

A Design Methodology for a Biomedical Literature Indexing Tool Using the Rhetoric of Science

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Abstract

Literature indexing tools provide researchers with a means to navigate through the network of scholarly scientific articles in a subject domain. We propose that more effective indexing tools may be designed using the links between articles provided by citations.

With the explosion in the amount of scientific literature and with the advent of artifacts requiring more sophisticated indexing, a means to provide more information about the citation relation in order to give more intelligent control to the navigation process is warranted. In order to navigate a citation index in this more sophisticated manner, the citation index must provide not only the citation-link information, but also must indicate the function of the citation. The design methodology of an indexing tool for scholarly biomedical literature which uses the rhetorical context surrounding the citation to provide the citation function is presented. In particular, we discuss how the scientific method is reflected in scientific writing and how this knowledge can be used to decide the purpose of a citation.

within a research field by linking together works whose methods and results are in some way mutually relevant. Customarily, authors include citations in their papers to indicate works that are foundational in their field, background for their own work, or representative of complementary or contradictory research. Another researcher may then use the presence of citations to locate articles she needs to know about when entering a new field or to read in order to keep track of progress in a field where she is already well-established. But, with the explosion in the amount of scientific literature, a means to provide more information in order to give more intelligent control to the navigation process is warranted. A user normally wants to navigate more purposefully than “Find all articles citing a source article”. Rather, the user may wish to know whether other experiments have used similar techniques to those used in the source article, or whether other works have reported conflicting experimental results. In order to navigate a citation index in this more-sophisticated manner, the citation index must contain not only the citation-link information, but also must indicate the function of the citation in the citing article.

The goal of our research project is the design and implementation of an indexing tool for scholarly biomedical literature which uses the text surrounding the citation to provide information about the binary relation between the two papers connected by a citation. In particular, we are interested in how the scientific method structures the way in which ideas, results, theories, etc. are presented in scientific writing and how the style of presentation indicates the purpose of citations, that is, what is the relationship between the cited and citing papers.

Our interest in the connection between scientific literature (our focus), ontologies, and databases is that the content and structure of each of these three repositories of scientific knowledge has its foundations in the method of science. Our purpose here is twofold: to make explicit our design methodology for an indexing tool that uses

1 Introduction

1.1 The aim of citation indexing

Indexing tools, such as CiteSeer (Bollacker et al., 1999), play an important role in the scientific endeavour by providing researchers with a means to navigate through the network of scholarly scientific papers using the connections provided by citations. Citations relate articles

the rhetoric of science as its foundation to see whether the ideas that underly our methodology can cross-fertilize the enquiry into the other two areas, and to discuss the tool itself with the purpose of making known that there exists a working tool which can assist the development of other projects.

A *citation* may be formally defined as a portion of a sentence in a citing document which references another document or a set of other documents collectively. For example, in sentence 1 below, there are two citations: the first citation is *Although the 3-D structure... progress*, with the set of references (Eger et al., 1994; Kelly, 1994); the second citation is *it was shown... submasses* with the single reference (Coughlan et al., 1986).

- (1) Although the 3-D structure analysis by x-ray crystallography is still in progress (Eger et al., 1994; Kelly, 1994), it was shown by electron microscopy that XO consists of three submasses (Coughlan et al., 1986).

A *citation index* enables efficient retrieval of documents from a large collection—a citation index consists of source items and their corresponding lists of bibliographic descriptions of citing works. The use of citation indexing of scientific articles was invented by Dr. Eugene Garfield in the 1950s as a result of studies on problems of medical information retrieval and indexing of biomedical literature. Dr. Garfield later founded the Institute for Scientific Information (ISI), whose Science Citation Index (Garfield, no date) is now one of the most popular citation indexes. Recently, with the advent of digital libraries, Web-based indexing systems have begun to appear (e.g., ISI's 'Web of Knowledge', CiteSeer (Bollacker et al., 1999)).

Authors of scientific papers normally include citations in their papers to indicate works that are connected in an important way to their paper. Thus, a citation connecting the source document and a citing document serves one of many functions. For example, one function is that the citing work gives some form of credit to the work reported in the source article. Another function is to criticize previous work. Other functions include foundational works in their field, background for their own work, works which are representative of complementary or contradictory research.

