documents with annotations by describing relations between these sets and setting separate filters over each one of them. Analogously to conventional faceted queries, the effect of these filters is to select subsets $S'_1 \subseteq S_1, \ldots, S'_n \subseteq S_n$. In contrast to a conventional faceted query, we can now “navigate” between different types of documents and select what documents $S'_i \subseteq S_i$ are to be returned as query output.

In what follows, we formalise the notion of faceted query, starting with the notion of basic faceted query.

**Definition 3.** A basic faceted query (BFQ) over $V$ is a pair $F = (X, \Gamma)$, where $X \in V_N$ and $\Gamma \subseteq V_L \cup V_D$.

Intuitively, a document satisfies a BFQ $(X, \Gamma)$ if it is $X$-annotated with some value in $\Gamma$. We illustrate BFQs on an example.

**Example 4. The following are BFQs about politicians:**

- $Q^1_P = (\text{type, \{president\}})$,  
- $Q^2_P = (\text{has\_child, \{}\})$.

The query $Q^1_P$ asks for (all the documents about) presidents. $Q^2_P$ for politicians with American citizenship, $Q^3_P$ for politicians with children. The empty condition $\{}\$ is used in $Q^2_P$, since we impose no restrictions on the children. Moreover, the BFQ

$$Q_C = (\text{is\_graduated\_from, \{d_h, d_s\}})$$

over the children of politicians in $C$ asks for documents about children of politicians graduated from Harvard ($d_h$) or Stanford ($d_s$).

We now define how to combine BFQs in complex queries. Faceted search is typically initiated by a keyword search that returns the initial set of documents over which a user can set filters. To model keyword-based search, we introduce a special set $C\text{\_kw}$ disjoint from $V$, and assume that every element $S \in C\text{\_kw}$ stands for a set of documents retrieved by a specific keyword-based search.

**Definition 5.** A (faceted) query expression

$$\text{expr ::= start \mid start/\text{rest}}$$

over $V$ is defined by the following grammar:

- $\text{start ::= S \mid \ast(S)}$
- $\text{rest ::= path \mid (path \circ path)}$
- $\text{path ::= F \mid \ast(F)}$
- $\text{step ::= \text{rest} \mid \text{rest/step}}$

where $\circ \in \{\land, \lor\}$, $S \in V_N$ and $F$ is a BFQ over $V$. A (semantic) faceted query (FQ) over $V$ is a query expression over $V$ where the symbol $\ast$ occurs exactly once.

The starting point (start) of a query expression $\text{expr}$ captures the content of the initial search used in typical interfaces (prior to faceted navigation), which is given by a keyword search. In each step (step) of the remainder of the query expression (rest), a BFQ is applied to narrow down the search results. These steps are put together in paths (path), where each path is a sequence of BFQs that have to be applied according to the sequence order. A branching (path$_1 \land$ path$_2$) can be applied in a query expression indicating that each of the search results has to satisfy the sequence of conditions specified by both path$_1$ and path$_2$. Finally, the symbol $\ast$ in a query expression indicates which documents must be returned. In a faceted query this symbol is mentioned exactly once, as the result of such query is one set of documents. We illustrate the syntax and semantics of FQs in the following example.

**Example 6.** Consider the following information request about the scenario introduced in Examples 2 and 4:

Find children of US presidents who graduated from Harvard University or Stanford University.

It corresponds to the following FQ:

$$S_{\text{politician}}/(Q^1_P \land Q^2_P \land (\ast(Q^3_P)/Q_C))$$

Intuitively, the query first retrieves all documents of $S_{\text{politician}} \in C\text{\_kw}$, i.e., all documents returned by a keyword search with politicians. Then these results are filtered with $Q^1_P$ and $Q^2_P$, obtaining the set of documents about American presidents. Finally, this set is filtered by using $\ast(Q^3_P)/Q_C$, returning the set of documents about children of American presidents who graduated from Harvard or Stanford.

Semantic Faceted Search using RDF and SPARQL. Semantic annotations can be realised using different technologies. Our demo implementation exploits RDF, which we see as the most natural choice: URIs can be seen as documents of $V_D$, object and data properties as facet-names of $V_N$, literals as labels of $V_L$. Moreover, annotations are encoded in RDF as triples: each triple $(\text{p} : \text{v})$ corresponds to a $p$-annotation of a document $\text{v}$ with a facet-value $p$.

As we will see in Sections 3 and 4, RDF gives more than that: by using more than one document property as facet-value, one can easily extend the notion of facet to a tree-like structure. This is particularly useful in faceted search, for example to combine filters on the country and the president.

