

# WordNet 2 - A Morphologically and Semantically Enhanced Resource

<b>Sanda M. Harabagiu</b>	<b>George A. Miller</b>	<b>Dan I. Moldovan</b>
Department of Computer Science and Engineering Southern Methodist University Dallas, TX 75275-0122 sanda@seas smu edu	Cognitive Science Laboratory Princeton University 221 Nassau Street Princeton, NJ 08542 geo@clarity princeton edu	Department of Computer Science and Engineering Southern Methodist University Dallas, TX 75275-0122 moldovan@seas smu edu

## Abstract

This paper presents an on-going project intended to enhance WordNet morphologically and semantically. The motivation for this work stems from the current limitations of WordNet when used as a linguistic knowledge base. We envision a software tool that automatically parses the conceptual defining glosses, attributing part-of-speech tags and phrasal brackets. The nouns, verbs, adjectives and adverbs from every definition are then disambiguated and linked to the corresponding synsets. This increases the connectivity between synsets allowing the retrieval of topically related concepts. Furthermore, the tool transforms the glosses, first into logical forms and then into semantic forms. Using derivational morphology new links are added between the synsets.

## 1 Motivation

WordNet has already been recognized as a valuable resource in the human language technology and knowledge processing communities. Its applicability has been cited in more than 200 papers and systems have been implemented using WordNet. A WordNet bibliography is maintained at the University of Pennsylvania (<http://www.cis.upenn.edu/~josephn/wn-biblio.html>). In Europe, WordNet is being used to develop a multilingual database with basic semantic relations between words for several European languages (the EuroWordNet project).

**Capabilities** WordNet was conceived as a machine-readable dictionary, following psycholinguistic principles. Unlike standard alphabetical dictionaries which organize vocabularies using morpho-

logical similarities, WordNet structures lexical information in terms of word meanings. WordNet maps word forms in word senses using the syntactic category as a parameter. Although it covers only four parts of speech (nouns, verbs, adjectives and adverbs), it encompasses a large majority of English words (<http://www.cogsci.princeton.edu/~wn>).

Words of the same syntactic category that can be used to express the same meaning are grouped into a single synonym set, called *synset*. Words with multiple meanings (polysemous) belong to multiple synsets. An important part of the 99,643 synsets encoded in WordNet 1.6 contain word collocations, thus representing complex nominals (e.g. the synset {*manufacturer, maker, manufacturing business*}), complex verbals (e.g. the synset {*leave office, quit, step down*}), complex adjectivals (e.g. the synset {*true, dead on target*}) or complex adverbials (e.g. the synset {*out of hand, beyond control*}). The representation of collocations as synset entries provides for their semantic interpretation.

Words and concepts are further connected through a small set of lexico-semantic relations. The dominant semantic relation is the *hypernymy*, which structures the noun concepts in 11 hierarchies and the verb concepts into 512 hierarchies. Three meronym relations are encoded between noun concepts: the *has\_member*, the *has\_stuff* and the *has\_part* relations. Logical operations between events or entities are modeled through *entailment* and *cause\_to* relations between verb concepts or *antonymy* relations among nouns, verbs, adjectives or adverb words. There are only a few morphologically motivated connections between words known as *pertainym* relations.

**Limitations** The main weaknesses of WordNet cited in the literature are

1. The lack of connections between noun and verb hierarchies.

- 2 Limited number of connections between topically related words
- 3 The lack of morphological relations
- 4 The absence of thematic relations/ selectional restrictions
- 5 Some concepts (word senses) and relations are missing
- 6 Since glosses were written manually, sometimes there is a lack of uniformity and consistency in the definitions

The key idea in our project is to put to work the rich source of information contained in glosses that now can be used only by humans to read the definition of synsets. For example, WordNet 1.6 lists the concept {cat, true cat} with the gloss (feline mammal usually having thick soft fur and being unable to roar, domestic cats, wildcats). Currently, from a concept like this, only a few other concepts could be reached. In Extended WordNet, the concept {cat, true cat} will be related to 215 other concepts (10 from its own gloss, 38 from the glosses of its hypernyms, 25 concepts that use it in their glosses as a defining concept plus other 142 concepts with which the concept interacts in these 25 glosses). This level of information is rich enough to presume that the Extended WordNet will work well as a knowledge base for common-sense reasoning.

