# IISWS: Integrative Intelligent System for a Multi-Domain Diversified Semantic Search

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**Abstract**
The information density is steeply rising over the World Wide Web and there is an urgent need of an integrative intelligent approach for facilitating recommendations from the Web owing to the data density of the Web. Knowledge-Driven Web-based recommendation systems are required to reduce the cognitive gap between the user query and the recommendable contents. An Integrative Intelligent approach for knowledge-centric recommendations from the Web has been proposed with the unification of SPARQL Endpoints from several heterogeneous sources through a domain indexing service that yields reasonable dynamic knowledge into the recommendation framework. The approach integrates classification, Synonymization, Intertwining with RDF, and a cognizable semantic similarity model for recommendation of queries and thereby the user relevant web pages with the diversification of search results. The proposed IISWS furnishes an overall accuracy of 91.84% with a small FDR of 0.1 for the WebKB Corpus dataset. A Normalized Discounted Cumulative Gain of 0.91 has been achieved by the IISWS.

**Keywords**
Content Based Filtering, Hash Table, Knowledge Modeling, Ontologies, Semantic Latent Analysis, Semantic Web

## 1. Introduction

The World Wide Web is the largest storehouse of Information. The Web 2.0 is revolutionizing into the Semantic Web which is the "Web of Data" with very high data density and cohesiveness. Information Extraction from the current configuration of the World Wide Web is not just a laborious task but also involves a lot of effort to link the user queries with the contents in the World Wide Web. Even if there is a proper learning mechanism incorporated, most web-based search algorithms tend to lag owing to the density of the information that looks quite similar. Most of the Web-based recommendation system are either only query-centered or user-centered. The query-centric web page recommendation systems focus only on the relevance of the web pages to the query that is being entered into the system. However, when the web page recommendation system is user-centric, the focus is mainly on the personalization and satisfying the needs of the user. Most of these queries centric and user-centric systems are quite efficient and have tackled the problems of synonymy and polysemy.

These systems do not facilitate the diversification of search results as there is a sparsity of real-world knowledge that is being instilled into the system. Owing to the evolution of the existing Web 2.0 into a perspicuous Semantic Web, a large amount of data available on the current structure of the Web and to reason out, a strong semantic approach with can transform the existing data into knowledge or which can incorporate knowledge for the recommendation. A knowledge-centric web search is the most amicable in the current situation where there is an evident transition from the conventional Web to the Semantic Web. There are also a large number of domain-centric knowledge bases and RDF stores that are authorized and a few of them are collective revised and newer versions are released progressively. It is strategic when the knowledge that has been dynamically integrated based on Intertwining or Interlinking of the RDF structures from the World Wide Web to the semantic inference algorithm for facilitating knowledge-driven web search and yield diversified and yet contents that are relevant to the query and also satisfy the user needs, based on the diversification of contents.

***Motivation*:** Knowledge-Driven paradigms with low computational complexity is the need of the hour in Web-based Recommendation Systems to cater to the demanding informational needs of users. Also, the Web-based Recommendation Systems needs to be quite lightweight by transforming the traditional learning paradigm into reasoning based inferential strategy for recommending query relevant and user-relevant information from the Web.

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***Contributions*****:** A dynamic knowledge-centric model for recommending queries and web pages based on the standards and constructs of Web 3.0 has been proposed. The approach integrates an initial classification model that carefully selects the top-25% of the most relevant results to cognitively enrich an RDF driven real-world knowledge from a series of SPARQL Endpoints based on the domain of relevance of the Query. The strategy blends a WordNet 3.0 based Synonymization as well as Intertwining Real-World Knowledge through indexing services and SPARQL Endpoints that are quite heterogeneous. Also, an inferential cognizable semantic similarity by fusing the Jaccard and the NPMI model is used to inferentially select the recommendable entities. Experimentations are conducted on the WebKB Corpus and an overall accuracy of 0.91 with a reasonably small FDR of 0.1 has been achieved. The proposed IISWS is validated by two baseline models and knowledge-centric variations to prove the efficacy of derived knowledge and its role in web page recommendation.

