Ontology Based Information Retrieval - An Analysis

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Abstract— Ontology is a description of concepts with relation and properties to be used in knowledge engineering as a knowledge base. Ontology is used in information retrieval to retrieve more relevant information from a collection of unstructured information source. In this paper various Ontology based information retrieval methods have been analysed. There are various approaches developed to make the information retrieval more efficient. The methods have been classified as vector space, probabilistic and semantic based techniques. Semantic based information retrieval can still be classified as semantic similarity, semantic association and semantic annotation. A comparative analysis is made on all the available methods, which will guide the developer to choose the appropriate Ontology based information retrieval method.

Keywords— Ontology; information retrieval; semantic search; vector space model; probabilistic model

I. INTRODUCTION

Information retrieval is the process of retrieving relevant information from collection of unstructured information that meets the user need. The amount of information available in World Wide Web (WWW) is very large and still growing, which makes retrieval of information from WWW a tedious task. There are many search engines developed to address this problem, but most of them adopt the traditional keyword based search. Keyword based search method uses the user query to retrieve set of relevant documents from the indexed document those fit the terms given by the user. Semantic Web is an extension of current web in which information provides well-defined meaning that enables system and people for better understanding and can enable to work effectively by understanding information from different sources [51]. The introduction of semantic web is a great leap from the existing Web 2.0 in which the user not only interacts with the web, but also has the capability to generate more meaningful information. The complete information is represented with the help of Ontology. Ontology allows knowledge to be represented as a set of concepts, properties and the relations between them [52]. In information retrieval, the users don't search with the exact terms represented in the documents in most of the cases. Hence, relevant documents are not fetched by the keyword-based information retrieval but the semantic web makes the information retrieval more users driven than that of keyword driven. Hence it helps to retrieve more relevant documents.

Many researchers widely used Natural Language Processing (NLP) to understand the meaning of the user query input in Ontology based information retrieval. The semantic web makes use of various types for Ontologies for understanding the user query input in information retrieval. Widely, linguistic Ontologies like WordNet [53], VerbNet [54], FrameNet [55], ConceptNet [56] are used to understand the concepts of user query. There are also other Ontologies like application or domain specific Ontology, contextual Ontology and user history based generative Ontology used in information retrieval based on the user's requirement. This paper is organized as follows: Section 2 describes the related work being carried on basics of traditional keyword based information retrieval and Ontology based information retrieval. Background work to study various types of developed Ontology based information retrieval methods is explained in section 3. A comparative analysis of various Ontology based information retrieval methods is made in Section 4. Section 5 discuss about the Ontology based information retrieval.