The aim of citation analysis studies has been to categorize and, ultimately, to classify the function of scientific citations automatically. Many citation classification schemes have been developed, with great variance in the number and nature of categories used. Garfield (1965) was the first to define a classification scheme, while Finney (1979) was the first to suggest that a citation classifier could be automated. Other classification schemes include those by Cole (1975), Duncan, Anderson, and

McAleese (1981), Frost (1979), Lipetz (1965), Moravcsik and Murugesan (1975), Peritz (1983), Small (1978), Spiegel-Rösing (1977), and Weinstock (1971). Within this representative group of classification schemes, the number of categories ranges from four to 26. Examples of these categories include a *contrastive*, *supportive*, or *corrective* relationship between citing and cited works. But, the author's purpose for including a citation is not apparent in the citation per se. Determining the nature of the exact relationship between a citing and cited paper, often requires some level of understanding the text that the citation is embedded in.

1.2 Citation indexing in biomedical literature analysis

In the biomedical field, we believe that the usefulness of automated citation classification in literature indexing can be found in both the larger context of managing entire databases of scientific articles or for specific information-extraction problems. On the larger scale, database curators need accurate and efficient methods for building new collections by retrieving articles on the same topic from huge general databases. Simple systems (e.g., (Andrade and Valencia, 1998), (Marcotte et al., 2001)) consider only keyword frequencies in measuring article similarity. More-sophisticated systems, such as the Neighbors utility (Wilbur and Coffee, 1994), may be able to locate articles that appear to be related in *some* way (e.g., finding related Medline abstracts for a set of protein names (Blaschke et al., 1999)), but the lack of specific information about the nature and validity of the relationship between articles may still make the resulting collection a less-than-ideal resource for subsequent analysis. Citation classification to indicate the nature of the relationships between articles in a database would make the task of building collections of related articles both easier and more accurate. And, the existence of additional knowledge about the nature of the linkages between articles would greatly enhance navigation among a space of documents to retrieve meaningful information about the related content.

A specific problem in information extraction that may benefit from the use of citation categorization involves mining the literature for protein-protein interactions (e.g., (Blaschke et al., 1999), (Marcotte et al., 2001), (Thomas et al., 2000)). Currently, even the most-sophisticated systems are not yet capable of dealing with all the difficult problems of resolving ambiguities and detecting hidden knowledge. For example, Blaschke et al.'s system (1999) is able to handle fairly complex problems in detecting protein-protein interactions, including constructing the network of protein interactions in cell-cycle control, but important implicit knowledge is not recognized. In the case of cell-cycle analysis for *Drosophila*, their system is able to determine that relationships exist between **Cak**,

Cdk7, CycH, and Cdk2: **Cak** inhibits/phosphorylates **Cdk7**, **Cak** activates/phosphorylates **Cdk2**, **Cdk7** phosphorylates **Cdk2**, **CycH** phosphorylates **Cak** and **CycH** phosphorylates **Cdk2**. However, the system is not able to detect that **Cak** is actually a complex formed by **Cdk7** and **CycH**, and that the **Cak** complex regulates **Cdk2**. While the earlier literature describes inter-relationships among these proteins, the recognition of the generalization in their structure, i.e., that these proteins are part of a complex, is contained only in more-recent articles: “There is an element of generalization implicit in later publications, embodying previous, more dispersed findings. A clear improvement here would be the generation of associated weights for texts according to their level of generality” (Blaschke et al., 1999). Citation categorization could provide just these kind of ‘ancestral’ relationships between articles—whether an article is foundational in the field or builds directly on closely related work—and, if automated, could be used in forming collections of articles for study that are labelled with explicit semantic and rhetorical links to one another. Such collections of semantically linked articles might then be used as ‘thematic’ document clusters (cf. Wilbur (2002)) to elicit much more meaningful information from documents known to be closely related.

An added benefit of having citation categories available in text corpora used for studies such as extracting protein-protein interactions is that more, and more-meaningful, information may be obtained. In a potential application, Blaschke et al. (1999) noted that they were able to discover many more protein-protein interactions when including in the corpus those articles found to be related by the Neighbors facility (Wilbur and Coffee, 1994) (285 versus only 28 when relevant protein names alone were used in building the corpus). Lastly, very difficult problems in scientific and biomedical information extraction that involve aspects of deep-linguistic meaning may be resolved through the availability of citation categorization in curated texts: synonym detection, for example, may be enhanced if different names for the same entity occur in articles that can be recognized as being closely related in the scientific research process.

