# Automatically generating hypertext by computing semantic similarity

by

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# Abstract

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We describe a novel method for automatically generating hypertext links within and between newspaper articles. The method is based on lexical chaining, a technique for extracting the sets of related words that occur in texts. Links between the paragraphs of a single article are built by considering the distribution of the lexical chains in that article. Links between articles are built by considering how the chains in the two articles are related. By using lexical chaining we mitigate the problems of synonymy and polysemy that plague traditional information retrieval approaches to automatic hypertext generation.

In order to motivate our research, we discuss the results of a study that shows that humans are inconsistent when assigning hypertext links within newspaper articles. Even if humans were consistent, the time needed to build a large hypertext and the costs associated with the production of such a hypertext make relying on human linkers an untenable decision. Thus we are left to automatic hypertext generation.

Because we wish to determine how our hypertext generation methodology performs when compared to other proposed methodologies, we present a study comparing the hypertext linking methodology that we propose with a methodology based on a traditional information retreival approach. In this study, subjects were asked to perform a question-answering task using a combination of links generated by our methodology and the competing methodology. The result is that links between articles generated using our methodology have a significant advantage over links generated by the competing methodology. We show combined results for all subjects tested, along with results based on subjects' experience in using the World Wide Web.

We detail the construction of a system for performing automatic hypertext generation in the context of an online newspaper. The proposed system is fully capable of handling large databases of news articles in an efficient manner.

*To Lisa.*

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# Chapter 1

# Introduction

The popularity of graphical interfaces to the World Wide Web (WWW) has shown that a hypertext interface can make what was once a daunting task, accessing information across the Internet, considerably easier for the novice user. Along with — and perhaps because of — the growth of the Web, many newspapers are beginning to take their first steps into the online world. A survey, reported in Outing (1996), found that there were 1,115 commercial newspaper online services world-wide, 94% of which were on the Web. Of the total, 73% (814) of the online newspapers were in North America. Outing predicted that the number of newspapers online would increase to more than 2000 by 1997. His prediction was reasonable, as by the middle of 1997 there were 1715 online newspapers, 95% of which were on the WWW (see Outing, 1997 for up-to-date statistics). These totals do not include services such as InfoSeek and InfoSage that provide access to a number of full-text databases over the WWW.

The problem is that these services are not making full use of the hypertext capabilities of the Web. The user may be able to navigate to a particular article in the current edition of an online paper by using hypertext links, but she must then read the entire article to find the information that interests her. Many services offer keyword searching for articles of interest, but there are almost no links between related articles.

These collections are "shallow" hypertexts; the documents retrieved as the result of a search are usually dead-ends in the hypertext, rather than starting points for other explorations. The hypertext capabilities of the WWW are hardly used at all. In order to truly reflect the hypertext nature of the Web, links would need to be placed within and between the documents.

## 1.1 Current efforts in Web-based news

The *Washington Post*'s Web site, WashingtonPost.com (Washington Post, 1997, http://www.-WashingtonPost.com) is, in many ways, a typical newspaper Web site. The top-level page resembles a traditional newspaper's front page, with links from short descriptions of articles to the full text of the articles themselves. What distinguishes this site is that some articles offer links to related articles. For example, an article about a standoff between the government and a militia group in Texas was linked with a profile of the militia group, and recent Associated Press stories on the standoff. Along with these news links, there are links to related sites on the Web, for example, a link to the home page of the militia group. These links are assigned by hand by WashingtonPost.com editors, and so only the top stories of the day receive this treatment.

College NewsLink (Simon and Schuster, 1997, http://www.ssnewslink.com/) is a service designed to provide course-related news items to students around the world. The service collects articles from various news sources (e.g., the *Globe and Mail* and the *New York Times*), automatically classifies them into subject areas (e.g., Multimedia), and mails them out to users as a page of HTML. One of the selling points of this service is that the articles have been annotated with hypertext links. For the most part, however, these links simply connect named entities (e.g., IBM or Netscape) to their Web pages. These links connect to the top-level domain of these sites, and do not seem to take into account the context in which an entity is mentioned (e.g., Netscape's new Web browser). There are no links within the articles, and certainly no links to other articles, and thus, no way for an interested user to break out of the classification hierarchy.

