Discovering Diversified Paths in Knowledge Bases

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ABSTRACT

Vast amounts of world knowledge is now accessible through Knowledge Graphs (KGs) in RDF format and can be queried using SPARQL. Yet, finding paths between nodes in such graphs is not part of the official SPARQL 1.1 standard; only the simpler functionality of checking reachability is supported, i.e., assessing whether two nodes are connected based on certain conditions formalized as property paths but without providing information on how they are actually connected. To close this gap of functionality, we propose JEDI, a Jena Extension for DIscovering diversified paths in knowledge bases. JEDI extends a popular SPARQL engine, Jena, with the ability to compute the paths connecting entities in a KG. JEDI shows the k most relevant results to the user where relevance is assessed as a trade-off between path length and diversification of the intermediate nodes in the path. Moreover, our solution is not limited to a single property path pattern but supports queries containing multiple property path patterns. While JEDI is able to work with any KG, for demonstration purposes some predefined KGs, such as YAGO and DBLP, are provided, as well as example queries. Attendees will be encouraged to interact with the JEDI system to try their own queries.

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1. INTRODUCTION

In the past decade, representing and querying knowledge in a structured way using Knowledge Graphs (KGs), such as YAGO [4] and DBpedia [1], have become more and more popular. Recently, several commercial KGs such as the Google KG, the Facebook Entity Graph, and Microsoft Satori have been proposed with applications to search engines and personal voice assistants. Given the proliferation of KGs and their verbose structure, there is a clear need for algorithmic techniques to facilitate interactive exploration and analysis of semantic relationships between entities in a KG.

For representing and querying KGs, the W3C recommends RDF[1] and SPARQL[2] as standards. Due to the versatility of RDF and expressiveness of SPARQL, they have been widely adopted in the Semantic Web community. The recent introduction of SPARQL 1.1[3] has enabled novel approaches and optimizations [5, 6, 8]. In particular, with the introduction of property paths it has now become possible to formulate SPARQL queries checking the transitive reachability of entities (vertices) in RDF graphs using regular expressions involving operators such as '*' (zero or more occurrences–kleene star), '|' (OR operator), '∧' (NOT operator), etc. For a more detailed description of property paths we refer the reader to the SPARQL 1.1 property path specifications[3].

However, these operators are only of very limited use for exploring semantic relatedness between entities as they do not return the full paths between the entities but merely check for its existence. For example, a property path query with the clause "`Princess_Margaret_of_Connaught hasChild* Margrethe_II_of_Denmark`" only checks if `Margrethe_II_of_Denmark` is transitively reachable from `Princess_Margaret_of_Connaught` via any number of `hasChild` property relationships but omits the intermediate entities in the path.

There is currently only very little related work in this area. Some systems try to address this issue by computing the complete paths connecting a given pair of entities defined in a user query [3, 10] or sets of entities [11], respectively. However, these systems are either limited to queries involving a single property (as opposed to queries supporting arbitrary paths involving a diverse range of properties occurring in the KG) or ignore the properties completely. There is usually also no advanced support for combining property path expressions with other standard SPARQL operators. Moreover, to the best of our knowledge there is no system that supports retrieving full paths for queries involving multiple property path patterns.

To address these issues, we propose a system coined JEDI (Jena Extension for DIscovering diversified paths in knowledge bases). In JEDI, we extend the grammar of the property paths with a new operator '→', which, in addition to checking the reachability, also enumerates all the property paths matching a given arbitrary property path query. In general, however, it is not sufficient to simply enumerate all paths fulfilling the property path pattern as such results are often large in number and redundant. We therefore introduce a ranking scheme using a diversification metric as a post-processing step. As we implement our solution as an extension to Jena[4], a popular framework for parsing and processing SPARQL queries, JEDI is able to combine property paths with other operators known from

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[1] https://www.w3.org/RDF/
[2] https://www.w3.org/TR/rdf-sparql-query/
[3] https://www.w3.org/TR/sparql11-property-paths/
[4] https://jena.apache.org/

