Searching and Establishment of S-P-O Relationships for Linked RDF Graphs: An Adaptive Approach

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Abstract—In the coming era of semantic web linked data analysis is a very burning issue for efficient searching and retrieval of information. One way of establishing this link is to implement subject-predicate-object relationship through Set Theory approach which is already done in our previous work. For analyzing inter-relationship between two RDF Graphs, RDF-Schema (RDFS) should also be taken care of. In the present paper, an adaptive combination rule based framework has been proposed for establishment of S-P-O (Subject-Predicate-Object) relationship and RDF Graph searching is reported. Hence the identification of criteria for inter-relationship of RDF Graphs opens up new road in semantic search.

Keywords—RDF Graph, RDFSet, Blank Node, RDF Graph Relation, Triple, Subject-Predicate-Object, adaptiveness, Dampster Shafer Rule, URIService, Pattern analyzer

I. INTRODUCTION

The Resource Description Framework (RDF) is a family of World Wide Web Consortium (W3C) specifications originally designed as a metadata model. As per W3C study, it supports a generalized method for conceptual description or modeling of information which uses various types of syntactical formats to be implemented in web resources. In semantic environment RDF represent the web data as subject-predicate-object triplet format which are basically the URIs or literals and therefore the linking structure of the Web is redefined. This triple form of RDF leads to the path of Graph representation which comprises of the interrelationship between more than one RDF triples using S-P-O linking. This is called as N-Triple Graph. The following N-Triples file consists of three RDF statements:

| TABLE I. | N-TRIPE REPRESENTATION OF RDF |
|----------|-----------------------------|
| 1        | Subject: <http://www.w3.org/2001/sw/RDF Core/triplet> |
|          | Predicate: <http://purl.org/dc/elements/1.1/creator> |
|          | Object: “Dave Beckett” |
| 2        | Subject: “http://www.w3.org/2001/sw/RDF Core/triplet” |
|          | Predicate: “<http://purl.org/dc/elements/1.1/creator>” |
|          | Object: “Art Barstow” |
| 3        | Subject: “http://www.w3.org/2001/sw/RDF Core/triplet” |
|          | Predicate: “<http://purl.org/dc/elements/1.1/publisher>” |
|          | Object: “http://www.w3.org/” |

In the following table [16] three sets of RDF Triples are represented. The relationships expressed in these triples lead to the establishment of the relation in between the resources and property values of RDF which is nothing but the Subject-Predicate-Object relations. So the representation of RDF data in triple format is known as N-Triple Graph or NTGraph. Establishment of the interrelationships in between NTGraphs and their characterization is proposed in this following framework using simple Set Theoritic approach. This will impart a great effect in the searching of RDF data in semantic environment.

When RDF Graphs are represented with set diagrams, the intersection of given two RDFSets will denote the relationship between them. The set representation of an RDF consists of three subsets: subject, predicate and object. Moreover for the categorization of these inter-relationships the impact of RDF Schema is very important.

In this paper, for the establishment and categorization of S-P-O relationships, the impact of Set theoretic approach is presented.

II. LITERATURE REVIEW

Semantic Web is a metadata data model. In this environment data models and syntax of the interrelations are specified by RDF[6]. This data model is consisted of URI[4] or literals. There may be some resources which are not containing any URIs or literals. They are “anonymous” resources and called as Blank Nodes[5].

Jonathan Hayes proposes a map from RDF Graphs to directed labeled graphs in his diploma thesis [1]. This proposal is thought to complement the default representation of RDF by graphs as provided by the RDF specification[2]. Even though this proposal claims to be formal and unambiguous, the fundamental limitations inherent in the modeling of RDF as directed labeled graph persist.

The graph representation of an RDF is basically the the mapping of S, P or O triples. In this context, ontology matching [7, 8, 9,11] (ontology alignment) and instance matching are the two most-studied sub-problems of
interlinking. The latter papers often refer to the process of determining whether two descriptions refer to the same real-world entity in a given domain [12, 13]. Although these two problems are related, they are neither necessary nor sufficient to solve each other. Samur Araujo1, Jan Hidders1, Daniel Schwabe2, Arjen P. de Vries [3] has given solution for the instance-matching problem is composed of two phases: the selection phase and the disambiguation phase. In the selection phase, for each instance r in a dataset A, they search for instances in a target dataset B that may refer to the same entity in the real world as r, by using a literal type of matching that has a high recall but a low precision.

