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Abstract
The purchase of a very expensive, complex product or service requires a great deal of information and reliable expert advice. The quality of advice provided by retail sales consultants has been shown to improve noticeably when they have fast, easy access to reliable product information that closely matches the customer’s desired preferences. This paper discusses the implementation such a system. An architecture for a World Wide Web based semantic matching system using software agents, formal ontologies and micro-domains is proposed.

Keywords: Knowledge Based Systems, Data Semantics, Human/Computer Interaction

1. Introduction

The purchase of a very expensive, complex product or service requires a great deal of information and reliable expert advice. Intermediaries such as retail sales consultants provide benefits to customers that include “assistance in search and evaluation, needs assessment and product matching, risk reduction, and product distribution/delivery” (Sarkar, 1997). They can improve their performance by implementing systems that provide fast, easy access to reliable product and personal experience information (Milne, 1996; O’Brien, 1998).

This paper discusses the implementation of a system that provides sales consultants with fast, easy access to reliable product information that closely matches the customer’s desired preferences. An architecture for a World Wide Web based semantic matching system using co-operating software agents and formal ontologies is proposed.

The system could be applied generally to retrieval of information from the internet, however to minimise cost and implementation time, it has been initially designed to operate in a restricted domain and application area, namely to provide retail sales consultants with...
product matching tools to improve their sales performance. This will allow the effectiveness of the system to be demonstrated more cost effectively.

2. Purpose

Most existing World Wide Web (WWW) search engines rely on keyword out of context, or free text searching for words or boolean combinations of words to identify matching sites and pages. This assumes that the meaning of the words or keywords (semantics) is the same in the mind of the searcher and the page creator. While this may be true in many cases, it is not so in the vast majority of cases. For example an Australian searcher who is looking for recipes for the first course of a dinner party would use the word entrée for a search. This is likely to result in hits on main courses from US sites (as main courses are called entrees in the US), lobbying sites related to gaining access (entree) to decision makers, not to mention the large number of French language sites that would contain this word. To reduce the number of hits to a manageable number the search needs to be narrowed to something like “entrée AND Australia AND food”. This is only possible if the searcher is aware of the different meaning of the word entrée in different countries, languages and domains, and that they understand, and can use boolean logic correctly.

When searching for web pages that match particular criteria, two key issues arise, polysemy and synonymy. Polysemy (a word or word form that can have multiple meanings) causes hits on irrelevant web pages to occur, for example, when searching for “entree”. Synonymy (two or more words or word forms that have the same meaning) causes relevant pages to be missed, for example, fly fishing and angling.

The purpose of this research is to develop an ontology based intelligent system that automatically resolves most issues of polysemy and synonymy to assist sales consultants to efficiently and accurately match customer preferences to product characteristics. This will allow the consultants to provide higher quality information to their clients at minimal additional cost.

3. Word Sense Disambiguation

To eliminate hits on irrelevant web pages, it is necessary to eliminate irrelevant senses of search keywords. This is commonly known as word sense disambiguation. The problem of word sense disambiguation (WSD) has been a rich area of research in computational linguistics, particularly in natural language processing (Kaplan, 1950; Oswald, 1952; Masterman, 1962; Yarowsky, 1992; Resnick, 1992, 1993, 1995). Two primary sources of information are required to effectively assign senses to words: the context of the word to be disambiguated and external knowledge sources (Ide and Veronis, 1998). Both of these types of information can be obtained from WWW pages themselves if some standardised semantic information (metadata) about the content of the page is encoded into each page.

Towell and Voorhees (1998) argue that fully automated WSD is not possible as there are some words that are highly polysemous and cannot be accurately disambiguated. In these cases more information must be obtained from the searcher about her/his meaning of the word. For example, if the US WWW entrée recipe pages indicated that they were “main courses”, and the search word was converted to “first course” there would be no match.

Recent work has shown that a combination of ontologies, linguistic databases, thesauri and WSD techniques can be used to automatically retrieve data with a high degree of accuracy (Guarino et al, 1999; Resnick, 1993, 1995; Yarowsky, 1992). In particular, Resnick (1993,
1995) has shown that ontological similarity involving a common ancestor in an ontology is a powerful disambiguator.

4. Ontologies

Formal ontologies provide a means of representing, or at least approximating, a conceptualisation of the world (See Figure 1). Guarino (1998) defines a conceptualisation as a set of conceptual relations on a domain space, where a domain space is a set of possible states of affairs within a specific domain.