II. RELATED WORKS

The main goal of information retrieval is to retrieve relevant information based on the user request on external information source. The existing traditional keyword based search is not sufficient in most of the cases. Keyword based search process on indexed set of documents contains the keyword along with the document location. One the user query input is given to the search engine, the query is pre-processed to remove all the stop words and to obtain all the keywords from the query. These set of keywords are searched in the document index and the document that correspond to the keywords are retrieved to the user. Figure 1 shows the workflow of keyword-based information retrieval. The semantic search has improved the information retrieval by retrieving more relevant information than that of keyword based search. The keyword based search fails in many scenarios as the user don't know the exact term what he is searching for. In the Ontology based information retrieval, the user's query input is semantically expanded by query processing with Ontologies. This semantically enhanced query searches for documents in the semantically indexed cluster of documents to retrieve the relevant information. The workflow of Ontology based information retrieval is given in figure 2.
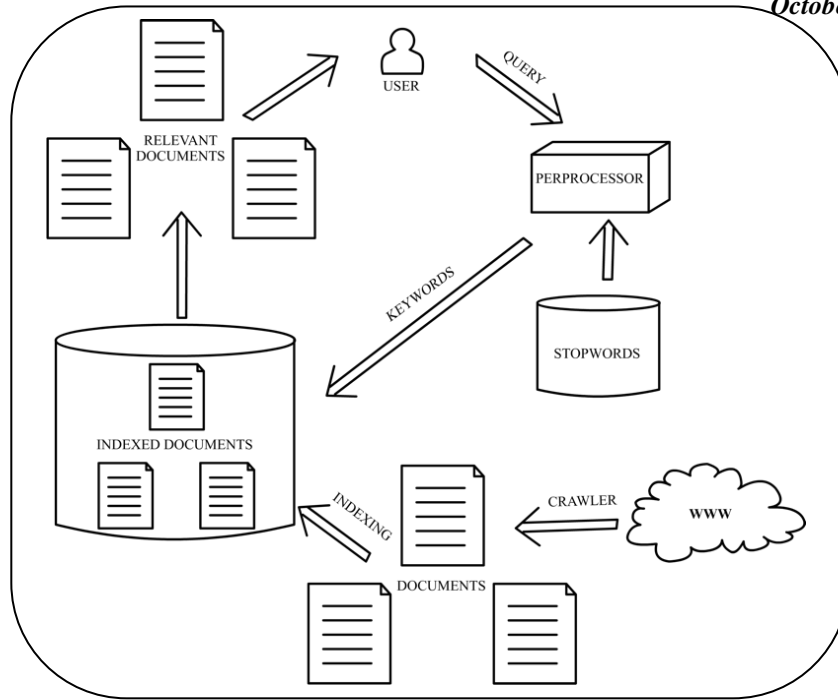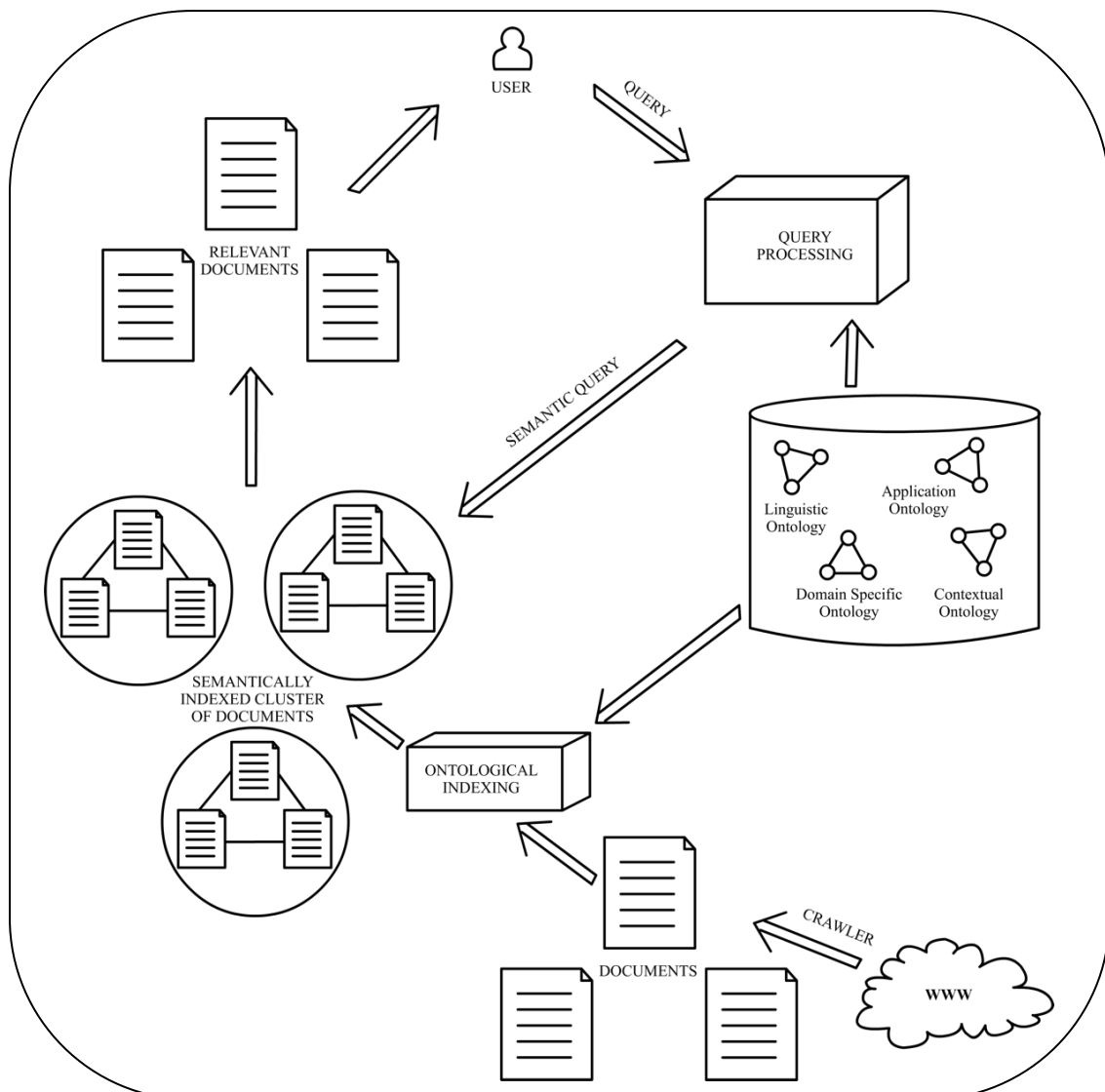
Fig. 1 Keyword Based Information retrieval