With the essence of those previous works, a new concept has been proposed in this paper for identification and categorization of the relationship between two RDF Graphs that represent RDF triples. This relationship is primarily driven by the subject-predicate-object relation of RDF triples and RDFS vocabularies.

III. INTER-RELATIONSHIP BETWEEN RDF GRAPHS

In this paper RDF Graphs are represented with set diagrams where subject, predicate and object are three subsets. The intersection of given two RDFSets will denote the relationship between them. But existence of a blank node is critical to this point. In RDF Graph representation, a node, which is not containing any URI or literal, is called as a blank node or bnode. The resource represented by a blank node is also called an anonymous resource. By using Reification technique the blank nodes can be represented in RDF Graph model. The anonymous resource (bnode) is reified by splitting up into two triples. This concept is shown in Fig.2:

\[ \text{Fig. 1. Blank Node Reification} \]

In the statement "John has a friend born on 21st of April", the expression can be represented by coupling two triples with a blank node denoting the anonymous friend of John.

\[ \text{John} \langle \text{subject} \rangle \ldots \text{knows} \ldots \text{p1} \langle \text{predicate} \rangle \ldots \text{p1} \langle \text{object} \rangle \ldots \text{born on} \ldots \text{21st of April} \langle \text{object} \rangle \]

where \text{p1} is the bnode.

Now the blank nodes are also converted into general triple format. So, the conditions for the intersection in between these subsets are given below:

Let \( V \) be a vocabulary, \( T \) be an RDF Graph with vocab(T) \( \subseteq V \) and \( G_{\text{dir, label, multi}} \) the set of directed, edge- and node-labeled multigraphs. We then define a map

\[ \delta: \text{RDF Graph}(V) \rightarrow G_{\text{dir, label, multi}} \]

as follows: \[ \delta(T) = (N, E, L_N, L_E), \]

\[ N = \{ n_x : x \in \text{Subj}(T) \cup \text{Obj}(T) \} \]

\[ L_N(n_x) = \begin{cases} x & \text{if } x \text{ is literal and } d_x \text{ is datatype identifier} \\ x & \text{else} \end{cases} \]

\[ E = \{ (e_{s,p,o}, (S, P, O) \in T) \} \]

from \( (e_{s,p,o}) = n_s, \) to \( (e_{s,p,o}) = n_o \) and \( L_E(e_{s,p,o}) = P \)

The inter relationship between two RDF Graph is important from semantic search perspective. As mentioned in previous discussions, the semantic expressiveness of a statement can potentially be stored through RDF Graph and hence discovery of inter relationship criteria for RDF Graphs could form the basis of a formalized graph based search algorithm in the context of reservation and exploration of semantic nature of the statements or assertions.

On this background following section characterizes the criteria for establishing relationship between two RDF Graphs.

IV. CHARACTERIZATION OF INTER-RELATIONSHIP BETWEEN TWO RDF GRAPHS

The need of characterization of RDF Graph relationship is steeply growing as more and more data are being published in Semantic Web with RDF standard. The challenge of mining data from Semantic Web mostly can be met with the proper identification of related triples based on semantic constructs like subject or objects etc. The network of those related RDF Graphs forms the local reference frame for the information to be searched.

On the context of present discussion following subsections characterizes RDF Graphs through a Set Theory approach [15].

A. Subject-Subject and Predicate-Predicate relationship

Subject-Subject and Predicate-Predicate relationship described in Fig. 2, characterizes the specific criteria of RDF Graph relationship, where two RDF Graphs \( T_1 \) and \( T_2 \) share common subject and predicate. The significance of these criteria is that two statements are semantically equivalent from the Subject and its property perspective. The only difference exists in a point that the two statements have different values for the same properties of the same subjects. It is evident that this criteria dictates a strong relationship between two RDF Graphs \( T_1 \) and \( T_2 \) and between two corresponding statements as well.

\[ \text{Fig. 2. Subject-Subject/Predicate-Predicate Relationship of two given RDF Graphs} \]
Mathematically, there exists a Subject-Subject and Predicate-Predicate relationship between two RDF Graphs $T_1$ and $T_2$, if the following set theoretical expressions are all true.