***Organization***: The rest of paper is organized as follows. The Literature Survey is detailed in Section 2. The Proposed Architecture is described in Section 3. The Implementation in represented is in Section 4. The Performance Evaluation are portrayed in Section 5. The Conclusions are formulated in Section 6.

## 2. Related Literature

Soto et al., [1] have put forth a semantic search engine which is domain-specific for biomedical abstracts that update auxiliary knowledge from PubMed on a daily basis. The search engine uses a NER approach for biomedical entities and a context-sensitive Acronym Resolution for concept recognition. Xie et al., [2] have recommended web pages based on two-fold clustering where the relationship between the user behavior and topics are correlated. Bhavithra et al., [3] have formulated an approach for case-based reasoning focusing on clustering as a paradigm which is based on weighted association rule mining for recommending web pages. Singh et al., [4] have imbibed sequential rules partially ordered web page recommendation which predicts the future interests of the users' web page information. Katarya et al., [5] have incorporated the fuzzy c-means clustering technique for the recommendation of web pages that makes use of users' navigation details of web pages.

Ontologies have been used in several possible combinations in several Web Search paradigms. Ali et al., [6] have used Fuzzy Ontologies in combination with SVM for web content classification. Thanapalasingam et al., [7] have recommended editorial products based on the domain ontology model. They have depicted the usefulness of domain ontology and its impact in recommendation specific to the computer science domain. In [8-11] Deepak et al., have incorporated several intelligent semantics paradigms in combination with ontologies for recommending web contents in web search and personalization. Deepak et al., [12] have proposed the Differential Semantic Algorithm (DSA) that uses differential threshold on semantic similarity algorithms for facilitating personalized web search.

Elshaweesh et al., [13] have personalized and recommended web pages based on user profile analysis, latent semantic analysis, and the browsing behavior of the user with semantic knowledge via the Ontologies. Sumathi et al., [14] have proposed the IFWIAR for query recommendation based on the usage of a domain specific ontology with improved weighted fuzzy iterative rule-based ontology processing. Though they have achieved results that are appreciable, the knowledge sparsity is visible as it is highly domain specific and integration of real-world knowledge isn't visible. Omar et al., [15] have introduced a personalized approach for integrating domain knowledge and user profile-based ontology for transportation domain using WordNet API and semantic conceptual knowledge.

## 3. Proposed Architecture

Figure 1 judiciously describes the architecture of the proposed which intelligently integrates the phases of initial classification and integration of real-world knowledge to facilitate web page recommendation. The proposed IISWS does not make use of any static ontologies or knowledge resources, instead a dynamic ontology modeling scheme for upper ontology derivation has been imbibed into the approach using existing real-world collaborative cognitive knowledge to ensure that recommendations are not restricted to the conceptual level but also yield enough individuals when there is a conflict of interest, specifically when homonymous terms are identified by the Web Search System. The core principle behind the IISWS is to overcome the Sparsity problem in Web Search and strategically overcome the problems of synonymy, polysemy, and homonymy. Also, the design of IISWS is in away such that Serendipity problem is also overcome by ensuring the user query is subject to Query Pre-processing such as the Tokenization, Stop Word

Removal, and Lemmatization. On the pre-processing of the query terms, a query word set is furnished. In order to enhance the probability of integration of likewise entities, the Query Word Set is subject to Synonymization where several Synsets for a specific query word is anchored with the Query word. The Synonymization was done based on the integration with a WordNet 3.0 synset generator, and several relationships like the Homonym terms, and terms with polysemous contents has been identified at this stage. However, the synonyms generated with polysemous and homonym terms are reserved for future knowledge enrichment during the Intertwining phase.