Fig. 2 Ontology Based Information retrieval

III. BACKGROUND WORKS

The semantic web, also known as Web 3.0 views the web as collection of data rather than set of documents. Semantic web uses Ontology to represent knowledge, share it and reuse it across various applications. There are various Ontology based information retrieval methods to search information with enhanced semantics from the user query input to retrieve high relevant information in the literature classified and explained below.

A. Vector Space Based Information Retrieval

Vector space model represents the documents and concepts as column and row vector where the cosine angle between the documents are used to measure the similarity between the documents. The similarity between the documents is determined by the closeness of documents in the vector space. Jan Paralic and Ivan Kostial [45] developed an Ontology based information retrieval, where the user query is preprocessed using Ontology to retrieve the set of concepts, which is compared with the concepts in the document vector. Weights are drawn for those of individual concepts in the document vector using which relevant documents are retrieved.

Pablo Castells et al. [4, 21] proposed semantic based personalization for Ontology based information retrieval and an adaptation of Ontology in information retrieval. Personalization method works by triggering a formal Ontology based query followed by vector space information retrieval technique. The cosine similarity of concepts and keywords with documents as vector is used. Finally the document weights are adjusted based on user's personalization. Adaptation model works by annotating documents with concepts in vector-space model. The list of relevant instance from the RDF knowledge base is retrieved using query engine. RDQL query is triggered based on the user keyword, which executes on the knowledge base and retrieves the tuple that are relevant. The weight of each keyword can be varied based on the user requirement while triggering RDQL query.

Ontology based information retrieval for e-learning was developed by Rachid Ahmed-Ouamer and Arezki Hammache [30]. The query and the documents are represented as vector space. Outdistance between vectors is used to calculate the similarity of the document to a given query. Finally cosine measure is used along with the vector value to retrieve most relevant document. Xutang Zhang et al. [9] proposed "Query semantic extension" in which the documents are clustered based on the Ontology and the input query is analysed for semantics and expanded using domain Ontology. The latent semantic analysis is used to compare the relation between the expanded semantic queries and the domain content and vectors are used to determine the relation between words and documents.