$\text{Sub}(T_1) \cap \text{Sub}(T_2) = \emptyset$

$\text{Obj}(T_1) \cap \text{Obj}(T_2) = \emptyset$

$\text{Sub}(T_1) \cap \text{Obj}(T_2) = \emptyset$

$\text{Obj}(T_1) \cap \text{Sub}(T_2) = \emptyset$

$E_1 \cap E_2 = \emptyset$

Following is an example of above mentioned relationship:

T1: Subject: http://www.example.org/staffid/85740
Predicate: http://www.example.org/terms/design
Object: http://www.example.org/club/treasurer

T2: Subject: http://www.example.org/staffid/85740
Predicate: http://www.example.org/terms/design
Object: http://www.example.org/club/treasurer

B. Object-Object and Predicate-Predicate relationship

Object-Object and Predicate-Predicate relationship identifies the criteria of RDF Graph relationship, where two RDF Graphs $T_1$ and $T_2$ share common object and predicate. Two RDF Graphs related with this kind of condition, must have different subjects which hold same property with same values. Object-Object and Predicate-Predicate relationship has immense importance where the semantic search is based on some property and its specific values. It is evident that this criteria also dictates a strong relationship between two RDF Graphs $T_1$ and $T_2$ and between two corresponding statements as well.

A condition for Object-Object and Predicate-Predicate relationship is presented in Fig.3.

![Fig. 3. Object-Object/Predicate-Predicate Relationship of two given RDF Graphs](image)

Mathematically, there exists a Object-Object and Predicate-Predicate relationship between two RDF Graphs $T_1$ and $T_2$, if the following set theoretical expressions are all true.

$\text{Obj}(T_1) \cap \text{Obj}(T_2) = \emptyset$

$\text{Sub}(T_1) \cap \text{Sub}(T_2) = \emptyset$

$\text{Sub}(T_1) \cap \text{Obj}(T_2) = \emptyset$

$\text{Obj}(T_1) \cap \text{Sub}(T_2) = \emptyset$

$E_1 \cap E_2 = \emptyset$

Following is an example of above mentioned relationship:

T1: Subject: http://www.example.org/staffid/85740
Predicate: "published"

C. Subject-Predicate relationship

Subject-Predicate relationship has a different significance and consequence than the other two types of relationships discussed above. In this case, two RDF Graphs $T_1$ and $T_2$ never share their subject, object or predicate, rather the resource described by one’s subject is same as that of resource described as predicate of others. With this condition, the subject of one statement acts as a property of the other statement. The two RDF Graphs related with their Subject-Predicate relation can represent complex indirect search construct. The two statements with completely different subjects could be linked with each other through this relationship.

A condition for Subject-Predicate relationship is presented in Fig.4. Mathematically, there exists a Subject-Predicate relationship between two RDF Graphs $T_1$ and $T_2$, if the following set theoretical expressions are all true.

$\text{Sub}(T_1) \cap \text{Sub}(T_2) = \emptyset$

$\text{Obj}(T_1) \cap \text{Obj}(T_2) = \emptyset$

$\text{Sub}(T_1) \cap E_2 = \emptyset$

$E_1 \cap E_2 = \emptyset$

Following is an example of above mentioned relationship:

T1: Subject: http://www.example.org/staffid/85740
Predicate: http://www.example.org/terms/design
Object: http://www.example.org/club/treasurer

T2: Subject: http://www.example.org/staffid/85740
Predicate: "published"

Object: http://www.wikipedia.com/technology/C.V.

V. SEARCHING RDF GRAPH SEQUENCES: INTRODUCING ADAPTIVENESS

In the above sections, how the relationships can be established and quantified among $n$ number of RDF Graphs is proposed. These relationships can be of SS-PP, OO-PP, S-P and O-P within 1 to n-dimensional status. So the resources about any subject in WEB 3.0 will be chunked in the RDF Graphs which are inter-related using those quantified relationships as well as form a complex Graph sequences.
Now the question is that, if a query is triggered about any subject, the information about that subject is scattered in those complex RDF_Relational_Graph structures which are individually not inter-related. So the the searching will be partial. To overcome this difficulty, all the RDF_Relational_Graphs are represented as Relational_Sequences and using these sequences, Relational_Sequences storage has been created. From this storage using Gen____Repetitive_Seq and Gen_Relational_Patter algorithm (described in next section) a Relational_Pattern will be derived. As this Relational_Pattern is a subset of all Relational_Sequences, when searching information for a specific subject, using this Relational_Pattern all the individual SS-PP, OO-PP, S-P and O-P RDF_Relational Graphs can be completely searched.