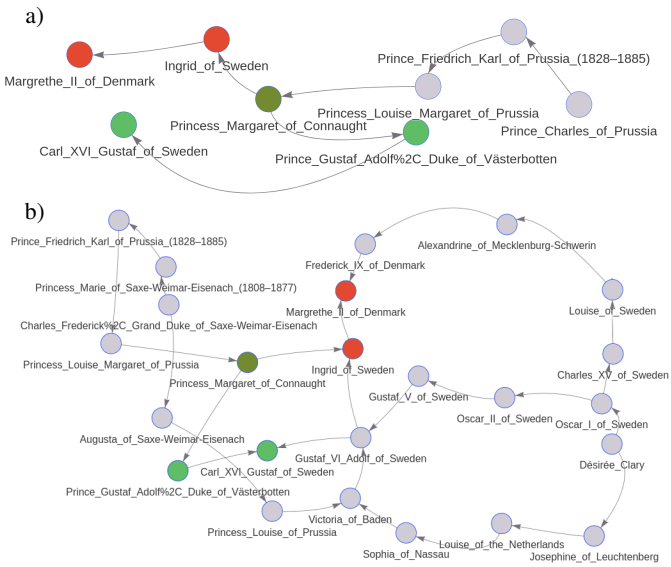

Figure 1: Top-3 paths for the query in Listing 1: (a) Without diversification, (b) With diversification. Red nodes denote nodes in the path of the first line, green nodes denote nodes in the path of the second line, mixed color nodes signifies nodes that are part of both paths and gray nodes denote the nodes in other paths than the top-1 path.

standard SPARQL queries.

Example Query

Suppose we are interested in finding any possible links between the Danish and Swedish royal families along with their lineage, then we can express a property path query with the $\rightarrow$ operator to retrieve all the common ancestors of the Queen of Denmark and the King of Sweden as shown in Listing 1.

```
PREFIX yago: <http://yago-knowledge.org/resource/>
PREFIX rdfs: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
SELECT DISTINCT * WHERE {
  ?a yago:hasChild->  yago:Margrethe_II_of_Denmark .
  ?a yago:hasChild->  yago:Carl_XVI_Gustaf_of_Sweden .
  ?a rdfs:label ?b
}
```

Listing 1: SPARQL query Q1 to retrieve links between Danish and Swedish royal families

In Figure 1, we visualize the graph formed by the top-3 paths matching the query in Listing 1 and illustrate the need for diversification. When we rank the results purely based on path lenghts (Figure 1(a)) we can see that all paths share the same subpath after the entity `Princess_Margaret_of_Connaught`. In Figure 1(b), when we use the diversification metric to select the top-3 paths, we discover new paths, e.g. from the paternal side of `Margrethe_II_of_Denmark`, via the entity `Frederik_XI_of_Denmark` even though it is a much longer path. These new paths do not involve the same subpath as when we rank purely based on path lengths, and thus are more diverse.

2. SYSTEM OVERVIEW

JEDI has been implemented on top of Jena[4]. We have extended the grammar of property path operators accepted by Jena with a new operator, $\rightarrow$, which is able to produce, in addition to the reachability check between two nodes, the actual paths that connect two nodes. JEDI comes with a Java Web Application for graphical user interaction that allows the user to explore the query results both in a tabular format and in a more visual graph-based format. JEDI allows the user to select one or more results in table to highlight the corresponding paths in the graph. JEDI's code is available at http://qweb.cs.aau.dk/jedi/. The overall architecture of JEDI is sketched in Figure 2. JEDI consists of three main components: a Graphical User Interface, a Query Executer and a Diversifier.

Graphical User Interface. This component provides the user with a Web Interface to interact with JEDI in two modes: (i) a *simple query mode* for less experienced users requiring help in formulating SPARQL queries and (ii) an *advanced query mode* allowing users to directly input arbitrary SPARQL queries. In the simple query mode (see Figure 3 (b)), users are guided to provide every component of a SPARQL query using input fields and the assistance of auto-completion functionality based on ElasticSearch[5] and At.js[6] to compute and present suggestions to the user. Property path operators can be chosen from a list; for binary operators another field is dynamically added for the remaining operand. Additional triple patterns or property path patterns can easily be added as well. The '$\rightarrow$' operator in enabled by activating a check box (see Figure 3 (d)); if not activated the standard implementation of property paths is applied during query evaluation. For more complex queries, the advanced query mode provides the user with a textbox where he/she can freely edit and input an arbitrary SPARQL query. The Web Interface also displays the results both as a table and as a graph, and allows the users to explore the results by selecting some query result (rows in the table) to highlight the corresponding paths in the graph and choosing the colors used to highlight the paths.[7]

In the simple query mode, this component relies in a SPARQL Query Generator to obtain the SPARQL query that is passed to the Query Executer. In both modes, it relies on a Graph Builder[8] to present the top k diverse results to the user as a graph that allows for visualizing and exploring the obtained paths.