B. Probabilistic Information Retrieval

Probabilistic information retrieval uses the similarity measure to retrieve the documents that are relevant to the query. The document relevance of the given query using probability model is estimated by the ratio of probability of relevant terms present in the document to the probability of irrelevant terms present in the same document. Various researches have been performed to incorporate semantic knowledge in probabilistic information retrieval using Ontologies. Ontology based information retrieval by Nenad Stojanovic et al. [19] has two methods to support query refinement. One is to provide equivalence attributes that can lead to the related content and the other is to retrieve the resources that match the user's query for further processing. The probability of right interpretation of user query input is analysed for better interpretation of user query.

Logic based query refinement method by Nenad and Ljiljana [18] for Ontology based information retrieval extends the initial user query using Ontology and then an acceptance test is made on the extended query to inspect the extended terms. In this method, the query is refined step-by-step based on the fuzzy probability. Jun Zhai et al. [47] developed fuzzy Ontology based semantic information retrieval where the user query is expanded using order relation, equivalence relation, inclusion relation, reversion relation and complement relation by combining fuzzy domain Ontology with fuzzy linguistic variable Ontology. Probabilistic latent semantic index (PLSI) [13] is a technique in which the query is expanded and then Term Frequency Indexing (TFI) is used to compute the document scores for information retrieval. The size of PLSI is very large when compared to that of TFI. This method can provide high precision with increased delay.

C. Context Based Information Retrieval

Contextual parameters like location, time, date, user's details contribute a lot in retrieving more relevant information. Various authors have taken various contextual parameters into account for retrieving relevant information. Humaira Liaqaut et al. [36] developed context aware information retrieval using role Ontology. This model considers various parameters like the user's profile details, time and date, device used and user's history to retrieve relevant information. This also uses words expander to expand the user terms based on thesaurus, domain Ontology, WordNet and hyponyms. Multi-agent information retrieval framework based on Ontology developed by Jing-Yan Wang and Zhen Zhu [35] also addresses the contextual problem in the existing information retrieval system. The user's input is converted into command parameter. The user can set his own customized Ontology or domain Ontology to use for searching. The custom Ontology consists of personalized user's requirements and regularly updated based on user's feedback.

Jibran Mustafa et al. [8] developed a framework for semantic based information retrieval by considering the context of concept(s). The user query input is expanded with synonym and semantic neighbourhood. The search is performed in the RDF triple with the relationship between the concepts also considered. A personalized Ontology based query expansion designed by Silvia Calegari and Gabriella Pasi [12], which uses a two-step query expansion. First step is to find the context of the query terms with respect to the user's past search and then the WordNet is used to enrich the semantics of

the query terms. Engineering information retrieval using Ontology developed by Yuangang Yao et al. [33] has a framework to semantically analysis the user's input and the documents. The user input is handled by query processing module for query analysis based on Ontology. Intentional feedback to user is provided by the retrieval oriented Ontology. Ontology based query expansion was developed by Jouni Tuominen et al. [42], which uses queries are expanded with spatio-temporal Ontology. Spatio-temporal Ontology contains concepts related to user's geographical location and time. Huiying Gao et al. [31] developed an Ontology based enterprise information retrieval. The user query is processed by sentence splitting and extraction of related enterprise information from Ontology. Semantic query is triggered with the extracted resource to retrieve the relevant information. Semantic based information retrieval for blog developed by Ying Chen et al. [26]. Triggering Semantic query on blog and domain Ontology that are specific to the blog context semantically expands the user's query request. Jie Yu et al. [24] redesigned sliding window algorithm for context based information seeking. The semantic relations between the concepts are retrieved using sliding window algorithm. The concepts and the window size are given as input and the number of co-occurrence of concept is retrieved as result.

OntoSense – An Ontology-based information retrieval was proposed by Iulian-Florin Toma [34]. The OntoSense engine makes the user to directly enter the query to Ontology by suggesting query attributes based on user's previous query. R.Suganyakala and Dr.R.R.Rajalaxmi [28] developed movie related information retrieval using Ontology. The input query is converted into semantic entities using which SPARQL query is constructed and executed in Ontology repository triples. Thus the user query is converted to semantic triples thereby executing directly on conceptual Ontology. Personalized knowledge search developed by Yuh-Jen Chen et al. [16], which is based on user's history log on the domain Ontology. Each time the user search, the log stores the portion of Ontology in which the user is most interested. This knowledge is used along with the user's profile information and the context in which the user is searching to retrieve the new result.