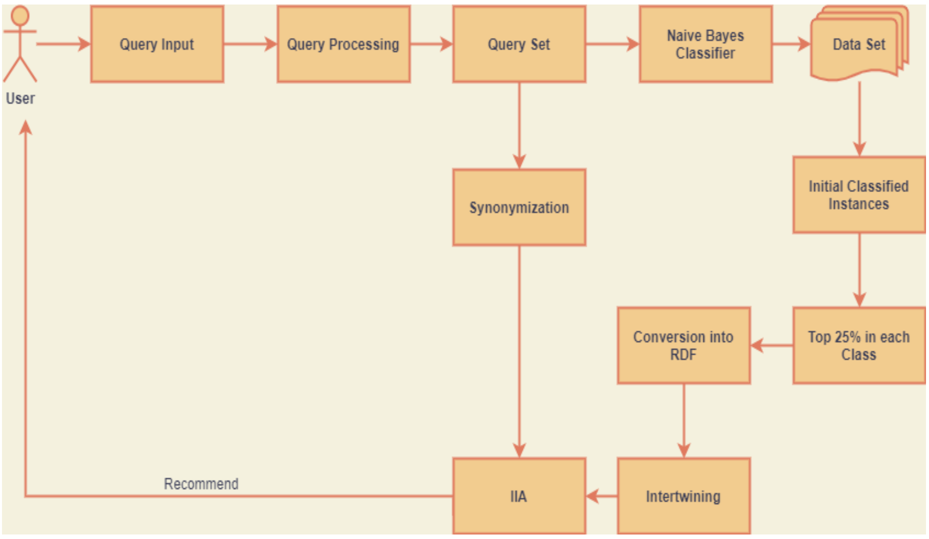


**Figure 1: Architecture of the Proposed IISWS**

The initial query words generated are subject to initial level classification of the labelled dataset that has been cleaned and pre-processed. The classification is done based on a traditional Naïve Bayes Classifier by fixing the class labels as the pre-processed query word set. The reason for using a conventional classifier is mainly owing to the reason that classification need not be emphasized for being highly accurate, and the methodology requires approximate classification for future reasoning and inferencing during recommendation. For each of the classes, top 25% of classification results under each label, i.e., the query word is taken into consideration and is transformed into its equivalent RDF structure. Once the classification results in the top 25% is transformed into RDF, the process of Intertwining is performed where the RDF is linked with real-world SPARQL Endpoint server to associate the real-world entities along with their equivalent class labels and formulate a linked RDF structure with dynamic aggregation of real-world ontological knowledge in the form of RDF data.

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The SPARQL Endpoint is linked to Wikidata, DBPedia, LinedCT, voiD Data, and UniProt based on the query centric domain relevant identification of entities. However, each of these data stores and their domain availability is identified with the help of an interim repository that has been indexed with the domain and sub-domain terminologies. Once the Intertwining has been successfully staged, there is synonym induction that has been computed previously in order to further enrich the density of query centered domain knowledge based on dynamic Ontology Generation through RDF Intertwining. The RDF Intertwining generates extensive

Cognitive Knowledge for formulation of queries and recommending query words based on Bigram and Trigram integration. The methodology requires an intelligent recommendation strategy for regulating the query formulation which is done based on the computation of the standard Jaccard Similarity and the Normalized Pointwise Mutual Information Computation Scheme, wherein the top 15% integration of common elements from either of the two schemes has been formulated. The recommendation strategy has been depicted in the Intelligent Inference Algorithm that has been depicted in the further sections. The recommendation results are re-arranged in the declining order of the values of semantic similarity, and further yielded to the user. The results have a high degree of diversity as the user has a lot of choices to select because of the strategies followed in the proposed approach. Further, if the user is dissatisfied with the yielded results, then the query words are re-substituted by the current user click sub-topics in the recommendation, and thereby driving the recommendation to a much-focused topic and thereby altering the feasible recommendable terms until the user is satisfied. The semantic similarity is computed using the intersection of the Jaccard Similarity and the Normalized Pointwise Mutual Information (NPMI). The Jaccard Similarity is computed with a threshold of 0.75 while the NPMI is considered between 0 and 1 without yielding to its negative values. The threshold of 0.5 is considered for the NPMI. Further the intersection of the datapoints between the individual threshold of the Jaccard Similarity and the NPMI is taken into consideration for recommending the terms to formulate queries and further choose the relevant web pages. The Jaccard Similarity is depicted by Equation (1) and the NPMI is depicted in Equation (2). The Normalized pointwise mutual information is dependent on the pointwise mutual information measure portrayed by Equation (3). Equation (4) illustrates the intersection incidence of both the Jaccard Similarity and the Normalized Pointwise Mutual Information measure.