Let us consider a Set A where $A = \{S^0, S^1, \ldots, S^t\}$ and up to $t$ numbers of Relational_Sequences can be stored within Set A. Now, using the Adaptive Algorithm [Algorithm 1][14] PatternAnalyzer will identify $k$ number of $l$ length Relational_Pattern out of Set A. The length $l$ will be tuned adaptively in between two limiting values and $k \geq 1$. These limiting range values will clarified in the next section. Using all the identified $k$ number of $l$ length Relational_Patterns, another Set B will be formed.

K1 and K2 are two boundary integer values which will tune the length of the Relational_Pattern $l$. Initially the value of K1 will be assigned by 1 at $t=0$, otherwise for $t>0$ and for the next sessions the value of K1 will be equal to the value of the length of last Relational_Pattern. The value of integer K2 will be assigned up to the total length of the Relational_Sequences i.e., n. Let us consider an integer variable x with a value within the range of K1 and K2. Identification of a Relational_Pattern for any specific Relational_Sequences storage is basically driven by the value of x. Another integer variable r has to be considered to define the number of most repetitive sequence identified for a given length x. Now in the time of computation of most repetitive sequence for a specific Relational_Sequences storage, many pairs of $(r, x)$ will be generated. The ratio of each pair of $(r, x)$ i.e., $\lambda = r/x$ actually effects the lengthwise variation of the Relational_Pattern $l$.

Output: Relational_Pattern $P^l$ for $l^{th}$ Relational_Sequences

Step 0: for all $x$ (where $K_1 \leq x \leq K_2$), do Step 1 to Step 2

Step 1: call Gen_Repetitive_Seq subroutine (described next)

to have repetitive sequence $P$ and number of repetitive sequence $r$.

Step 2: compute $\lambda = r/x$ and if $\lambda \leq \lambda_{min}$, $\lambda_{min} \leftarrow \lambda$

Step 3: designate $x$ for which $\lambda = \lambda_{min}$ as $x'$

Step 4: $P^l \leftarrow P$

Step 5: Stop.

Adaptiveness is implemented by the algorithm stated above for the identification of Relational_Pattern using the derived knowledge of Relational_Sequences storage. Although the repetitive sequence search or the most subsequent occurrence search is controlled by deterministic approach, change in the value of $K_1$ boundary in every iteration, makes the next session adaptive with the knowledge which is derived and translated via $x'^{-1}$ to the next session for each iteration. The decreasing difference between two boundaries values of $K_1$ and $K_2$ depends on the adaptiveness of $x'^{-1}$ and as a result the searching time of Relational_Pattern in between RDFs will be minimized with the progress of time.

A search for repetitive sequence within Relational_Sequences storage is described next. This search could be optimized (with respect to time) by employing any smarter deterministic algorithm. The time complexity of the algorithm Gen_Repetitive_Seq to search out a repetitive sequence of any length from the Relational_Sequences storage is $(r(n + p)^r)$. Hence the above algorithm requires $((K_2 - K_1)r(n + p)^r)$ time to search for desired Relational_Pattern, by repetitive calling of this sub-routine. So Relational_Pattern generation can be done in polynomial run time.

VI. MATCHING OF RDF GRAPHS USING S-P-O RELATION

To apply Dempster Shafer Rule of Combination in two RDF Graphs, a non empty finite set $\{A\}$ has been taken, which contains the URISequence at RDF Graph1, i.e $S^1$ gets directly mapped with $\{A\}$. Similarly let us take another non empty finite set $\{B\}$ containing the URISequence at RDF Graph2, i.e $S^2$.