D. Semantic Based Information Retrieval

The semantic based information retrieval intends to search with concepts rather than with terms, which retrieves more relevant information. Various semantic based search techniques have been adopted since the evolution of semantic web. Huiyong Xiao and Isabel F. Cruz [46] designed semantic query processing technique to retrieve personal information. Semantic query is constructed from the user's query input by using one or more domain Ontologies thereby retrieving related information. Ontology driven information retrieval developed by Jian Guan et al. [37] allows user to type in or draw the query input. This input is semantically enhanced using query-processing module by triggering a RQL query to the Ontology. The semantically enhanced query is used to extract the information from the document set and retrieve relevant document. User query input is sent to query builder to semantically enhance it using legal Ontologies in EgoIR [39] model. The concepts and instances are associated with the documents in the legal Ontologies thereby helping to enhance the user query input.

Been-Chian Chien et al. [6] developed fuzzy Ontology based information retrieval. The initial query is pre-processed to find keyword and eliminate stop words. Different Ontologies like WordNet, domain Ontology and automatically constructed Ontologies are used to semantically extend the user's input. A 3-layer indexing technique was created by Zheng Gu and Song-Nian Yu [7] to index Ontology with URL using keyword. The user query input is processed to obtain the semantic query by retrieving the related words from WordNet and fetch the concepts from Ontology for those terms. Initial taxonomy is constructed in [14] using the user's query and the related superclass. This is used to retrieve initial set of documents upon which the exact match for user's query is searched using Stanford Part of Speech tool. These concepts are again sent to Ontology Building module for candidate concept discovery. Allowing user to select the candidate concepts related to the initial query could perform the next level of refinement thereby retrieving documents.

Ontology query model was designed by Antonio et al. [10], which generates the set of concepts that are related to the user query. The user can visually select the concepts that are more relevant. Lexicon cleansing is used to remove the terms that are not available in the documents. Metathesaurus based controlled vocabularies are used in Ontology based query expansion by Liang Dong et al. [20] for biomedical information retrieval. Metathesaurus consists of concepts and inter-concept relations. The query expansion uses weight for semantically related vocabularies. Srabani Sarkar [22] generated Ontology using Fuzzy-valued Variable. To retrieve the relevant document, first the keywords from the query are searched in Ontological forest, followed by the synonym of the keywords. The sub trees of the corresponding trees form the query set.

A Non-metallic pipe information retrieval system using domain Ontology was designed by GUO Rong and WU Jun [32]. The user's natural language query undergoes its initial transformation into concepts. These concepts make use of knowledge base to transform itself to a knowledge base query. Jinwoo Kim and Dennis McLeod [2] developed "3-Tuple query interface" which uses statistical Ontology to find either subject, linking word or object from two known entities. Known-Net was adopted by Hong Zhoua et al. [17] for improvement of the search query using Ontology label. The keyword is analysed for concepts, individuals, relations and attributes. The improvement of the user's query is done through merging, editing and natural language treatment. Poonam Yadav and R.P. Singh [48] developed Ontology based augmented approach for document retrieval by extracting the concepts from the user query input, removing stop words retrieving related Ontologies and indexing them in an array to compare the generated values thereby retrieving the relevant results.