We now discuss how to embed our faceted query language in SPARQL 1.1. The standard language for querying RDF. One can provide semantics to our faceted query language by translation into first-order logic and show that any FQ corresponds to a filter-free SPARQL 1.1 query $Q$ that: (i) is positive (neither OPTIONAL nor NOT EXISTS nor MINUS construct occurs in $Q$); (ii) is tree-shaped (the dependency graph of $Q$’s variables, where $?x$ and $?y$ are connected if there is a triple $?x \rightarrow {?y}$ in $Q$, is tree-shaped); and

\footnote{A similar query was used to illustrate the Parallax system in [5].}
的政治家和商界领袖，是美国和英国军队的军官，商人……

我们的接口还支持用户在facet上使用(·)操作符，该操作符可以用于选择输出文档的下一种输出文档。到 facets。
Showing Relevant Information. Another important challenge for faceted search interfaces is to avoid “dead ends” (i.e., facet-value selections that lead to queries with the empty answer). In conventional faceted search applications, the detection of such dead ends is data driven, in the sense that the interface does not display facet-values for which no document exists. Axioms provide an alternative, declarative, way to detect dead ends during faceted search. E.g., in the presence of the axiom

\[
\text{DisjointClasses}(\text{USPresident FrenchPresident})
\]

once the facet-value USPresident is selected, the interface should not display the value FrenchPresident. Axioms are particularly important when annotations are inconsistent (this can happen with automatically generated annotations). SemFacet uses both axiom and data-driven techniques to avoid dead ends during search.

4. BACK-END

SemFacet is available as a Web service [16] and runs on a machine with 1vCPU, 4Gb of memory, and 20Gb of disk space. SemFacet is implemented on top of a fragment of Yago [20] and DBpedia [4] abstractions; it contains around 15 million RDF triples extended with OWL 2 axioms. A general architecture of SemFacet is in Figure 4. SemFacet’s back-end relies on RDFox [3] for storing RDF triples, performing reasoning, and answering queries. RDFox is a massively parallel in-memory RDF triple store; it implements reasoning for the OWL 2 RL profile. RDFox supports only a conjunctive fragment of SPARQL 1.1; thus, to answer faceted queries, we extended its query module with a support of UNION.

In short, the back-end’s workflow is the following. First, DBpedia abstracts are loaded to Lucene and RDFox; Yago is loaded in RDFox only. Every initial user’s input via keyword based search is executed over Lucene that returns initial relevant document IDs, and a view of IDs is created. Based on the view of IDs, the initial facets and answer snippets compound of abstracts, thumbnails, and links to Wikipedia are generated. Then, the user performs query refinement and refocusing as described in Section 3 in the workflow of SemFacet. Faceted queries \( Q \) are translated into SPARQL 1.1 and executed by RDFox and the projections of results on the \( Q’s \) first variable are intersected with the view of IDs. We rely on Lucene’s ranking function to display answers under the default query focus; if the user refocuses the query, then we display answers in the order they are returned by RDFox. Note that SemFacet is implemented in such a way that both Lucene and RDFox can be substituted with any other software that provide the same functionality.

5. DEMO SCENARIO

During the demo we will show how one can find relevant information available in Wikipedia using semantic faceted search. The search will be performed over Yago using SemFacet system. The users will see several search scenarios that are hard to accomplish using conventional search engines, and we will show how they can be handle using SemFacet. Moreover, users will be invited to try to express their own information needs over SemFacet.

6. RELATED WORK

RDF has been proposed by many as a promising metadata model for faceted search [5, 6, 7, 18, 19] and several faceted search systems based on RDF have been developed [5, 8, 19]. Prominent examples are Parallax [5] and Humboldt [19]. Parallax provides faceted navigation on top of Freebase [9] and it supports a limited form of refocusing (it is possible to switch view between dif-

Figure 4: General architecture of SemFacet

ferent sets of entities while keeping faceted constraints; however, when switching back to entities visited before, some constraints are lost); it also does not support branching in queries. Humboldt [19] provides similar functionality to Parallax. Other RDF-based systems provide more limited functionality and in particular they do not support refocusing; these include BrowseRDF [6], Tabulator [7], parallel faceted browser [8], mSpace [10], /facet [11], Piggy Bank [12], FacetedDBLP [13], a faceted DBpedia browser [14], Ontotragor [15], and many others.Query model underlying all these systems is unclear; furthermore, their focus is on RDF while OWL 2 reasoning plays little or no role.

7. CONCLUSION

We demonstrated semantic faceted search over Yago. Our approach is flexible and versatile: the same back-end implementation can be used to power faceted search over any application based on RDF and OWL 2. Our system is still an early prototype. Further work includes development of ranking functions for both facets and answers, extension of the interface to support wider fragments of our query language, experiments with larger data sets, and work on improving systems scalability and concurrency of users’ access.

8. REFERENCES