Query Executer. We have implemented the JEDI functionality by extending Jena with a new operator, $\rightarrow$, able to compute, in addition to the reachability check done by the standard operator '*', the path that connects entities in a Knowledge Graph (KG). JEDI relies on a SPARQL complying service to access the KG, this service is not aware about nor handles the $\rightarrow$ operator, but is used to retrieve triples in the KG that possibly match some conditions, e.g., with a given subject or property. Hence, JEDI can be used to query an arbitrary SPARQL endpoint to evaluate the generated SPARQL queries over a KG. However, in the context of this demonstration, JEDI relies on a Virtuoso 7.2.4.2[9] endpoint as back-end.

Diversifier. Finding all the possible paths connecting entities can be very expensive, and overwhelm the user with too many results. In order to provide the user with the top k most relevant results, JEDI diversifies the results using a diversification metric (Section 2.1). JEDI is able to diversify results even for queries with multiple paths by using the diversification metric over the combination of all the connected paths present in each query result.

2.1 Diversification Metric

[5] https://www.elastic.co/products/elasticsearch
[6] https://github.com/ichord/At.js/
[7] This functionality relies on piklor.js, http://jillix.github.io/piklor.js/
[8] The graph is displayed using vis.js, http://visjs.org/index.html
[9] https://virtuoso.openlinksw.com/

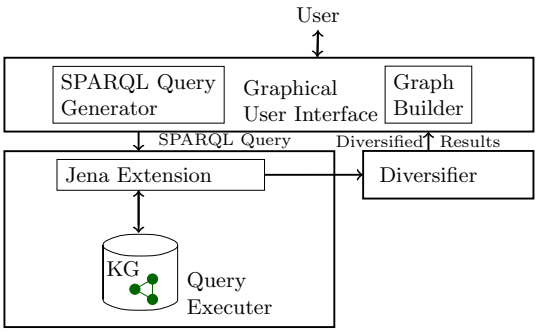

Figure 2: System architecture of JEDI.

In order to avoid redundant paths in the results, we propose a diversification metric and rank the paths accordingly. Our diversification metric aims for balancing the path length and the similarity among the result paths R of a given query Q. The balancing between these two is determined by a user-specified diversification parameter $0 \leq \lambda \leq 1$. If $\lambda = 0$, we rank the paths purely according to their lengths. On the other hand, if $\lambda = 1$, the k most dissimilar paths according to the Jaccard similarity irrespective of their path lengths are chosen. Given a query Q, with matching results R, our goal is to select $S \subseteq R$ according to the following objective:

$$DivP(R) = \arg\max_{S \subseteq R} \sum_{P_i \in S} (1-\lambda) \cdot \frac{\min_{P_j \in R} |P_j|}{|P_i|} - \lambda \cdot \max_{P_j \in S, P_i \neq P_j} \frac{|P_i \cap P_j|}{|P_i \cup P_j|} s.t. |S| = k \quad (1)$$

Each path P is represented as a set of entities and properties in P, this allows us to compute the path lengths ($|P|$) and Jaccard similarity using set intersection and union sizes. In order to bring the path lengths to the same range ($[0, 1]$) as the Jaccard similarity value, it is normalized by computing the ratio between each path's length and the shortest path length in the result set R. Note that the objective function $DivP(R)$ in Equation 1 is agnostic to the number of properties and entities in the paths and we can also replace the Jaccard similarity metric with any other similarity metric.

THEOREM 1. *The objective function for $DivP(R)$ in Equation 1 is submodular.*

PROOF. The proof follows from the Maximal Marginal Relevance problem proposed in [2]. □

COROLLARY 1.1. *Greedy algorithm for $DivP(R)$ guarantees $(1 - \frac{1}{e})$-Approximation.*

PROOF. Follows from the results in [9]. □

This allows us to design a greedy approximation algorithm that iteratively selects a path P_i in each step that makes the maximum contribution to the objective in Equation 1.