E. Semantic Similarity Based Information Retrieval

Simple semantic based information retrieval is not complete in most of the scenarios. Semantic similarity is used to measure the similarity between the concepts of the documents to that of the user query. A model of concept-based

information retrieval using Ontologies was developed by Rifat Ozcan and Y. Alp Aslandogan [43]. The user query is analysed in word space for extraction of concepts. These extracted concepts are matched with knowledge repository retrieved from the word space. The similarity between the concepts within a domain is identified using latent semantic analysis. Gábor Nagypál [41] developed a model for effective information retrieval using semantic metadata generation and Ontology based query expansion. This method generates the transformed query from the user query by combining query processing from different Ontology heuristics and then perform search independently using traditional search method. Customers' complaint related information retrieval technique using Ontology was formulated by MA Hui-nan et al. [29]. The user query is initially expanded using synonyms from thesaurus. Expanded query is compared with the complaint lexicon in order to retrieve feature word. With the help of feature words the search is performed in the entire Ontology model tree.

Sheng Qiuyan and Ying Guisheng [23] developed semantic similarity based retrieval method. The compound words to the input terms are retrieved from WordNet. Further the argument sets are used for searching the relevant documents. "Query Reformulation and Semantic Matching Layer" was introduced by Qian Gao [1] in Ontology-based semantic information retrieval model. In this user query is expanded using synonym, semantic neighbourhood, hyponym and Meronym using domain Ontology. This method uses semantic similarity matching algorithm to retrieve the relevant and similar documents. Rashmi Chauhan et al. [5] used domain specific semantic search with pre-constructed Ontology. Once the system receives the user query, it is sent to the query-handling module. The extraction of meaningful concepts from the user input and semantic query expansion is done in the query-handling module. The semantic query expansion is done in two stages. First, it expands with the equivalent words using WordNet, followed by a mathematical model to evaluate the weightage of concepts thereby providing higher percentage of relevancy in the retrieved document.

F. Semantic Association Based Information Retrieval

Associations are kind of direct or indirect relationship between the concepts that plays a major role in information retrieval. There are various approaches designed for association analysis and discovery. Min Song et al. [44] developed an association based query expansion, which can be employed in information retrieval. The user's query is initially used to retrieve relevant document using traditional keyword based approach. These documents are reweighted based on association rules, feature selection and Ontologies. A hybrid approach for association search was developed by HU Jun et al. [3]. This method searches using keyword and association. An approximation space of property set is constructed using association search method. Finally the initial document and approximation space are compared and similarity is computed using approximation space and then final document is retrieved. The evaluation F-measure for various query set concludes that this Ontology based retrieval has outperformed both Ontology based and keyword based retrieval.

Miao Chen [49] proposed a framework for use of relations in Ontology for information retrieval. The user query is expanded based on candidate relation and the corresponding semantic family is used to expand the query based on hypernym, hyponym and synonym. Semantic association based information retrieval using Ontologies was developed by Payam Barnaghi et al. [50]. The user query is semantically analysed to find the association-using domain Ontology thereby triggering semantic query to retrieve relevant documents. A method to expand queries in the domain of Gene Ontology was proposed by Alejandra et al. [15]. The expansion of terms is done with the relationship in the Ontology. New terms from Ontology with lexical distance of one are extracted. If the terms are not in Ontology, then the closest terms to those words are taken to find the resources. Chunchen Liu and Jianqiang Li [25] developed semantic based information retrieval for Enterprise search. The Query-document relevance is computed from the user query with semantically indexed documents. The "query concept recognition" identifies the candidate concepts in the domain Ontology and evaluates query-document relevance to retrieve the relevant documents.

G. Semantic Annotation Based Information Retrieval

Most of the cases the owner know the terms using which the information will be searched, so he will be annotating the documents with those terms to make it easy of search engine to index. Very few works have been carried out in annotation-based search as some developer use the irrelevant popular terms to make their site indexed to irrelevant terms. David Vallet et al. [38] developed an Ontology based information retrieval method with annotation weighting algorithm, which the user query directly executes a RDQL query on the knowledge base to retrieve the list of tuples that are relevant. These tuples are used to retrieve the relevant documents from the document base.