GLOBEnet (1997, http://www.theglobeandmail.com/) is the Web-based service of the *Globe and Mail* newspaper. When a user arrives at GLOBEnet's home page, she is presented with a choice of various information resources. One of these is the news of the day, divided into sections just as the print version is. The user can enter these sections, see short descriptions of the articles, and then click on a link to access the full versions. At this point, the browsing possibilities are simply to return to the top-level index of the paper, or to use the Web browser's *Back* button to return to the section level index. This is exactly the sort of "impoverished" hypertext that we described above — there is no easy way to get from this article to another, related article except by following the structure of the newspaper. GLOBEnet, however, offers a feature called *WebExtra*, a selection of stories that have been enhanced for the Web edition of the paper. As with College Newslink, these stories have links to related sites on the Web, but no links to related articles in the *Globe and Mail* itself.

In earlier versions, the Web edition of the *Globe and Mail* did try to provide automatically generated links to related articles. These links were built using the subject terms assigned to the article by InfoGlobe. Any article available on the Web site that shared a subject term (e.g., *forestry industry*) with the article in question was taken to be related, and a link was placed at the end of the article. The result was a large number of links to articles that were only peripherally related.

## 1.2 Large-scale hypertexts

If we consider the sites described above, it certainly seems that the creators of these sites want to be able to use the hypertext capabilities of the Web. Furthermore, as we shall see in section 2.6, novice users of information retrieval systems are often unable to form the complex queries that will retrieve only those documents that they are interested in. For the most part, these users will pose simple queries and browse through the results looking for information relevant to their particular needs. Clearly, this is a kind of interaction that a well-built hypertext would support very naturally. The user could begin by posing a query to the database or by browsing a "table of contents" and then use hypertext links within and between documents to navigate through the database.

This raises the question: *Why* are there no (or almost no) links in these Web sites? Westland (1991) has pointed out the economic constraints on building large-scale hypertexts. Manually creating and maintaining the large sets of links that would be needed for an online newspaper is prohibitively expensive, given the volume of newspaper and newswire articles produced every day. This could certainly account for the state of current WWW newspaper efforts.

Aside from the time-and-money aspects of building such large hypertexts manually, there have been indications that humans are very inconsistent in assigning hypertext links between the paragraphs of technical documents. That is, different people will tend to insert different hypertext links into the same document. In section 2.4.1 and in chapter 3, we will discuss the experiments that give us these results, both for technical documents and for newspaper articles.

The cost and inconsistency of manually constructed hypertexts does not necessarily mean that large-scale hypertexts can never be built. It is well known in the information retrieval (IR) community that humans are inconsistent in assigning index terms to documents, but this has not hindered the construction of IR systems intended to be used for very large collections of documents. Similarly, we can turn to automatically generated hypertext links to solve the problems of cost and inconsistency.

## 1.3 Automatic hypertext generation

There have been a few efforts in automatic hypertext generation, mostly aimed at building *structural* links — links that connect the parts of a document on the basis of its logical structure (e.g., the entries in a table of contents could be linked to the corresponding sections and subsections of the document). In contrast, very few people have attempted to automatically generate so-called *semantic* links that connect documents and parts of documents on the basis of their semantic similarity. Of those, only a very few have attempted to build systems that can cope with a large amount of text. For the most part, systems for automatic hypertext generation are intended for use with a single large document rather than a large collection of documents.

Automatic hypertext generation for large collections has often been treated as a special case of the more general information retrieval (IR) problem. In section 2.3 we will discuss some of the more successful approaches to IR, but for the most part, the basic premise underlying these systems is that documents that are related will use the same words. If two documents share enough terms, then we can say that they are related and should therefore have a link placed between them.

Two linguistic factors can affect this operation: *synonymy* (many words referring to the same concept) and *polysemy* (many concepts having the same word). The impact of synonymy is that documents that use words that are synonyms of one another will not be considered related or at best will be considered to be less related than they actually are. Polysemy will have the opposite effect, causing documents that use the same word in different senses to be considered related when they shouldn't be.