3. PATH DISCOVERY WITH JEDI

Using JEDI, users can explore paths for various use cases. In this section, we focus on a specific use case using the Knowledge Graph (KG) YAGO3 [7] and show how JEDI can be used to explore it.

Consider query **Q1** in Listing 1. Using Q1, it is possible to find links between the Danish and Swedish royal families. Q1 includes two property path patterns that start from the same common ancestor and end with the Danish Queen and the Swedish King respectively. The first property path pattern `?a yago:hasChild→ yago:Margrethe_II_of_Denmark`, is satisfied by any entity X that is connected directly to `yago:Margrethe_II_of_Denmark` through the property `yago:hasChild`, i.e., if the triple `X yago:hasChild yago:Margrethe_II_of_Denmark` is in the KG, or if X is connected directly to another entity Y that is connected (directly or through additional entities) to `yago:Margrethe_II_of_Denmark`. With the second triple pattern, the condition that the entity X should also be connected in a similar way to *yago:Carl_XVI_Gustaf_of_Sweden* is imposed.

Using the JEDI Web interface, Q1 can be input using the simple query mode as shown in Figure 3 (b). In this mode, the use of the → operator is activated by activating the checkbox next to the pattern (Figure 3 (d)). To obtain the top k diverse results, k can be provided through the field highlighted in Figure 3 (c) – 10 in this example.

The top-10 most diverse results are obtained and combined into a graph that is displayed in Figure 3 (a)[10]. In this figure, the user has selected a particular result which is consequently highlighted, both in the graph representation as well as in the results table (Figure 3 (a) and (f)). The orange path marks the path to the Danish Queen (first property path in the query), and the green path marks the path to the Swedish King (second property path in the query). Note that `Princess_Margaret_of_Connaught` is present in both paths of the selected row as it represents the connection between the two paths corresponding to `?a` in the given query. In general, nodes that belong to more than one path are highlighted using the color that results from mixing the colors of the involved paths. In this case, it is highlighted in a mix of the green and orange. It is also possible to select multiple rows, and to reset the selection. It is also possible to edit the color for each result path manually (Figure 3 (g)). [11]

JEDI is, of course, not restricted to this use case but can be used for numerous different use cases other than finding common ancestors between royal families, e.g., finding connections between politicians and researchers, etc.

4. DEMONSTRATION

At the conference, we will demonstrate JEDI using a number of selected KGs. Although JEDI can work with any KG as its implementation only relies on the availability of a SPARQL endpoint to access the data (supporting endpoints hosted on other servers), for the demonstration we will run JEDI and the SPARQL endpoint on the same machine to avoid any problems caused by unstable internet connections during the conference.

To ease interaction with the system, we will prepare several interesting SPARQL queries involving property paths. Conference attendees will then have the opportunity to build upon these example queries by editing parameters and exploring the results. In addition, experts are invited to freely formulate SPARQL queries using the extended property path operator proposed in this paper. After JEDI has computed and displayed the results, including their graphical representation, users will be able to freely explore the results by selecting specific paths, marking them in the graph, and in doing so discover connections between specific entities.

One of the KGs that we will use for the demonstration is YAGO3 [7]. It provides information extracted from Wikipedia and contains 1+ billion triples covering a broad range of topics. This

[10] In this example, the diversification parameter λ is set to 0.5.