## 2 Related work

Machine Readable Dictionaries (MRDs) have long been recognized as valuable resources in computational linguistics. In their paper, Ide and Veronis (Ide and Veronis, 1993) projected a rather pessimistic outlook for the utility of MRDs as knowledge sources, a view that has impeded the enthusiasm of some researchers. (Wilks et al 1996) make a strong argument in favor of using MRDs and share their positive experience with using some dictionaries. The MindNet project at Microsoft aims at fully automating the development of a very large lexical knowledge base using two MRDs: the Longman Dictionary of Contemporary English (LDOCE) and the American Heritage Third Edition (AHD3). Many technical aspects of this project are rooted in the works of Vanderwende (Vanderwende 1996) and Richardson (Richardson 1997).

## 3 Word sense disambiguation of gloss concepts

There are several differences between gloss disambiguation and text disambiguation. A major difference is that in our project we know the meaning of

each gloss, namely the synset to which a gloss applies. Second, the glosses contain a definition, comments, and one or more examples.

We address the word sense disambiguation problem by using three complementary methods: (a) heuristics, (b) conceptual density, and (c) statistics on large corpora. The first two methods rely entirely on the information contained in WordNet, while the third one uses other corpora. Specifically, the sources of knowledge available to us are: (1) lexical information that includes part of speech, position of words (i.e. head word), and lexical relations; (2) collocations and syntactic patterns; (3) synset to which a gloss belongs; (4) hypernyms of synset and their glosses; (5) synsets of polysemous words and their glosses; (6) hypernyms of synsets of polysemous words, and their glosses, and so on.

### Method 1 Classes of heuristics for word sense disambiguation

A suitable technique for disambiguating dictionaries is to rely on heuristics able to cope with different sources of information. Work in this area was done by Ravin (Ravin 1990) in a similar project at IBM, (Klavans et al 1990), and others. We present now some of the heuristics used by us.

#### 1. Class: Hypernyms

A way of explaining a concept is to specialize a more general concept (i.e. a hypernym). It is likely that an explanation begins with a phrase whose head is one of its hypernyms, and the features are expressed either as attributes in the same phrase or as phrases attached to the first phrase.

*Example* The gloss of synset {intrusion} is (entrance by force or without permission or welcome).

- entrance#3, the head of the first phrase, is a hypernym of intrusion, thus we pick sense 3 of noun entrance. (The senses in WordNet are ranked according to their frequency of occurrence in the Brown corpus, entrance#3 means sense 3 of word entrance.)

#### 2 Class: Linguistic Parallelism

It is likely that the syntactic parallelism of two words translates into semantic parallelism and the words may have a common hypernym, or one is a hypernym of the other. For adjectives, the hypernymy is replaced by the similarity relation. Other heuristics in this class check whether or not two polysemous words belong to the same synset, or one is a hypernym of the other, or if they belong to the same hierarchy.

*Example* The gloss of {interaction} is (a mutual or reciprocal action).

- Adjective *reciprocal* has only one sense in WordNet 1.6, whereas *mutual* has two senses. But we find that between sense 2 of *mutual* and *reciprocal* there is a *similar* link in WordNet 1.6, thus pick *mutual#2*.

### 3. Class. Gloss Comments.

In glosses, comments and examples are meant to provide supplemental information. It is possible to find the specialization or typical relation linking the comment to the preceding head phrase in one of the synsets (or gloss) of the head phrase.

*Example* The gloss of the synset {*scuff*, *scuffing*} is (the act of scuffing (scraping or dragging the feet)).