By committing to an ontology, users of that ontology, either human or intelligent agents, agree to represent their conceptualisations of the world using a common language. Although each conceptualisation is language independent, ontologies are language dependent (Guarino, 1998). If the models of their conceptualisations overlap they share a common conceptualisation of the world and are able to communicate at a semantic level. This shared conceptualisation of the world is essential for shared understanding between users. Shared understanding allows semantic matching of concepts between users and agents. Semantic matching is the underlying process used in information retrieval, natural language translation, intelligent assistants and agents and many other areas of information systems.

In many cases an exact match of customer preferences to available products or destinations will not be possible. This problem of semantic heterogeneity between product and destination features and customer preferences requires that a “best match” is made rather than an exact match. By using the meronyms of the heterogeneous concepts a partial match can be achieved automatically by matching the parts.

5. Use Of Ontologies In World Wide Web Information Storage And Retrieval

Formal ontologies are now being used in application areas such as knowledge engineering, natural language processing, natural language translation, electronic commerce, bills of materials, information extraction, standardised product knowledge, legal information systems and biological information systems (Guarino, 1998).

An area where ontologies have been shown to be useful is in information storage and retrieval (Guarino, 1998; Guarino et al, 1999; Borgo and Guarino, 1997). Lewis and Sparck Jones (1996) distinguish three areas of information retrieval: text or document retrieval, data retrieval and knowledge retrieval. Text retrieval typically involves searching for documents that contain a sequence of words. Data retrieval involves the use of structured queries to retrieve structured data that matches the search criteria. Knowledge retrieval involves much more expressive language for encoding and retrieval (Guarino et al, 1999).

Most Internet search engines provide text/document retrieval capabilities only. Performance of this method is dependant on both the richness of linguistic descriptions within the pages/documents and the relevance of the word string supplied by the searcher. Most web pages lack the former and most searchers are not familiar enough with the content they are searching for to provide an optimal search string. Consequently, the accuracy and completeness of the set of pages retrieved by most search engines pages is generally poor.

Data retrieval systems require that the searcher is familiar with the structure of the database to be searched and the valid range of values for each attribute. It is unreasonable to expect that a searcher is aware of the structure of thousands, if not millions, of databases distributed
worldwide that may contain the required data. The set of retrieved pages in this case would necessarily be incomplete.

On the other hand, knowledge-based retrieval allows information to be retrieved on the basis of a _semantic_ match of concepts and relations from an agreed, well-defined ontology. To achieve this, the data must be encoded with a more expressive language that allows the taxonomy and relations between words and sub-concepts to be defined, and the searcher must be able to use the more expressive language for knowledge-based queries. Encoding and query formulation can be complex and time-consuming tasks, therefore, in practice, computerised tools need to be provided to both the encoder and searcher to minimise the complexity. Information retrieval is now achieved by matching the knowledge-based query, a description of the desired concept encoded in an expressive language with information that contains the same concept, encoded in the same language. There are many different knowledge representation techniques for encoding concepts but most are complex and far more expressive than is necessary for most applications. The _lexical conceptual graph_ (LCG) (Guarino, 1998) is a concept encoding technique that is adequately expressive for most practical applications, is easy to represent electronically, both within web pages and databases, and facilitates automated comparison (Guarino et al, 1999).

6. Micro-Domains, Micro-Ontologies and Micro-Rulebases

By restricting the context to a particular domain, a number of word senses can be automatically eliminated because they are not relevant to the domain. Reducing the number of possible word senses can significantly simplify the selection of the correct sense (Gale, Church and Yarowsky 1992). Restricting the domain implicitly restricts the valid contexts in which a particular word or concept can be considered. For example, if the domain is restricted to _recreational activities_, the word _fishing_ only needs to be considered in the context of _recreational fishing_. All _commercial fishing_ contexts can be implicitly eliminated.

Yarowsky (1993, 1994) suggests that word senses can be disambiguated with 90 to 99 percent accuracy by checking only a three to four word window around the word to be disambiguated when operating in a very restricted (local) context.

As “Context is the only means to identify the meaning of a polysemous word.” (Ide and Veronis, 1998), restricting the size of the domain restricts the contexts, which consequently restricts the size and complexity of both the ontology describing that domain (micro-ontology) and the rule base needed to automatically resolve polysemy (micro-rule base).

Even with very restricted domains, it is still highly unlikely that the WSD process can be fully automated. Dahlgren (1988) demonstrated that restricting the domain does not eliminate ambiguity for some words that are highly polysemous. For example, _hand_ has 16 senses and retains 10 of them in almost any context. Therefore, it is important that any information retrieval system provides a fallback to the user in these cases.