2 Our Guiding Principles

2.1 Scientific writing and the rhetoric of science

The automated labelling of citations with a specific citation function requires an analysis of the linguistic features in the text surrounding the citation, coupled with a knowledge of the author’s pragmatic intent in placing the citation at that point in the text. The author’s purpose for including citations in a research article reflects the fact that researchers wish to communicate their results to their scientific community in such a way that their re-

sults, or *knowledge claims*, become accepted as part of the body of scientific knowledge. This persuasive nature of the scientific research article, how it contributes to making and justifying a knowledge claim, is recognized as the defining property of scientific writing by rhetoricians of science, e.g., (Gross, 1996), (Gross et al., 2002), (Hyland, 1998), (Myers, 1991). Style (lexical and syntactic choice), presentation (organization of the text and display of the data), and argumentation structure are noted as the rhetorical means by which authors build a convincing case for their results.

Our approach to automated citation classification is based on the detection of fine-grained linguistics cues in scientific articles that help to communicate these rhetorical stances and thereby map to the pragmatic purpose of citations. As part of our overall research methodology, our goal is to map the various types of pragmatic cues in scientific articles to rhetorical meaning. Our previous work has described the importance of *discourse cues* in enhancing inter-article cohesion signalled by citation usage (Mercer and Di Marco, 2003), (Di Marco and Mercer, 2003). We have also been investigating another class of pragmatic cues, *hedging cues*, (Mercer, Di Marco, and Kroon, 2004), that are deeply involved in creating the pragmatic effects that contribute to the author’s knowledge claim by linking together a mutually supportive network of researchers within a scientific community.

2.2 Results of our previous studies

In our preliminary study (Mercer and Di Marco, 2003), we analyzed the frequency of the cue phrases from (Marcu, 1997) in a set of scholarly scientific articles. We reported strong evidence that these cue phrases are used in the citation sentences and the surrounding text with the same frequency as in the article as a whole. In subsequent work (Di Marco and Mercer, 2003), we analyzed the same dataset of articles to begin to catalogue the fine-grained discourse cues that exist in citation contexts. This study confirmed that authors do indeed have a rich set of linguistic and non-linguistic methods to establish discourse cues in citation contexts.

Another type of linguistic cue that we are studying is related to hedging effects in scientific writing that are used by an author to modify the affect of a ‘knowledge claim’. Hedging in scientific writing has been extensively studied by Hyland (1998), including cataloging the pragmatic functions of the various types of hedging cues. As Hyland (1998) explains, “[Hedging] has subsequently been applied to the linguistic devices used to qualify a speaker’s confidence in the truth of a proposition, the kind of caveats like *I think*, *perhaps*, *might*, and *maybe* which we routinely add to our statements to avoid commitment to categorical assertions. Hedges therefore express tentativeness and possibility in communication, and their ap-

appropriate use in scientific discourse is critical (p. 1)”.

The following examples illustrate some of the ways in which hedging may be used to deliberately convey an attitude of uncertainty or qualification. In the first example, the use of the verb *suggested* hints at the author’s hesitancy to declare the absolute certainty of the claim:

- (2) The functional significance of this modulation is suggested by the reported inhibition of MeSo-induced differentiation in mouse erythroleukemia cells constitutively expressing c-myb.

In the second example, the syntactic structure of the sentence, a fronted adverbial clause, emphasizes the effect of qualification through the rhetorical cue *Although*. The subsequent phrase, *a certain degree*, is a lexical modifier that also serves to limit the scope of the result:

- (3) Although many neuroblastoma cell lines show a certain degree of heterogeneity in terms of neurotransmitter expression and differentiative potential, each cell has a prevalent behavior in response to differentiation inducers.

In Mercer (2004), we showed that the hedging cues proposed by Hyland occur more frequently in citation contexts than in the text as a whole. With this information we conjecture that hedging cues are an important aspect of the rhetorical relations found in citation contexts and that the pragmatics of hedges may help in determining the purpose of citations.

We investigated this hypothesis by doing a frequency analysis of hedging cues in citation contexts in a corpus of 985 biology articles. We obtained statistically significant results (summarized in Table 1 indicating that hedging is used more frequently in citation contexts than the text as a whole. Given the presumption that writers make stylistic and rhetorical choices purposefully, we propose that we have further evidence that connections between fine-grained linguistic cues and rhetorical relations exist in citation contexts.

Table 1 shows the proportions of the various types of sentences that contain hedging cues, broken down by hedging-cue category (verb or nonverb cues), according to the different sections in the articles (background, methods, results and discussion, conclusions). For all but one combination, citation sentences are more likely to contain hedging cues than would be expected from the overall frequency of hedge sentences ($p \leq .01$). Citation ‘window’ sentences (i.e., sentences in the text close to a citation) generally are also significantly ($p \leq .01$) more likely to contain hedging cues than expected, though for certain combinations (methods, verbs and nonverbs; res+disc, verbs) the difference was not significant.