In this thesis, we will propose a novel method for building hypertext links within and between newspaper articles. Our method is intended to be a strong first step towards accounting for the problems of synonymy and polysemy. In addition, we will use a more general notion of relatedness than is used in traditional IR systems: We will consider two documents to be related not only if they use the *same* words, but also if they use *semantically related* words. The method is based on *lexical chaining*, a technique for extracting the sets of related words that occur in texts. In chapter 4, we will describe the development of a method for placing links within articles, and, in chapter 5, we will describe a method for building links between articles.

We focus on newspaper articles for two reasons. First, as we stated above, there is a growing number of services devoted to providing this information in a hypertext environment. Second, many newspaper articles have a standard structure that we can exploit in building hypertext links.

When developing a methodology such as the one in this thesis, it is necessary to evaluate it to see how it performs. In chapter 6, we will describe the design and results of an experiment that tests our proposed automatic hypertext generation methodology against a methodology based on a traditional IR system. In chapter 7, we describe how our methodology could be deployed in a Web newspaper to automatically generate hypertext links "on the fly".

# Chapter 2

# Background and previous work

## 2.1 The structure of newspaper articles

Newspaper articles are divided (generally speaking) into two types: news and feature articles. While these two types may exhibit very different writing styles, there are some generalizations that can be made. Both types have a *lead*, an initial paragraph (or group of paragraphs) that reflects the shape of the story.

*Hard leads* are used in news stories. They give the reader all of the facts of the story as quickly as possible, and are designed so that the reader can stop reading after the lead if they wish and still have a good idea of the important information contained in the story. The hard lead may (some say should) be as short as 35 words (Cumming and McKercher, 1994, p. 132).

*Soft leads* are used in feature stories to draw the reader into the following text. They are not concerned so much with the facts of the story as with getting the reader interested in the story. In recent years, there has been an increase in the number of feature articles appearing in newspapers, and writing styles have been changing so that even news articles may be written using a soft lead, rather than a traditional hard lead.

Newspaper articles are often written in the *inverted pyramid* style. The most important information is offered in the lead of the story, and further paragraphs offer progressively more detailed information. If there are several aspects to a story, then the most important information for each aspect is offered first, followed by the next-most important information, and so on. The benefit of using such a style is that the reader can stop reading at the end of any paragraph and still feel as though they have read a complete article. Along with the trend towards using soft leads, there has been a movement towards writing articles with a *narrative* style, which is meant to engage, as well as inform, the reader.

## 2.2 Lexical chains

A *lexical chain* (Morris and Hirst, 1991) is a sequence of semantically related words in a text. For example, if a text contained the words *apple* and *fruit* they would appear in a chain together, since *apple* is a kind of *fruit*. Generally speaking, a document will contain many such chains, each of which captures a portion of the cohesive structure of the document. *Cohesion* is what, as Halliday and Hasan (1976) put it, helps a text "hang together as a whole". The lexical chains contained in a text will tend to delineate the parts of the text that are "about" the same thing. Morris and Hirst (1991) showed that the organization of the lexical chains in a document mirrors, in some sense, the discourse structure of that document.

The lexical chains in a text can be identified using any lexical resource that relates words by their meaning. While the original work was done using *Roget's Thesaurus* (Chapman, 1992), our current lexical chainer, which is similar to the one described in St-Onge (1995), uses the WordNet database (Beckwith et al., 1991). The WordNet database is composed of synonym sets or *synsets*. Each synset contains one or more words that have the same (or nearly the same) meaning. A word may appear in many synsets, depending on the number of senses that it has. Synsets can be connected to each other by several different types of links that indicate different relations. For example, two synsets can be connected by a hypernym link, which indicates that the words in the source synset are instances of the words in the target synset.

For the purposes of lexical chaining, each type of link between WordNet synsets is assigned a direction of up, down, or horizontal. Upward links correspond to generalization: for example, an upward link from *apple* to *fruit* indicates that *fruit* is more general than *apple*. Downward links correspond to specialization: for example, a link from *fruit* to *apple* would have a downward direction. Horizontal links are very specific specializations. For example, the antonymy relation in WordNet is considered to have a horizontal direction, since it specializes the sense of a word very accurately.