7. Software Interface Agents

“Interface agents are in charge of interacting with the user and of making the other agents transparent to him. It is able to understand the user's requests and translate them for the other agents. It is also in charge of coordinating the work of the other agents. It is the main reference point of the user.” (D’Aloisi and Giannini, 1996).
The interface agent performs a number of tasks that are crucial for the correct operation of an intelligent semantic matching system:

- assisting the user in performing requests and compiling his profile;
- deducing the user's information needs by both communicating with her and observing her "behavior";
- translating the requests of the user and selecting the agent(s) able to solve his problem(s).
- presenting and storing the retrieved data. 

(D’Aloisi and Giannini, 1996).

A great deal of work has been carried out into the use of interface agents in recent years (Balabanovic and Shoham, 1995, Knoblock et al, 1994; Lieberman, 1995; Resnick et al, 1994; Rich and Sidner, 1996). A number of prototype information retrieval systems have been developed that incorporate intelligent interface agents. Some notable examples are InfoSleuth (The InfoSleuth Agent System, 1998), RETSINA (1998) and WebMate (Chen and Sycara, 1998).

Many of the systems are based on ontologies (Borgo et al, 1997; Guarino et al, 1999; InfoSleuth, 1998) but most rely on centralised ontology databases. The emergence of XML, OML and RDF allows the ontology metadata to be embedded in the encoded web document, facilitating semantic matching by retrieval agents. The encoding agents may still refer to centralised ontology databases during the encoding process, but the databases can now also be encoded in XML. The commercial success of XML makes it a practical choice as an encoding language.

8. Semantic Matching Systems

Guarino et al (1999) have implemented a prototype of a general-purpose tool for ontology-based information retrieval called OntoSeek (See Figure 2). OntoSeek is a system designed for content-based information retrieval from on-line information sources that combines an ontology-driven content-matching mechanism with a moderately expressive representation formalism. Its main design criteria were:

- Possibility of using *arbitrary natural language terms* for accurate resource descriptions in the encoding phase.
- Complete terminological flexibility for the queries, due to a process of *ontology-driven semantic match* between queries and resource descriptions
- Interactive assistance on query formulation, generalisation or specialisation.
- State-of-the-art Internet architecture.
- Good recall and precision factors, and reasonable efficiency on very large data volumes.
- Good scalability and portability.

(Guarino et al 1999)

The system uses LCGs to represent queries and resource descriptions. Content matching is achieved by using ontology-driven graph matching, where individual nodes and arcs match if the ontology indicates that a subsumption relationship holds between them. To exploit the advantages of a *linguistic* ontology, OntoSeek links the graphs to it by constraining their labels to be lexical terms in the WordNet lexical database (Miller, 1995). WordNet is a lexical database management system that allows relationships between word senses to be examined. It allows synonyms, antonyms, hyponyms and hypernyms to be identified. The
meronym relationship can be extracted. The WordNet database is composed of a collection of synonym sets (synsets). Each synset is made up of a collection of synonymous word senses and a list of relational pointers. Each relational pointer is a word in another synset that is an antonym, hyponym, hypernym or meronym of this synset (Haines, 1995). These lexically constrained conceptual graphs (LCGs) can be seen as simplified variants of Sowa’s conceptual graphs (Guarino et al, 1999).

OntoSeek has been shown to be effective in improving web page retrieval accuracy and completeness (Guarino et al, 1999). However, OntoSeek currently requires the user to manually disambiguate polysemous terms when encoding or retrieving, and also requires the user to manually create LCGs using a visual tool. Further automation could be achieved in OntoSeek by applying current artificial intelligence and computational linguistic techniques.

9. An Ontology Based Sales Consultant’s Assistant (OSCA)

OSCA extends the OntoSeek system by enhancing the user interface to automate polysemy resolution and LCG construction using WSD and expert systems techniques. This will provide a more effective tool for sales consultants to match products with customer preferences.

OSCA is a system of co-operating software agents consisting of a sales consultant’s interface agent (CIA), a product (and destination) encoding agent (PEA), an Ontology Interface Agent (OIA), and a Resource Interface Agent (RIA) (Figure 3). All four agents use a shared domain ontology and a shared lexical database (WordNet) for encoding and retrieving web pages containing product information.

To operate effectively the system must address the problems of polysemy and synonymy. For example:

- recreational fishing is synonymous with angling. WordNet would represent this as a synset such as {fishing, angling}
- entrée is polysemous with main course, first course, entry and introduction. WordNet would represent this as 4 synsets such as {entrée, main course}, {entrée, first course}, (entrée, entry), {entrée, introduction}.