Social annotation based web search was developed by Shenghua Bao et al. [40]. The web pages are indexed with the search keywords used by user to visit the pages. So, when a new user searches for the same term, the system retrieves the pages based on the maximum number of user's interest. Carlos Miguel Tobar et al. [27] designed Ontology based information retrieval for wikis using multiple queries. The equivalent terms are retrieved from synonyms and related verbs in the annotations. The each occurrence of term or synonym or related verb contributes to equivalent weight for information retrieval. Miriam et al. [11] proposed a semantic retrieval framework the user is allowed to directly enter the SPARQL query which process on semantic index to retrieve the semantic entities with the weighted semantic annotations.

IV. ANALYSIS

There are various types of Ontology based information retrieval available and it has been classified as vector space model, probabilistic model, context aware model and semantic based approach. Semantic based approach can be categorized on similarity, association or annotation used to measure the similarity as in Figure 3.
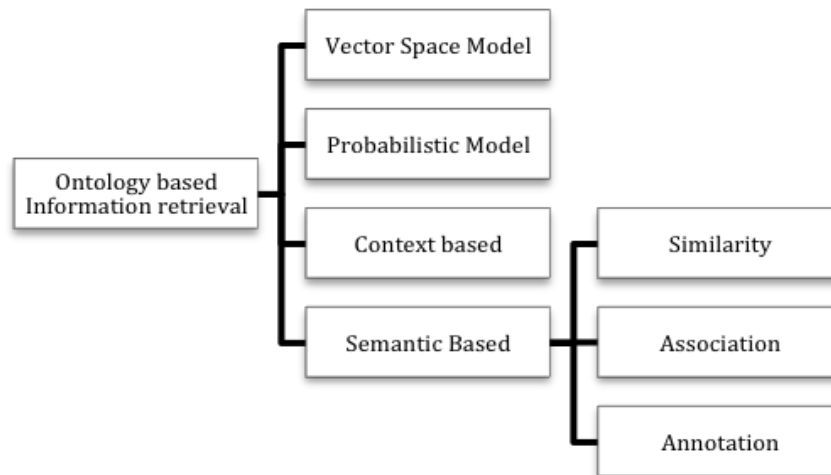
Fig. 3 Example of an image with acceptable resolution

Table 1 specifies the evaluation of various information retrieval methods based on the real time applications, precision, recall, pre-processing and retrieval time complexity. The higher number of star (★) determine good and vice versa. There are large number of real time applications developed based on semantic similarity and vector space model. Semantic similarity and vector space information retrieval have higher precision. Semantic based and semantic similarity based information retrieval retrieves more relevant information there by having a high recall score. Creation of association and annotation of documents takes large pre-processing time. The computation time of retrieval for vector space model is high as to measure the similarity between the documents and the query must be computed.

TABLE I
EVALUATION OF INFORMATION RETRIEVAL METHODS

Ontology based Information Retrieval method	Real time applications	Precision	Recall	Preprocessing Time	Retrieval Time
Vector Space	★★★★	★★★	★★★	★★★★	★
Probabilistic	★	★	★★	★★★★★	★★★★★
Semantic	★★★	★★★	★★★	★★★★	★★★★
Semantic Similarity	★★★★★	★★★★★	★★★★	★★★	★★★
Semantic Association	★★	★★★★	★★★★★	★	★★★
Semantic Annotation	★	★★	★	★★	★★

★- Average ★★- Normal ★★★- Good ★★★★- Very Good ★★★★★- Best

V. SUMMARY

Information retrieval is the science of retrieving all relevant information from a large collection of information. There are various steps in information retrieval process like organizing, storing and representing information to retrieve high quality information mainly from the World Wide Web and from some specific application domain. There are many Ontology based information retrieval developed, which can be classified based on the method as vector space, probabilistic and semantic. Semantic similarity, semantic association and semantic annotation are further classification of semantic method. Though there are many existing methods of information retrieval, there is no one such technique that can be perfect for all the application need. Compared to all the models semantic association and Semantic similarity method retrieve more relevant documents.

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