Given these types of links, three kinds of relations are built between words:

**Extra strong** An extra strong relation is said to exist between repetitions of the same word.

**Strong** A strong relation is said to exist between words that are in the same WordNet synset (i.e., words that are synonymous), as in figure 2.1(a). Strong relations are also said to exist between words that have synsets connected by a single horizontal link, as in figure 2.1(b), or words that have synsets connected by a single IS-A or INCLUDES relation, as in figure 2.1(c).

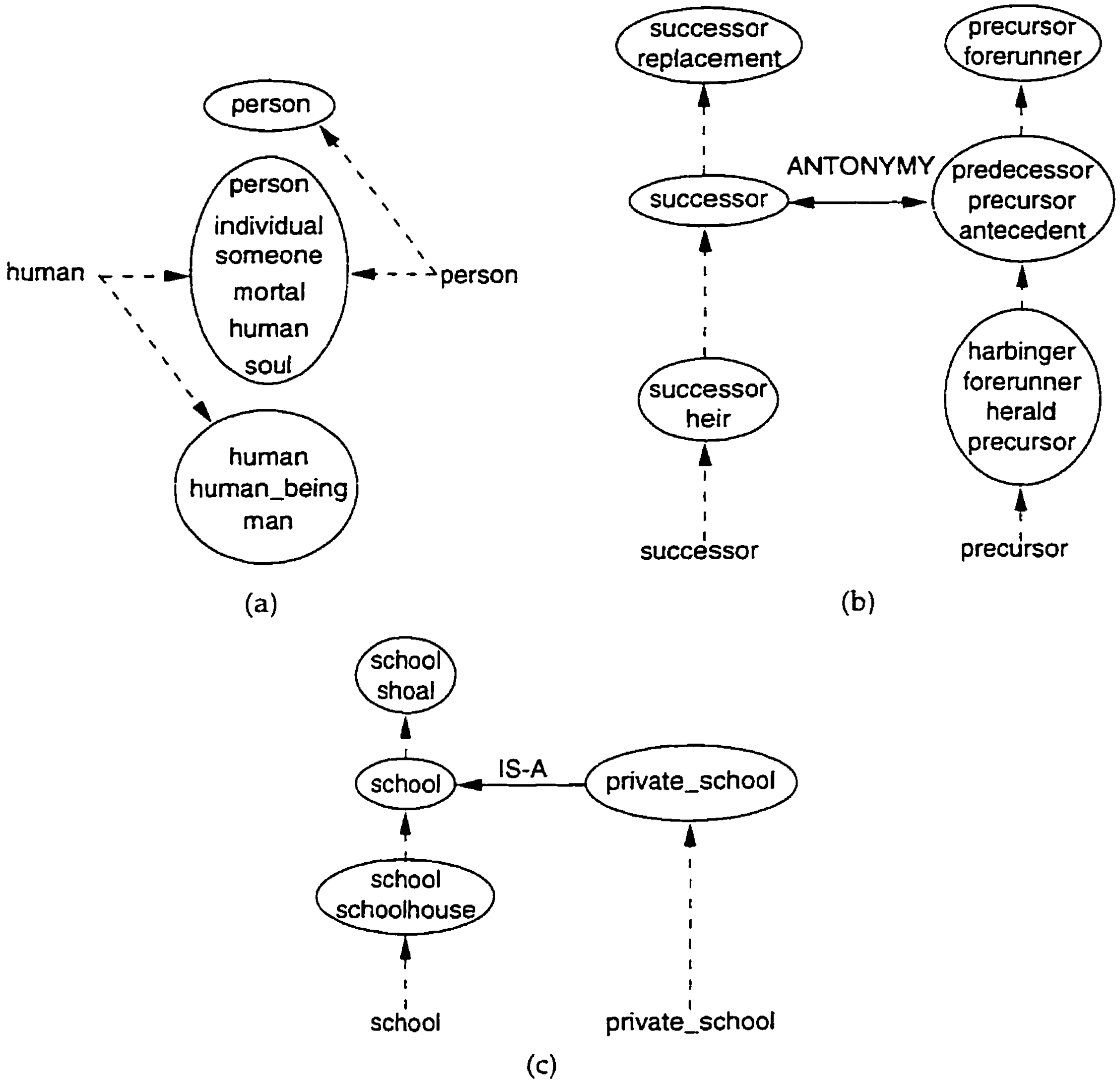


Figure 2.1: Strong relations between words.