- In WordNet 1.6 there is a synset {*scuff#1*, *drag*}, thus verb *scuff* is disambiguated.

### 4 Class. Gloss Examples

Examples in WordNet provide collocational information of the words in synsets. The intrinsic semantic tag of the word from the synset which is used in the example can occur in the same lexical relation in some other gloss, carrying the semantic tag with it.

*Example* Synset {*penetration*} has the gloss (the act of forcing a way into something).

- $[w_1rw_2] = [\text{force way}]$ . The gloss of {*way#9*} contains the example (“I had it my way”), providing the lexical relation  $[w_3rw_2] = [\text{have way}]$ .

- Noun *way* is disambiguated (sense 9), and verbs *have#7* and *force#9* have a common hypernym, therefore verb *force* is also disambiguated.

### 5 Class Collocations

Nouns representing actions are nominalizations of some verbs. If a verbal collocation contains a noun, and is also a synonym of some morphologically related verb, then it is likely to be the nominalization source. The verb from the gloss of a synonym describing an action, if not the source of the nominalization, is likely to belong to the same hierarchy as the true nominalization source, since they must share some properties.

*Example* Let  $s = \{\text{escape, flight}\}$ , with the gloss (the act of escaping physically).

- The verb *escape* is morphologically identical to the noun *escape* from synset  $s$ .

- Sense 1 of verb *escape* has a hypernym collocation using noun *flight* from  $s$ , thus is selected.

### 6 Class Lexical Relations

A lexical relation using a word  $w$  both in the gloss of a synset  $s$  and in some other gloss signals a property of  $w$  associated with  $s$ . In other cases when two relations  $[w_i, w_j]$  and  $[w_i, w_k]$  are found in two glosses of WordNet, and there are senses of  $w_j$  and  $w_k$  that

have a common hypernym, it is likely that the correlation between  $w_i$  and the common hypernym is projected in both collocations.

*Example* The gloss of the synset {*Underground Railroad*} is (abolitionists secret aid to escaping slaves).

- We have  $[w_1rw_2] = [\text{aid to slave}]$
- The gloss of {*aid#4*} is (aid to someone)
- The pronoun *someone* can refer to {*slave#1*} thus sense 4 of noun *aid* is picked.

### Method 2 Conceptual density method

We have implemented a WSD system for free text that disambiguates multiple words simultaneously (Mihalcea and Moldovan, 1999). The method is based on measuring the number of common nouns shared by the verb and noun hierarchies, and thus gets around the lack of connections problem. As an example, consider a verb - noun pair of words. Denote with  $\langle v_1, v_2, \dots, v_h \rangle$  and  $\langle n_1, n_2, \dots, n_l \rangle$  the senses of the verb and the noun in WordNet. For each possible pair  $v_i - n_j$ , the *conceptual density* is computed as follows:

1. Extract all the glosses from the sub-hierarchy of  $v_i$  and determine the nouns from these glosses. This constitutes the noun-context of verb  $v_i$ . Each such noun is stored together with a weight  $w$  that indicates the level in the sub-hierarchy of the verb concept in whose gloss the noun was found.

2. Determine the glosses of the noun sub-hierarchy of  $n_j$  and determine the nouns in them.

3. Compute the *conceptual density*  $C_{ij}$  of the common concepts between the nouns obtained at (1) and the nouns obtained at (2) using the metric

$$C_{ij} = \frac{\sum_k^{|\text{cd}_{ij}|} w_k}{\log(\text{descendents}_j)} \quad (1)$$

where,

- $|\text{cd}_{ij}|$  is the number of common concepts between the hierarchies of  $v_i$  and  $n_j$ ,
- $w_k$  are the levels of the nouns in the hierarchy of verb  $v_i$ ,
- $\text{descendents}_j$  is the total number of words within the hierarchy of noun  $n_j$ .