Synonymy can be easily addressed by using WordNet synsets. To minimise missed pages a search could be initiated for all words in the synset using a Boolean OR. This has the advantage that it will find all pages including those that have not been encoded with the agreed ontology terms. It is, however, rather inefficient. By including the agreed ontology term in the synset, and providing a way to identify the agreed term (underlining in the above examples), a search can be initiated for the agreed term only. By attaching an ontology identifier to the preferred term, different ontologies could use the one lexical database. WordNet will need to be modified to allow for this.

As discussed above, addressing the polysemy problem is much more difficult to automate. Determination of which meaning is the correct one can only be achieved through intelligent behaviour. OSCA’s PEA and CIA attempt to eliminate most of the manual encoding and query formulation by using WSD and simple rule-based expert system techniques. An initial set of basic rules (micro-rule base) will be built for each agent. Encoding and query formulation will be carried out automatically, if possible, using these rules and a very limited window of adjacent words (micro-context). Terms in the rule base will be based on word senses rather than specific words to address the problem of synonymy.
If the encoding and query formulation cannot be completed automatically, the agent will interact with the user to resolve the ambiguity. The information obtained from the user will then be used to modify the rule base. The performance of the automated query formulation and encoding will improve with usage.

To minimise the complexity of the rule base, the size of the domain must be limited. OSCA will be designed to operate in the Travel and Tourism domain only but will be able to be used in another domain if required by creating a new rule base and ontology.

To further reduce implementation complexity it is necessary to restrict vocabulary size, reduce description complexity, minimise description heterogeneity and increase query specificity (Guarino et al, 1999). To achieve this, OSCA borrows from WSD techniques (Oswald, 1952; Yarowsky, 1993) and the object oriented principles of inheritance and composition. A number of very restricted domains (micro-domains) and rule bases (micro-rule bases) that are sub-domains of a common super-domain will be used to simplify development and testing. Most polysemy can be resolved by choosing the appropriate micro-domain using high-level heuristics and user interaction. The rest is done automatically using the rule base. Selection of the appropriate micro-domain and micro-rule base will be achieved by higher-level heuristics that draw on the ontology to resolve polysemy.

Once tested the micro-domains and micro-rule bases can be consolidated to create larger domains and rule bases. Noy and Musen (1999) have developed SMART, an algorithm that aligns (or links) and merges two separate ontologies by examining class names and structure of relations within each ontology. As it is unrealistic to expect that all ontologies can be automatically linked, particularly at the semantic level, SMART adopts a hybrid approach where most of the linking is automated and other possible links are suggested to the user for her action. The use of micro-domain will ensure that a minimal amount of user intervention is required.

The most difficult issue is the automatic determination of relations (arcs in LCGs). Heuristics and rules that use ontologies to resolve the semantic ambiguities must be used. The number of possible options is limited by selectional constraints of the ontology therefore a rich ontology of relations is required even for small domains. Consequently the size of the domain must be kept as small as possible (micro-ontology) to minimise implementation complexity and cost. The agent then uses the micro-ontology to master the micro-domain by looking for generalisations or specialisations and building new rules from them.

A rudimentary learning mechanism will be built into the CIA to allow it to capture the consultant’s responses for future use. When new product web pages are created, the human product encoder uses the PEA to embed ontology information in the page using the agreed micro-domain ontologies. The data to be encoded is converted into an LCG by the PEA by referring to the modified WordNet database, the micro-ontology and micro-rule base.

If there is only one matching synset then the OIA returns it to the PEA which extracts the ontology term and uses it to replace the term supplied by the encoder. If there is more than one matching synset, the OIA returns them all to the PEA which applies any defined rules to resolve the polysemy. If there are no suitable rules defined, all the matching synsets are displayed to the encoder who must then select the most appropriate synset. The ontology term from the selected synset is then encoded into the web page. If no match is found, the PEA obtains more information from the product encoder until a match is found. If no match can be made, the encoder must send a request to the authority controlling the ontology to have a
new term added. If the addition of the new term is not approved, the page must be encoded using existing terms.

The validated LCG is then passed to the Resource Interface Agents (RIAs) that are registered as having committed to the ontology. The RIAs may be distributed, centralised or a combination of both. The resource interface agent determines how the encoded pages are stored and indexed. This could be by passing them to an ontology aware search engine for indexing, storing them and indexing them in a local database or by inserting XML code directly into the locally stored pages.

Encoding of some information could be automated but in most cases human intervention is required during the encoding process. This is particularly true for non-textual information such as images, sound and video clips. Existing pages can be encoded in a similar way.