**Regular** A regular relation is said to exist between two words when there is at least one *allowable* path between a synset containing the first word and a synset containing the second word in the WordNet database. A path is allowable if it is shorter than a given length (usually 4) and adheres to three rules:

1. No other direction may precede an upward link,
2. No more than one change of direction is allowed, except in the case that:
3. A horizontal link may be used to move from an upward to a downward direction.

Figure 2.2 shows the regular relation that can be built between *apple* and *carrot*.

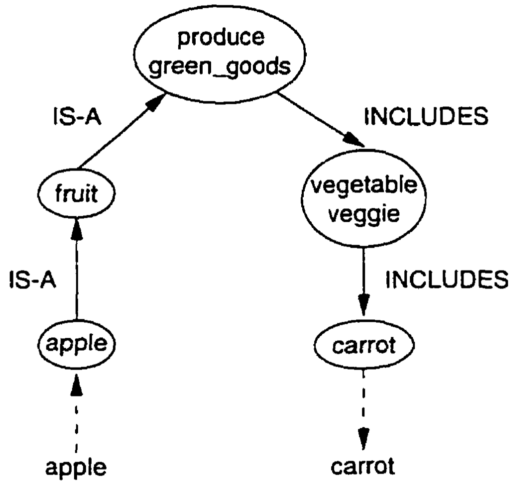


Figure 2.2: A regular relation connecting *apple* and *carrot*.

The result of lexical chaining is a file containing the lexical chains from a document and another file containing a description of which chains appear in which paragraphs of the document. Figure 2.3 shows the second and eighth paragraphs of an article about the trend towards "virtual parenting" in which all of the words participating in chains have been tagged with their chain numbers.

### 2.2.1 An implementation of lexical chaining

In the current implementation of the chainer, there are three distinct steps in the recovery of the lexical chains from a document. In the first stage, all extra strong relations (i.e., term repetitions) are found, and this set of unique terms is used as the starting set of lexical chains. Initially, each term in a chain has associated with it all of the WordNet synsets in which it appears. During the second stage of chaining, all strong relations between chains are recovered. The number of strong relations between the synsets from each pair of chains is calculated. The pair of chains

Although no one is **pushing**$^{12}$ virtual-reality **headgear**$^{16}$ as a **substitute**$^{1}$ for **parents**$^{1}$, many technical ad **campaigns**$^{13}$ are promoting cellular **phones**$^{22}$, **faxes**$^{22}$, **computers**$^{1}$ and pagers to **working**$^{1}$ **parents**$^{1}$ as a way of bridging **separations**$^{17}$ from their **kids**$^{1}$. A recent **promotion**$^{13}$ by A T & T and **Residence**$^{2}$ **Inns**$^{7}$ in the **United States**$^{6}$, for **example**$^{3}$, suggests that **business**$^{3}$ **travellers**$^{1}$ with **young**$^{1}$ children use **video**$^{3}$ and **audio tapes**$^{22}$, **voice**$^{3}$ **mail**$^{3}$, videophones and E-mail to **stay**$^{3}$ connected, including **kissing**$^{23}$ the **kids**$^{1}$ **good night**$^{21}$ by **phone**$^{22}$.

More **advice**$^{3}$ from **advertisers**$^{1}$: **Business**$^{3}$ **travellers**$^{1}$ can dine with their **kids**$^{1}$ by **speaker**$^{1}$-phone or "tuck them in" by cordless **phone**$^{22}$. Separately, a **management**$^{10}$ **newsletter**$^{24}$ recommends faxing your **child**$^{1}$ when you have to **break**$^{17}$ a **promise**$^{3}$ to be **home**$^{2}$ or **giving**$^{12}$ a **young**$^{1}$ **child**$^{1}$ a beeper to make him **feel**$^{23}$ more secure when **left**$^{5}$ alone.

Figure 2.3: Two portions of a text tagged with chain numbers.

that share the most strong relations are merged. During the merging, the synsets that participated in strong relations are retained, and all other synsets are removed. This process is repeated until there are no more strong relations between chains. The third stage is similar to the second, except that regular relations are considered.