4.  $C_{ij}$  ranks each pair  $v_i - n_j$ , for all  $i$  and  $j$ . Variants of this method work for other parts of speech pairs such as noun-noun, noun-verb, verb-verb, verb-noun, adjective-noun and verb-adverb. This is a powerful method that works surprisingly well even for free text. We have tested the method on SemCor, the part of the Brown corpus tagged with WordNet senses. With this technique it is possible to rank the senses and to keep not only the first ranked sense, but the second or third ranked senses.

especially when the ranking is sufficiently close and there is another way to check the validity of the disambiguation

### Method 3 Statistics on large corpora

As a last resort, we can use a statistical approach to disambiguate those words that can not be done with any of the methods described so far. Consider a collocating word-word pair  $w_1 - w_2$  in which we consider that  $w_1$  has been disambiguated already. The disambiguation of  $w_2$  proceeds as follows:

(1) For each sense  $w_2^i$ , form a similarity list with  $w_2^i$  and all other words that may be in that synset

$\{w_2^i, w_2^{i(1)}, w_2^{i(2)}\}$

(2) Form pairs of  $w_1$  and all the words in each similarity list for all  $i$

$\{w_1 - w_2^i, w_1 - w_2^{i(1)}, w_1 - w_2^{i(2)}\}$

(3) Search a large corpus for the occurrences of any of the pairs in the list above

$\{w_1 w_2^i \text{ OR } 'w_1 w_2^{i(1)}' \text{ OR } 'w_1 w_2^{i(2)}'\}$

We have searched the Internet using the AltaVista search engine. The number of hits for each similarity list measures the relatedness of  $w_1$  with each sense  $w_2^i$  and thus provides a ranking of the senses.

### Overall Procedure and Results

The following procedure was used to disambiguate 12,762 words from 1000 randomly selected glosses.

**Step 1** Identify and separate the monosemous words - that have only one sense in WordNet (in our experiment 6468 words were found)

**Step 2** Apply Method 1 - Heuristics - to the remaining 6294 polysemous words. Method 1 provides correct disambiguation for 5475 words, thus an accuracy of 87%. Out of the remaining 13% of the words, 3% were disambiguated erroneously and 10% could not be done with the heuristics used. The correct sense for each word was determined manually by a team of three students. We have found a few synsets such as {commemorate, remember} that have no links to any other synsets, ie no hypernyms and no hyponyms.

**Step 3** Apply Method 2 - Conceptual Density - to the 6294 polysemous words, starting fresh.

**Step 4** Apply Method 3 - Statistics - to the 6294 words using AltaVista on the Internet.

**Step 5** The results obtained with Method 1 and Method 2 are combined, that is, take all the words that were disambiguated, and in the case of conflict give priority to Method 1.

**Step 6** The results from Step 5 are combined with the results given by Method 3 and in the case of conflict give priority to results obtained in Step 5.

Table 1 indicates the accuracy obtained at each step. An overall accuracy of 94% was achieved. Our

goal is to improve the technique to be able to disambiguate all words automatically.

These results must be seen against the background average rate of 59.39% correct sense assignment achieved when the first WordNet sense is assigned to each polysemous word. This is considered the baseline performance level for word-sense disambiguation programs (Gale et al 1992) and is consistent with our own measurements.

## 4 Logical form transformation

Our extension of WordNet intends to serve as a lexico-semantic resource for a variety of NLP applications, many of them requiring pragmatic and common-sense knowledge (Harabagu and Moldovan 1998). It is beneficial to transform the conceptual glosses in logical formulae.

### Approach to implement Logical Form Transformations (LFTs)

(1) Traditional lexicographic principles determine the discrimination of any conceptual definitions into a *genus* and the *differentia*. Our LFTs implement the same distinction by always placing the genus predicate on the first position of the LFT, and the rest of the LFT viewed as the definition *differentia*.

(2) A predicate is generated for every noun, verb, adjective or adverb encountered in any gloss. The name of the predicate is a concatenation of the morpheme's base form, the part-of-speech and the WordNet semantic sense, thus capturing the full lexical and semantic disambiguation. For example, the LFT of the gloss of {student, pupil, educatee} contains the predicates learner n#1, enroll v#1 and educational\_institution n#1.