OntoSeek decouples meta-data from the resource it describes and stores it in a central database. OSCA will embed LCGs into web pages using XML. This will allow retrieval using LCGs by ontology-aware search engines but it also provides the flexibility to allow retrieval by any search engine or resource agent that supports XML. It is also accessible to applications through an applications programming interface. The XML code will be automatically inserted by parsing LCGs from the common ontology.

Information retrieval is initiated by the CIA which obtains the customer preference information from the consultant and converts it into an LCG by referring to the modified WordNet database, the micro-ontology and micro-rule base. A similar process to encoding is followed to obtain the matching page references. The CIA is responsible for requesting information from the consultant until it is able to encode the request into a form that is consistent with the agreed ontology. For example, if the consultant requests a 3 star hotel, the CIA cannot determine what facilities are required without knowing the city and country of origin of the request. If this cannot be obtained from the persistent context database, the consultant must be asked to enter this information. The responses are then recorded against that consultant's user identifier for future reference. The ontology aware search engine requires no further information as both the web pages and consultant's requests have already been encoded into a consistent form.

OSCA is a system of co-operating software agents that uses agreed and committed ontologies, a shared lexical database and a dynamic rule base to minimise ambiguities thereby improving semantic matching of product characteristics to customer preferences. The design of the system assumes that the PEA and the CIA will require human intervention. As such, it is designed to assist consultants to efficiently access higher quality, more relevant information, not to replace them completely. The OntoSeek prototype will be used as a basis for the development of OSCA. The SMART algorithm will be used to link micro-ontologies. All agents will be implemented in Java 2.0 using an existing agent building system. Only standard Internet protocols and services will be used.

The primary challenges in implementing the OSCA system are:

- automating the product encoding and query formulation process
- Automating polysemy resolution and specification of relationships between terms
- developing a rule based expert system interface to resolve polysemy and to specify relationships between terms in a cost effective manner
- automatically consolidating micro-domains and micro-rule bases into larger higher-level domains and rule bases.
10. Contribution to Body of Knowledge

OSCA differs from most current intelligent agent based systems in that it is ontology based, thereby allowing ontology-driven semantic matching between queries and resource descriptions, not just matching of keywords. The primary difference between OSCA and other systems such as OntoSeek is that OSCA is targeted at the World Wide Web and uses resource description languages such as XML, OML or RDF to encode the ontology information directly into the web pages. The encoded pages carry the semantic description of their contents with them. Furthermore, the query and classification encoding processes are also separated and distributed in the OSCA system.

The OSCA PEA and CIA are Expert Interface Agents. They expect to interface to expert users, not naïve users, as is the case with most intelligent interface agent systems. This interactive assistance “increases flexibility for query formulation, generalization or specialization” (Guarino et al, 1999). They are also adaptive, context aware, and have basic learning capabilities. OSCA is therefore a hybrid between a traditional expert system and an intelligent interface agent.

OSCA will contribute to the body of knowledge by demonstrating the effectiveness of ontology-based semantic matching systems for matching customer preferences with product characteristics in complex domains. Furthermore, it will demonstrate the effectiveness of micro-domains and micro-rule bases for minimising implementation complexity of rule-based systems for automated resolution of polysemy.

A secondary contribution will come from the decision to use XML to encode semantic information into product web pages. This will demonstrate the effectiveness of XML for this purpose. While there are other alternatives to XML, XML was chosen because of its widespread support in commercially available products and its suitability for encoding structured data into web pages.

11. Limitations and future research

To minimise implementation complexity, and to address a recognised commercial problem, the system has been designed to meet the specific needs of retail sales consultants. This should not limit its use to this application and domain. However, the user interface would need to be re-built for the new application and new rule bases and ontologies would need to be constructed for the new domain.

As the system has not yet been constructed, its performance in the field has not yet been proven. Once a prototype has been constructed a controlled experiment will be carried out to identify any change in performance of travel sales consultants when using OSCA. Performance will be measured against the following criteria:

- Completeness of information retrieved
- Accuracy of information retrieved
- Correctness of advice provided
- Closeness of fit between customer preferences and product characteristics
- Time taken to make recommendation
- Cost of Sale
The performance tests will be restricted to a single activity and a single destination. An exotic and unusual activity that is unlikely to be familiar to the participating agents will be chosen, for example fly fishing for Bass in streams in Queensland. This will minimise the effects of variation in information availability and quality between activities and destinations.

An exotic and unusual activity that is unlikely to be familiar to the participating agents will be chosen.

**Reference**


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Figure 1. Shared conceptualisation using an ontology (Guarino 1998)

Figure 2. The OntoSeek Architecture
Figure 3. OSCA Architecture