$$Jaccard(S,T)\frac{|S \cap T|}{|S|+|T|-|S\cap T|} \tag{1}$$

$$npmi(x;y)=\frac{pmi(x;y)}{-\log[p(x,y)]} \tag{2}$$

$$pmi(x;y)=h(x)+h(y)-h(x,y) \tag{3}$$

$$\text{SemanticSimilarity}= |\text{Jaccard}\ | \cap |\ \text{NPMI}\ | \tag{4}$$

# 4. Implementation

The implementation has been achieved using the Python NLTK library and the OntoSpy library. However, the SPARQL Wrapper interface was modeled with an agent such that the SPARQL endpoints can be queried for Intertwining. However, a customized domain index repository has been used for mapping and indexing the terms.

**Table 1: Proposed Integrative Intelligent Algorithm (IIA) for Web Page Recommendation**

| |
|---|
| ***Input: Initially Classified Dataset based on the Query Words as Labels, Query Word Set w, Real World Knowledge Bases,*** |
| **Output:** Recommended Expanded Queries and their corresponding Web Pages |
| ***Begin*** |
| **Step 1: while** ($Q_w$.next()!=NULL) |
| for each $Q_w$ as Label |
| HashSet $R'$ ←Select Top 25% and Convert into RDF |
| end for |
| **end while** |
| **Step 2: for each in R'** |
| 2.1Select the domain index for R'.current() from a Thesauri |
| 2.2 Based on Index Domain trigger SPARQLEndpoint |
| 2.3 Generate Intertwined Knowledge as Tree $I_w$ |
| **end for** |
| **Step 3:** Generate SynSets of $Q_w$ as $Q_{syn}$ |

**Step 4: while** ($Q_{syn.}$next()!=NULL)
Tree $I_{Enriched}$←Repeat Step 2 for $Q_{syn.}$current()
**end while**
**Step 5: while ($Q_{w.}$next()!=NULL)**
Set J←JaccardSim($Q_{w,}$ $I_{Enriched}$.pos())
Set N←NPMI (($Q_{w,}$ $I_{Enriched}$.pos())
return R←J∩N
**end while**
**Step 6:** Choose any two levels from R as either super concepts or sub concepts or
From its neighbor and recommend by applying Bigram & Trigram and
Recommend to the user.
**Step 7:** Repeat Step 5 by matching elements of user-click and by not visiting a single
node more than once.
**Step 8:** If there exist user clicks, then substitute the maximum topic of user click as
$Q_w$ and begin from Step 1 until there are no further user clicks.
***End***

The proposed Integrative Intelligent Algorithm for Web Page Recommendation is depicted in Table 1 which takes input as the Classified Datasets based on the Query Labels, Query Word Set, and SPARQL Endpoints via a domain indexing service for the Real-World Knowledge Stores. The Algorithm furnished the recommended expanded queries at first, and further their corresponding web pages. The algorithm selects the top 25% of the classified data from each of the classes with query words as a label and is transformed into its equivalent RDF. Further, the domain index for the class labels and randomized classes is selected, and based on the domain index a set of SPARQL Endpoints are selected for including relevant real-World Knowledge for Intertwining the RDF and formulate a Knowledge Tree, which is further enriched based on the initial set of synonyms generated. The generated synonyms are also intertwined into real-world knowledge. The selection of recommendable query entities is realized on the basis of the semantic similarity computation and the recommendation of queries is done by bigram and trigram formulation based on user query clicks. The web pages are selectively displayed based on the user-click of the recommended queries. The process is continued until each node of the enriched knowledge tree is visited or until the user has no clicks recorded. If all the nodes of the current knowledge tree have been visited, then the last few user clicks are once again considered as query words to facilitate newer recommendations until the user is satisfied, i.e., till no further user clicks are recorded.

# 5. Performance Evaluation

The experimentations for the proposed IISWS has been carried out for the WebKB Corpus with 492 benchmark test queries. 72 users were given 40 queries each to give their top 10 recommendations in terms of both query categories and individual web pages. However, each user got different variations of the same query, and finally for each query, top 10 frequently occurring webpage and the queries were considered as ground truth for experimentation.