(3) In the spirit of the Davidsonian treatment of the action predicates, all verb predicates (as well as the nominalizations representing actions, events or states) have three arguments: action/state/event-predicate( $e, x_1^i, x_2^j$ ), where

- $e, i$  represents the *eventuality* of the action, state or event  $i$  stated by the verb to take place,
- $x_1^i$  represents the *syntactic subject* of the action event or state, and
- $x_2^j$  represents the *syntactic object* of the action event or state.

In the case when the subject or the object are present in the gloss, they share the corresponding arguments with the action/state/event predicate. For example, the LFT of (a person who backs a politician) the gloss of {supporter, protagonist, champion, admirer, booster, friend} is LFT = [person n#1( $x_1$ ) & back v#1( $e_1, x_1, x_2$ ) & politician n#2( $x_2$ ) ]

	Method 1 (Step 2)	Method 2 (Step 3)	Method 3 (Step 4)	(M1) $\cup$ M2 (Step 5)	((M1) $\cup$ M2) $\cup$ M3 (Step 6)
Accuracy	87	80	68	92	94

Table 1 Summary of results in % for the disambiguation of 1000 glosses

(4) The role of complements within a phrase is replicated in the LFTs. Predicates generated from modifiers share the same arguments with the predicates corresponding to the phrase heads. Adjective predicates share the same argument as the predicate corresponding to the noun they modify. An exemplification is the LFT of the gloss of {artifact, artefact}, which maps (a man-made object) into [ object  $n\#1(x_1)$  & man-made  $a\#1(x_1)$  ]. Similarly, the argument of adverbial predicate is the argument marking the eventuality of the event/state/action they modify. For example, the gloss of the verb synset {hare} is (run quickly), producing the LFT = [run( $e_1, x_1, x_2$ ) & quickly( $e_1$ )]

(5) Conjunctions are transformed in predicates, which enable the aggregation of several predicates under the same syntactic role (e.g. subject, object or prepositional object). By convention, conjunction-predicates have a variable number of arguments, since they cover a variable number of predicates. The first argument represents the "result" of the logical operation induced by the conjunction (e.g. a logical *and* in the case of the and conjunction, or a logical *or* in the case of the or conjunction). The rest of the arguments indicate the predicates covered by the conjunction, as they are arguments of those predicates as well.

(6) We also generate predicates for every preposition encountered in the gloss. The preposition predicates always have two arguments: the first argument corresponding to the predicate of the head of the phrase to which prepositional phrase is attached, whereas the second argument corresponds to the prepositional object.

**Sources of information.** The implementation of LFTs relies on information provided by

- (a) Lexical and semantic disambiguation produced in the preprocessing and semantic disambiguation phases. This information contributes to the creation of predicate names.
- (b) Phrasal parsing, enabling the recognition of basic and complex phrases. This determines all complements to share the same predicate argument with the phrase head.
- (c) Syntactic transformation rules, discriminating the syntactic subject and object of every verb (or nominalization) based on the local syntactic context.

(d) Prepositional attachment resolution, indicating the arguments of the preposition predicates.

Table 2 illustrates the transformations for the gloss of {tennis, lawn tennis}.

## 5 Semantic form transformation

Many NLP problems rely on the recognition of the typical lexico-semantic relationships between linguistic concepts. The LFT codification merely acknowledges the following syntax-based relationships: (1) syntactic subjects, (2) syntactic objects, (3) prepositional attachments, (4) complex nominals and (5) adjectival/adverbial adjuncts. Semantic interpretations of utterances, as well as discourse processing, require knowledge about the semantic or thematic relationships between concepts. The *semantic form transformations* provide with constraint-based mappings of the syntax-based relations covered in the LFTs into binary thematic relations or semantic relations. (We distinguish between thematic relations such as *agent*, *experiencer*, etc., and semantic relations such as *a-kind-of*, *part-of*, etc.)