Next, let us consider $m = Mass\ Function$ of Belief or Basic Belief Assignment and hence as per Dempster Shafer Rule of Combination, the belief function of $\{A\}$ i.e bel($A$) is given by

\[
bel(A) = B_B \subseteq_A m(B).
\]

This equation directly derives

\[
m(A) = B_B \subseteq_A (-1)^{A-B}/bel(B).
\]

Therefore bel($B$) can be given as

\[
bel(B) = \frac{k}{a_B \subseteq_A (-1)^{A-B}}
\]

where $k$ is Shafer Normalization Factor and the mathematical expression is
The could be considered as a weak relationship, but it has no intrinsic search value. In this case, the relationship holds an incomplete search criteria over two RDF Graphs. As a result, this is noteworthy that Subject-Object and Predicate-Predicate relationship has insignificant impact over RDF Graph based semantic search.

VII. CONCLUSION

The current study has successfully met its objective of basic characterization of inter-relationships between two RDF Graphs. Set theory expressions guided by the adaptive framework using RDF vocabulary could be identified as necessary and sufficient conditions for discovering relationships between a RDF Graph pair. The potential of this investigation can further be exploited with future research focusing on probabilistic quantification of these relationships and graph traversal based search algorithms within the network of such inter-related RDF Graphs.

REFERENCES

[1] Jonathan Hayes: A Graph Model for RDF. Diploma Thesis. Technische Universität Darmstadt. Universidad de Chile (2004)
[2] Samur Araujo, Jan Hidders, Daniel Schwabe, Arjan P. de Vries.: SERIMI Resource Description Similarity, RDF Instance Matching and Interlinking. The 10th International Semantic Web Conference (ISWC 2011)
[3] Berners-Lee, Fielding, Masinter.: Uniform Resource Identifiers (URI): Generic Syntax Internet Draft Standard. IETF RFC 2396 (1998)
[4] Patrick Hayes (ed.): RDF Model Theory W3C Working Draft 2001. http://www.w3.org/TR/rdf-model/
[5] Ora Lassila, Ralph R. Swick.: Resource Description Framework (RDF) Model and Syntax Specification., World Wide Web Consortium. http://www.w3.org/TR/1999/REC-rdf-syntax-19990222 (1999)
[6] L. A. P. P. Leme, M. A. Casanova, K. K. Breitman, and A. L. Furtado.: Evaluation of similarity measures and heuristics for simple RDF schema matching. Technical Report 44088, Dept. Informatics, PUC-Rio (2008)
[7] Leme, L. A. P. P.: Conceptual schema matching based on similarity heuristics. D.Sc. Thesis, Dept. Informatics, PUC-Rio (2009)
[8] N. Choi, L-Y. Song, and H. Han.: A survey on ontology mapping. ACM SIGMOD Record, vol. 35, no. 3, pp. 34-41 (2006)
[9] Tim Berners-Lee.: An early draft of a semi-formal semantics of the N3 logical properties. http://www.w3.org/DesignIssues/Notation3.html
[10] M. Arenas, E. Prudhommeaux, and J. Sequea.: Direct mapping of relational data to RDF. W3C Working Draft 24 March 2011, http://www.w3.org/TR/rdf-direct-mapping/
[11] R. E. Tarjan and J. van Leeuwen.: Worst-case analysis of set union algorithms. J. ACM,31(2):242-281, 1984
[12] Patrick Hayes, Brian McBride: RDF Semantics. W3C Recommendation 10 February 2004, http://www.w3.org/TR/2004/REC-rdf-mt-20040210/
[13] Frank Manola, Eric Miller: RDF Primer. W3C Recommendation 10 February 2004, http://www.w3.org/TR/2004/REC-rdf-primer-20040210/
[14] Ayan Chakraborty, Shiladitya Munshi and Anirban kundu: An Adaptive Server Side Software Authentication Framework Based on Users Activity Pattern. 2nd EAIT 2011 20-21 February 2011, IEEE CS Proceedings Page: 153-156, Kolkata, India
[15] Ayan Chakraborty, Shiladitya Munshi and Debajyoti Mukhopadhyay: A Proposal for the Characterization of Multi-Dimensional Inter-relationships of RDF Graphs Based on Set Theoretic Approach. 3rd ICCSEA-2013 May 24th - 26th, 2013, Springer & Springer digital Library, Delhi, India
[16] N-Triples: W3C RDF Core WG Internal Working Draft; http://www.w3.org/2001/sw/RDFCore/nttriples/;Revision: 1.9