The Precision, Recall, Accuracy, F-Measure, and False Discovery Rate (FDR) were used as standard metrics for evaluating the performance of the proposed IISWS. Also, nDCG (Normalized Discounted Cumulative Gain) was used to measure the diversity of the results yielded. Equations (5), (6), (7), (8), and (9) depict the Precision, Recall, Accuracy, F-Measure, and FDR. Equations (10) and (11) represent the Normalized Discounted Cumulative Gain and the Discounted Cumulative Gain respectively.

$$\text{Precision}=\frac{\text{Retrieved}\cap\text{Relevant}}{\text{Retrieved}} \quad (5)$$

$$\text{Recall}=\frac{\text{Retrieved}\cap\text{Relevant}}{\text{Relevant}} \quad (6)$$

$$\text{Accuracy}=\frac{\text{Precision}+\text{Recall}}{2} \quad (7)$$

$$\text{F-Measure}=\frac{2\times\text{Precision}\times\text{Recall}}{\text{Precision}+\text{Recall}} \quad (8)$$

$$\text{FDR}=1-\text{PPV} \quad (9)$$

$$\text{nDCG} = \frac{\text{DCG}\alpha}{\text{IDCG}\alpha} \quad (10)$$

$$DCG = \sum_{i=1}^{\propto} \frac{Rel_i}{log(i+1)} \quad (11)$$

Since Query Recommendation is followed by the web page recommendation in the proposed IISWS, the performance measures were computed for the final web pages that have been furnished by the proposed system. The average performance evaluation for the WebKB Corpus has been depicted in Table 2 where the proposed IISWS and has been benchmarked with several other models and variants of knowledge. Also, a variation without specific knowledge model has been depicted. The IISWS is also baselined with the Differential Semantic Algorithm (DSA) [12] that uses a semantic strategy for recommending web pages and IFWIAR [14] that uses ontologies for yielding the web pages. The experimentations are conducted for every baseline models and other knowledge level variations in the same environment as of the proposed IISWS.

It is evident from Table 2 that the proposed IISWS furnishes an average precision, recall, and accuracy of 90.21%, 93.47%, and 91.84% respectively. IISWS furnished a very low FDR of 0.1 with an nDCG of 0.91 which is better performing than the baseline models and its variants. The IISWS yields a 13.6% higher accuracy than DSA and 6.38% higher accuracy than the IFWIAR. The reason for a better performance of the IISWS than the DSA is due to the reason that IISWS has an efficient semantic model and heterogenous integrative knowledge form several real-world knowledge resources through SPARQL Endpoints.

The DSA has a strong strategy of regulating the recommendation by a combination of semantic similarity measures with varied thresholds, however, the DSA only focuses on personalization, and does not use any external static knowledge or dynamic inferential knowledge. IFWIAR encompasses Ontologies with fuzzy weighted iterative association rule with static domain ontologies. However, owing to the sparsity of domain ontologies supplied into the IFWIAR, there is a predominant lag in its performance.

**Table :2 Performance Analysis of the Proposed IISWS Framework**

| **Model/ Variants** | **Precision %** | **Recall %** | **Accuracy %** | **FDR** | **nDCG** |
|---|---|---|---|---|---|
| **DSA** | 76.14 | 79.74 | 78.24 | 0.24 | 0.76 |
| **IFWIAR** | 84.17 | 86.74 | 85.46 | 0.16 | 0.86 |
| **Static Ontological Model** | 84.12 | 87.74 | 85.93 | 0.16 | 0.85 |
| **Fuzzy Ontologies** | 83.14 | 85.74 | 84.44 | 0.17 | 0.84 |
| **Without any Knowledge Model** | 79.47 | 81.14 | 76.98 | 0.21 | 0.74 |
| **Single Source SPARQL Endpoint** | 82.14 | 84.32 | 83.23 | 0.18 | 0.82 |
| **Proposed IISWS** | **90.21** | **93.47** | **91.84** | **0.1** | **0.91** |