### Approach to implement Semantic Form Transformations (SFTs)

1. The *syntactic subject* relations recognized in the LFTs by the predicative formula  $\text{subject}(x_1) \& \text{verb}(e, x_1, x_2)$  can be mapped into a variety of thematic relations. The definition of the thematic relations is entirely based on information internal to the WordNet database, expressed as constraints. For example, all the subjects of verbs that are hyponyms of the verb *cause* or have this concept as the genus of their glosses are defined to represent the role of *agents*.

(2) The *syntactic object* relations are recognized in the LFTs by the predicative formula  $\text{verb}(e_1, x_1, x_2) \& \text{noun}(x_2)$ . The definition of the thematic relations in which syntactic objects can be mapped is expressed in terms of verb synsets. The constraining verb synsets represent the upper-most hypernyms of all verbs that (i) have syntactic objects in the WordNet glosses and (ii) belong to the same hierarchy or are defined by gloss *geni* from the same hierarchy.

(3) The *prepositional predicates* are transformed into thematic or semantic relations. When a Word-

Gloss	(a game played with rackets by two or four players who hit a ball back and forth over a net that divides a tennis court)
LFT	game n#2(x <sub>2</sub> ) & play v#2(e <sub>1</sub> ,x <sub>1</sub> ,x <sub>2</sub> ) & with(e <sub>1</sub> ,x <sub>3</sub> ) & racket n#4(x <sub>3</sub> ) & by(e <sub>1</sub> ,x <sub>1</sub> ) & or(x <sub>1</sub> ,x <sub>3</sub> ,x <sub>4</sub> ) & two n#1(x <sub>3</sub> ) & four n#1(x <sub>4</sub> ) & player n#1(x <sub>1</sub> ) & hit v#1(e <sub>2</sub> ,x <sub>1</sub> ,x <sub>5</sub> ) & ball n#1(x <sub>5</sub> ) & back.and.forth r#1(e <sub>2</sub> ) & over(e <sub>2</sub> ,x <sub>6</sub> ) & net n#5(x <sub>6</sub> ) & divide v#5(e <sub>3</sub> ,x <sub>6</sub> ,x <sub>7</sub> ) & tennis.court n#1(x <sub>7</sub> )
SFT	<i>gloss</i> (tennis n#1,game n#2) <i>object</i> (game n#2,play v#2) <i>agent</i> (player n#1,play v#2) <i>attribute</i> (or(two n#1,four n#1),player n#1) <i>agent</i> (player n#1,hit v#1) <i>object</i> (ball n#1,hit v#1) <i>location</i> (net n#5,hit v#1) <i>agent</i> (net n#5,divide v#5) <i>object</i> (tennis.court n#1,divide v#5)

Table 2 Transformations associated with the gloss of synset {tennis, lawn tennis} (a game played with rackets by two or four players who hit a ball back and forth over a net that divides a tennis court)

Net semantic relation holds between the arguments of a prepositional predicate, that specific relation becomes the semantic transformation of the predicate. For example, the PP attachment [sacrament of penance] derived from the gloss of {confession} indicates a semantic *kind-of* relation due to the fact that in WordNet penance is a hyponym of sacrament.

(4) The transformation of *complex nominal predicates* into thematic or semantic constraints is done by first seeking a WordNet relation (or a combination of such relations) between the components of the predicate. If such a (chain of) relation(s) is found, predicate nn is transformed into the dominant WordNet semantic relation. Otherwise, the nn predicate is transformed into a thematic relation.

(5) The transformation of *adjectival and adverbial adjuncts*, represented in the LFTs as predicates sharing the same argument with the concepts they modify shall be connected to their modifiers through *attribute* relations.