Tables 2, 3, and 4 summarize the occurrence of hedging cues in citation ‘contexts’ (a citation sentence and the

surrounding citation window). Table 5 shows the proportion of hedge sentences that either contain a citation, or fall within a citation window; Table 5 suggests (last 3-column column) that the proportion of hedge sentences containing citations or being part of citation windows is at least as great as what would be expected just by the distribution of citation sentences and citation windows.

Table 1 indicates (statistically significant) that in most cases the proportion of hedge sentences in the citation contexts is greater than what would be expected by the distribution of hedge sentences. Taken together, these conditional probabilities support the conjecture that hedging cues and citation contexts correlate strongly. Hyland (1998) has catalogued a variety of pragmatic uses of hedging cues, so it is reasonable to speculate that these uses can be mapped to the rhetorical meaning of the text surrounding a citation, and from thence to the function of the citation.

3 Our Design Methodology

The indexing tool that we are designing is an enhanced citation index. The feature that we are adding to a standard citation index is the function of each citation, that is, given an agreed-upon set of citation functions, we want our tool to be able to automatically categorize a citation into one of these functional categories. To accomplish this automatic categorization we are using a decision tree—currently, we are building the decision tree by hand, but in future we intend to investigate machine learning techniques to induce a tree. Our aim is to have a working indexing tool whenever we add more knowledge to the categorization process. This goal appears very feasible given our design methodology choice of using a decision tree: adding more knowledge only refines the decision-making procedure of the previously working version.

Two factors influence the development of the tree as follows:

- The granularity of the citation categories determines how many leaves are in the decision tree; and
- The number of features that can be used to determine the category of a citation determines the potential depth of the tree.

In earlier work, Garzone and Mercer ((Garzone, 1996), (Garzone and Mercer, 2000)) proposed a citation classification scheme that, with 35 categories, was both more comprehensive than the union of all of the previous schemes and also amenable to implementation in an automated citation classifier. We use this categorization in the citation classifiers, but a finer or coarser granularity is obviously permitted.

Table 1: Proportion of sentences containing hedging cues, by type of sentence and hedging cue category.

	Verb Cues			Nonverb Cues			All Cues		
	Cite	Wind	All	Cite	Wind	All	Cite	Wind	All
background	0.15	0.11	0.13	0.13	0.13	0.12	0.25	0.22	0.24
methods	0.09	0.06	0.06	0.05	0.04	0.04	0.14	0.10	0.09
res+disc	0.22	0.16	0.16	0.15	0.14	0.14	0.32	0.27	0.27
conclusions	0.29	0.22	0.20	0.18	0.19	0.15	0.42	0.36	0.32

Table 2: Number and proportion of citation contexts containing a hedging cue, by section and location of hedging cue.

	Contexts		Sentences		Windows	
	#	%	#	%	#	%
background	3361	0.33	2575	0.25	2679	0.26
methods	1089	0.18	801	0.14	545	0.09
res+disc	7257	0.44	5366	0.32	4660	0.28
conclusions	338	0.58	245	0.42	221	0.38

Concerning the features on which the decision tree makes its decisions, we have started with a simple, yet fully automatic prototype (Garzone, 1996) which takes journal articles as input and classifies every citation found therein. Its decision tree is very shallow, using only sets of cue-words and polarity switching words (not, however, etc.), some simple knowledge about the IMRaD structure¹ of the article together with some simple syntactic structure of the citation-containing sentence. The prototype uses 35 citation categories. In addition to having a design which allows for easy incorporation of more-sophisticated knowledge, it also gives flexibility to the tool: categories can be easily coalesced to give users a tool that can be tailored to a variety of uses.

Although we anticipate some small changes to the number of categories due to category refinement, the major modifications to the decision tree will be driven by a more-sophisticated set of features associated with each citation. When investigating a finer granularity of the IMRaD structure, we came to realize that the structure of scientific writing at all levels of granularity was founded on *rhetoric*, which involves both argumentation structure as well as stylistic choices of words and syntax. This was the motivation for choosing the rhetoric of science as our guiding principle.