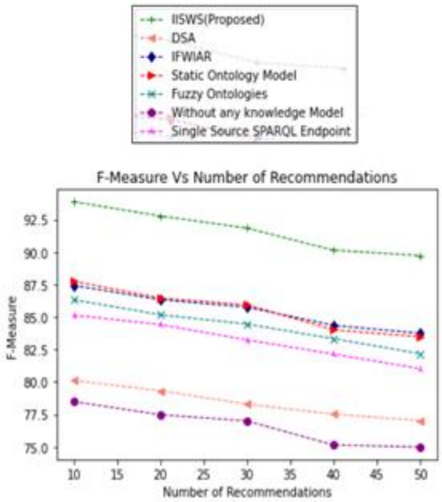


**Figure 2: F-Measure Vs Number of Recommendations**

Since the strategic amalgamation of auxiliary knowledge along with a strong inferential semantic similarity model is a requisite in the viscinity of the linked semantic data for achieving a higher performance, variations in regard to the knowledge models were demonstrated to show the effectiveness of the IISWS model which has been put forth. The replacement of the heterogeneous dynamic knowledge model with a single source SPARQL Endpoint decreased the Accuracy of the IISWS by 8.61%. Further, the use of Fuzzy Ontologies and the Static Ontologies, decreased the Accuracy of IISWS by 7.4% and 5.91% respectively. When a Single Source SPARQL Endpoint is incorporated, there is no sufficient knowledge amalgamation for the current query. However, when the Static Ontological Model is used, there is sufficient auxiliary knowledge but modeling the same is cumbersome. The Fuzzy Ontologies are comparatively less domain-specific than that of the Static Ontologies thereby exhibiting a lesser accuracy than that of the Static Ontologies. Finally, in the absence of a standard knowledge model in the environment of the inferential recommendation model of the IISWS, the accuracy decreased by 14.86% which clearly ensures that amalgamation of real-world dense cognitive knowledge reduces the strategic gap between the user-query and the finally recommended items.

The accuracy directly correlates with the Precision, Recall, and F-Measure and is inversely proportional to the FDR. With the increase in the Accuracy, there is a significant decrease of the FDR. The IISWS has the lowest FDR of 0.1 when compared to that of DSA and IFWIAR and all the other variants. The distribution of the percentage of F-Measure Vs the Number of Recommendations for the proposed IISWS framework and its variants of the baseline models is depicted in Figure 2 from where it is clearly evident that the F-Measure Distribution of the proposed IISWS is much higher when compared to the other variants in terms of knowledge and Ontological Models and the baseline systems namely the DSA and the IFWIAR. The proposed IISWS framework not just performs based on the relevance of the finally recommended results but also focuses on the diversification of results based on the integration of knowledge from varied sources. The diversity of results is quantitatively measured using the nDCG. It is evident from Figure 3 that the nDCG is the highest for the proposed IISWS framework and it measures to 0.91. However, the DSA and IWFIAR have a nDCG of 0.76 and 0.86 respectively. Even the variants of knowledge like that of Static Ontology Models and the Fuzzy Ontologies have a nDGC of 0.85 and 0.84 respectively. The Single Source SPARQL Endpoint has a nDGC of 0.82. The absence of any knowledge model has the lowest nDGC of 0.74. The reason for the diversification is owing to the rich amount of entities that are dynamically generated from a system of knowledge stores and repositories based on the nature of domain through SPARQL Endpoints. Since there is diversity and the density in the supplied auxiliary knowledge, the proposed IISWS outperforms the baseline approaches and the other variants of the same algorithm in terms of the knowledge models.

# 6. Conclusions

An Intelligent Integrative approach for Knowledge Centric web page recommendation has been proposed. The IISWS system initially recommends diversified queries and then the web pages on the basis of the knowledge rendered by heterogenous SPARQL Endpoints. The IISWS intelligently encompasses an initial classification of the dataset to choose the top 25% of each of the classification, which is further converted into RDF that is further interlinked with real-world knowledge stores through the Multi-source SPARQL Endpoints based on selective domain integration. The dynamic generation of the query relevant entities, synonymization, and an efficient semantic similarity-based recommendation of the web pages makes IISWS as the most desirable web page recommendation system. Moreover, the enrichment of knowledge into the system ensures diversified and yet query relevant recommendations. An overall accuracy of 0.91 with a reasonably small FDR of 0.1 and a nDCG of 0.91 has been attained by the proposed IISWS Framework for the WebKB Corpus dataset.

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