## 6 Include more derivational morphology

Since the organization of WordNet divides the English vocabulary into four separate domains—nouns, verbs, adjectives, and adverbs—closely related concepts are often entered in more than one of these domains. Many (probably most) of these relations can be identified in terms of derivational morphology, e.g., the noun *execution* is derived from the verb *execute* and so is an example of a deverbal noun. WordNet already contains some of this kind of derivational morphology: deadjectival nouns are linked to their root adjectives (*length* is derived from *long*), deadjectival adverbs are linked to their root adjectives (*rapidly* is derived from *rapid*), and some denominal adjectives are linked to their root nouns (*cellular* is derived from *cell*).

In order to increase the connectivity of WordNet it would be desirable to include more such deriva-

tional morphology. For example, derivational relations between nouns and verbs should be particularly useful (Hull and Gomez 1996) both deverbal nouns (*avowal* from *avow*) and denominal verbs (*summarize* from *summary*). Such connections would facilitate the recognition that the same idea can be expressed in different ways, e.g., that "He summarized the book" and "He gave a summary of the book" are effectively equivalent in meaning. Sometimes these morphological relations can be picked up from glosses, as when {*disagreement*} is defined as (the speech act of *disagreeing* or *arguing* or *disputing*), but these are generally regarded as uninformative definitions, and the reverse relation may not happen to occur.

Since many of the words are polysemous, morphological relations should not link words, but synsets that have related meanings. For example, {*execute*} meaning (to put to death) should be linked to {*execution*} meaning (the act of putting a condemned person to death), and {*execute*} meaning (to carry out a task) should be linked to {*execution*} meaning (the act of doing something successfully), etc. And in cases where the concepts of the noun and verb are different—e.g., {*womanize*} from {*woman*}—no semantic link would need to be created.

## References

- H Alshawi. Analysis the dictionary definitions. In B Boguraev and T Biscoe, editors, *Computational Lexicography for Natural Language Processing*, pages 153-170. Longman, London, 1989.
- R Bruce and L Guthrie. Genus disambiguation: a study in weighted preference. In *Proceedings of COLING92*, COLING92, pp 1187-1191.
- W Gale, K W Church and D Yarowsky. Estimating upper and lower bounds on the performance of word-sense disambiguation programs. In *Proceedings of the 30th Annual Meeting of the Asso-*

- ciation for Computational Linguistics*, Newark , Delaware, 1992
- S M Harabagiu and D I Moldovan A Parallel Inference System In *IEEE Transaction on Parallel and Distributed System*, Aug 1998, pp 729-747
- R D Hull and F Gomez Semantic interpretation of nominalizations In *Proceedings of the 13th National Conference on Artificial Intelligence AAAI-96*, Portland, OR, 1996
- N Ide and J Veronis Extracting knowledge bases from machine-readable dictionaries have we wasted our time? In *KB & KS*, Tokyo, Japan, Dec 1993
- J Klavans, M Chodorow and N Wacholder From dictionary to knowledge base via taxonomy In *Electronic Text Research*, University of Waterloo, Center for the New OED and Text Research, Waterloo, Canada, pages 110-132, 1990
- R Mihalcea and D I Moldovan A Method for Word Sense Disambiguation of Unrestricted Text In *Proceedings of the 37th Annual Meeting of the ACL*, June 1999
- S Montemagni and L Vanderwende Structural Patterns vs string patterns for extracting semantic information from dictionaries In *Proceedings of COLING92*, COLING '92, pp 546-552
- Y Ravin Disambiguating and interpreting verb definitions In *Proceedings of the 28th Annual Meeting of the Association for Computational Linguistics*, Pittsburgh, PA, pages 260-267, 1990
- S Richardson Determining similarity and inferring relations in a lexical knowledge base In *PhD dissertation*, City University of New York, 1997
- L Vanderwende The Analysis of Noun Sequences using Semantic Information Extracted from On-Line Dictionaries In *Ph D dissertation*, George Washington University, Washington D C , 1996
- Y A Wilks, B M Slator, and L M Guthrie Electric words dictionaries, computers and meaning In *MIT Press*, 1996