[11] A video of JEDI is available at http://qweb.cs.aau.dk/jedi/

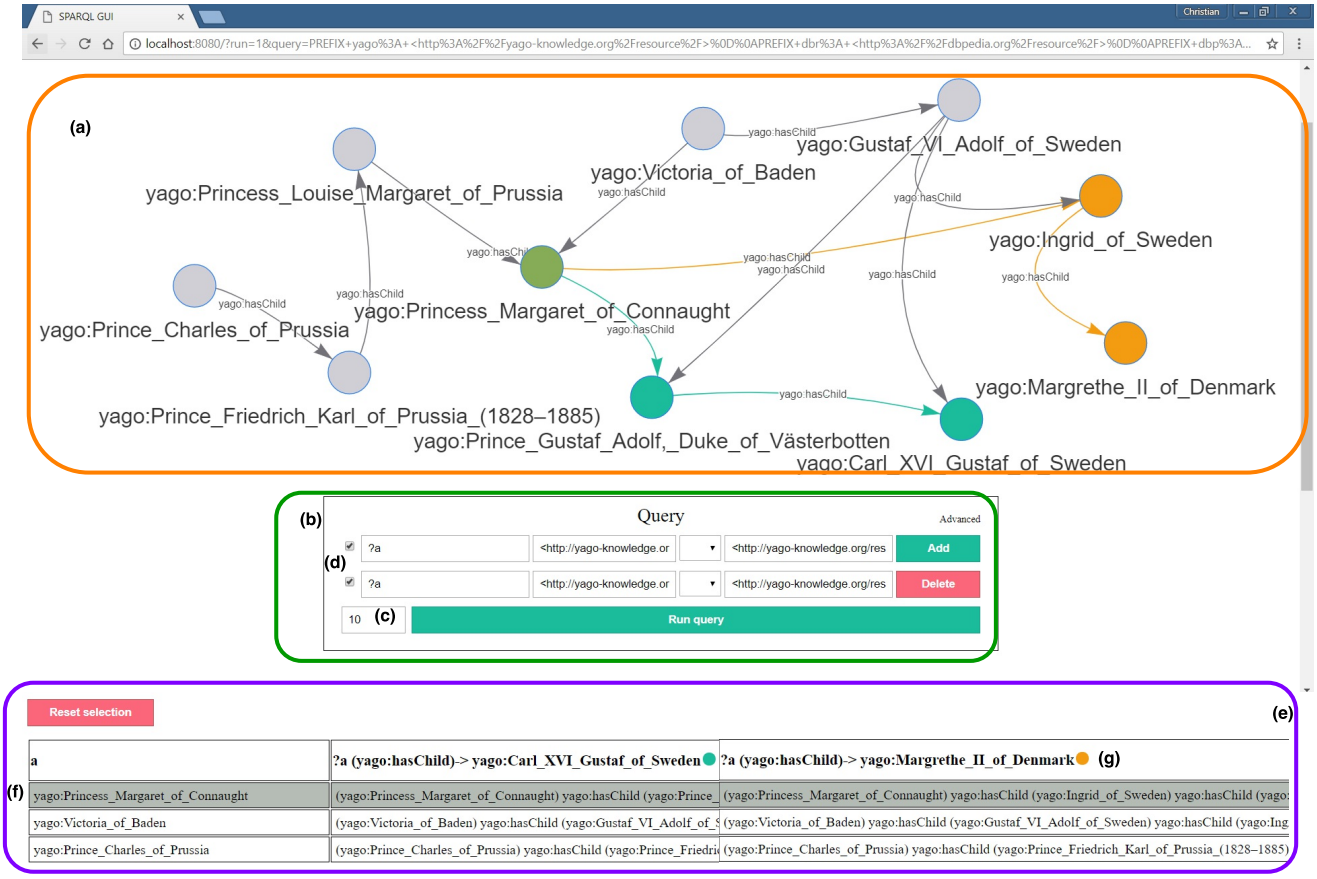

Figure 3: Interface when running Q1 in JEDI

dataset, for example, supports the queries and use cases outlined in Section 3.

In addition to YAGO3, we will also prepare queries over other KGs: DBLP[12] and DBpedia[13]. These KGs support queries about cross domain knowledge, such as "Brazilian book authors that have been influenced by French writers", or queries about specific domains, such as "How are authors of papers connected to track chairs via co-author relationships". DBpedia provides information extracted from Wikipedia in a wide range of topics including facts about persons, places, and organizations. For the demonstration, we use the English DBpedia 2016-04 with over 396 millions of facts. DBLP consists of bibliographic information about scientific publications in the domain of computer science. For the demonstration we use the instance of DBLP available at `http://lodlaundromat.org` containing over 76 million facts.

5. CONCLUSION

In this paper, we have presented JEDI, a system that enhances an existing SPARQL query engine, Jena, to ease the exploration of knowledge graphs using property path patterns that, differently from the SPARQL 1.1 standard, output the paths that connect entities. The generated paths comply with diversification metrics to produce the k most interesting results satisfying the user's query. In the current implementation, diversification is implemented as a post-processing phase. However, given that the number of paths connecting entities in the KG can be very large, as future work, we will integrate the diversification metric into the path generation step, reducing the space of explored paths and increasing JEDI's performance.

[12] `http://dblp.l3s.de`
[13] `http://wiki.dbpedia.org`

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