We rely on the notion that rhetorical information is realized in linguistic ‘cues’ in the text, some of which, although not all, are evident in surface features (cf. Hyland (1998) on surface hedging cues in scientific writing). Since we anticipate that many such cues will map to the same rhetorical features that give evidence of the text’s

¹The corpus of biomedical papers all have the standard Introduction, Methods, Results, and Discussion or a slightly modified version in which Results and Discussion are merged.

argumentative and pragmatic meaning, and that the interaction of these cues will likely influence the text’s overall rhetorical effect, the formal *rhetorical relation* (cf. (Mann and Thompson, 1988)) appears to be the appropriate feature for the basis of the decision tree. So, our long-term goal is to map between the textual cues and rhetorical relations. Having noted that many of the cue words in the prototype are discourse cues, and with two recent important works linking discourse cues and rhetorical relations ((Knott, 1996; Marcu, 1997)), we began our investigation of this mapping with discourse cues. We have some early results that show that discourse cues are used extensively with citations and that some cues appear much more frequently in the citation context than in the full text (Mercer and Di Marco, 2003). Another textual device is the hedging cue, which we are currently investigating (Mercer, Di Marco, and Kroon, 2004).

Although our current efforts focus on cue words which are connected to organizational effects (discourse cues), and writer intent (hedging cues), we are also interested in other types of cues that are associated more closely to the purpose and method of science. For example, the scientific method is, more or less, to establish a link to previous work, set up an experiment to test an hypothesis, perform the experiment, make observations, then finally compile and discuss the importance of the results of the experiment. Scientific writing reflects this scientific method and its purpose: one may find evidence even at the coarsest granularity of the IMRaD structure in scientific articles. At a finer granularity, we have many targeted words to convey the notions of procedure, observation, reporting, supporting, explaining, refining, contradicting, etc. More specifically, science categorizes into taxonomies or creates polarities. Scientific writing then

Table 3: Proportion of citation contexts containing a verbal hedging cue, by section and location of hedging cue.

	Contexts		Sentences		Windows	
	#	%	#	%	#	%
background	1967	0.19	1511	0.15	1479	0.15
methods	726	0.12	541	0.09	369	0.06
res+disc	4858	0.29	3572	0.22	2881	0.17
conclusions	227	0.39	168	0.29	139	0.24

Table 4: Proportion of citation contexts containing a nonverb hedging cue, by section and location of hedging cue.

	Contexts		Sentences		Windows	
	#	%	#	%	#	%
background	1862	0.18	1302	0.13	1486	0.15
methods	432	0.07	295	0.05	198	0.03
res+disc	3751	0.23	2484	0.15	2353	0.14
conclusions	186	0.32	107	0.18	111	0.19

tends to compare and contrast or refine. Not surprisingly, the morphology of scientific terminology exhibits comparison and contrasting features, for example, *exo-* and *endo-*. Science needs to measure, so scientific writing contains measurement cues by referring to scales (0–100), or using comparatives (larger, brighter, etc.). Experiments are described as a sequence of steps, so this is an implicit method cue.

Finally, as for our prototype system, we will continue to evaluate the classification accuracy of the citation-indexing tool by a combination of statistical testing and validation by human experts. In addition, we would like to assess the tool’s utility in real-world applications such as database curation for studies in biomedical literature analysis. We have suggested earlier that there may be many uses of this tool, so a significant aspect of the value of our tool will be its ability to enhance other research projects.

4 Conclusions and Future Work

The purposeful nature of citation function is a feature of scientific writing which can be exploited in a variety of ways. We anticipate more-informative citation indexes as well as more-intelligent database curation. Additionally, sophisticated information extraction may be enhanced when better selection of the dataset is enabled. For example, synonym detection in a corpus of papers may be made more tractable when the corpus is comprised of related papers derived from navigating a space of linked citations.

In this paper we have motivated our approach to developing a literature indexing tool that computes the functions of citations. The function of a citation is deter-

mined by analyzing the rhetorical intent of the text that surrounds it. This analysis is founded on the guiding principle that the scientific method is reflected in scientific writing.

Our early investigations have determined that linguistic cues and citations are related in important ways. Our future work will be to map these linguistic cues to rhetorical relations and other pragmatic functions so that this information can then be used to determine the purpose of citations.

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Table 5: Proportion of hedge sentences that contain citations or are part of a citation window, by section and hedging cue category.

	Verb Cues			Nonverb Cues			All Cues		
	Cite	Wind	None	Cite	Wind	None	Cite	Wind	None
background	0.52	0.23	0.25	0.47	0.28	0.25	0.49	0.26	0.26
methods	0.25	0.16	0.59	0.20	0.15	0.65	0.23	0.16	0.61
res+disc	0.26	0.19	0.55	0.21	0.19	0.60	0.23	0.19	0.58
conclusions	0.16	0.14	0.70	0.14	0.16	0.70	0.15	0.14	0.71

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