As lexical chaining proceeds through these three stages, the number of synsets associated with a particular term will decrease. Thus, the words in the chains are progressively sense-disambiguated during lexical chaining.

The algorithm described above has a few drawbacks. The first is that words that do not appear in WordNet are not included in lexical chains, even if they are repeated, so useful information (e.g., a chain containing all instances of a proper noun) is lost.

Compared to traditional document processing tasks in information retrieval (i.e., keyword extraction), the chaining process is slow. For example, chaining a database of approximately 30,000 newspaper articles (about 85 MB) takes 5 hours, compared to approximately 15 minutes for a traditional information retrieval system to process the same amount of text. Still, this is much faster than traditional computational linguistic techniques for discovering document structure (e.g., parsing), and there are several optimizations that could still be made to the chaining software.

Because we want to be able to process text as quickly as possible, we must accept some errors (or at least bad decisions) during the chaining process. For example, consider the two portions of text shown in figure 2.3. The words *kid* and *speaker* are in the same chain, because a *speaker* can be a kind of human, as can a *kid*. This is the incorrect sense of *speaker* for this text — it is clearly meant in the sense of *loudspeaker*.

We have also found that the current implementation of the lexical chainer is sensitive to several parameters, in that slight changes in these parameters can produce large changes in the lexical chains produced. For example, the size and contents of the stop-word list given to the chainer can affect the chains by removing "key words" used to build chains. Also, if we allow the path length in a regular relation to increase, then the chainer will generate more questionable connections between synsets and produce longer chains.

We have tried to mitigate these problems by using a very simple stop-word list (one provided with WordNet), and by choosing a path length that seems to balance between worthwhile connections and bad connections. Current research by Budanitsky (1998) is aimed at determining exactly how the measure of semantic distance used affects the structure of the lexical chains extracted from a document.

Another problem, unrelated to the implementation, is that the WordNet database is relatively unconnected, that is, it is difficult to build relations between nouns and verbs, since the noun and verb hierarchies are connected only at the top level. Currently we attempt to get around this problem by seeing whether a nominalization of a verb appears in the noun hierarchy and if it does, using the nominalization instead. This is an unsatisfactory solution, but the only one available to us. Fortunately, much of the content of a document is carried in the nouns rather than the verbs.

We do note, however, some advantages that lexical chaining has compared to traditional information retrieval processing. For example, in the paragraphs shown in figure 2.3, multiple word terms such as *United States* are taken whole, rather than taken as separate terms. Another advantage, which we will make use of later, is the sense disambiguation mentioned earlier. Despite the limitations, we believe that the current implementation of the chainer is sufficiently powerful to use for our research.

In fact, lexical chaining has been used in several applications. The current implementation of the chainer is based on the implementation described in St-Onge (1995), where lexical chains were used to detect and correct malapropisms. Stairmand (1994), implemented a different lexical chainer using WordNet and used the results for work in information retrieval. In a similar vein, Kominek and Kazman (1997) have used a derivative of lexical chains, lexical trees, to provide real-time concept indices for meetings. Barzilay and Elhadad (1997) have used lexical chains to automatically summarize documents.

## 2.3 Information Retrieval

Generally speaking, the task of Information Retrieval systems is to select from a large database of documents the subset that meets the information requirement of a user. Many different systems and methodologies have been proposed for dealing with this task. A general overview of work in the field can be found in Meadow (1992).

Here we will present only those aspects most relevant to our research. In general, we are interested in how document similarity is calculated in traditional (and non-traditional) IR systems so that we can consider ways in which it can be improved. As our lexical chaining technique is based on a thesaurus, we are also interested in seeing how thesauri have traditionally been used in IR systems. We begin with a discussion of how retrieval performance is measured, so that these concepts will be familiar when the time comes to evaluate our own work.

### 2.3.1 Measuring retrieval performance

One of the most interesting aspects of the IR field is its insistence on measuring the performance of proposed systems. The most commonly used measures of IR performance are *recall* and *precision*. Simply stated, recall is the proportion of the documents relevant to a query that were actually retrieved, while precision is the proportion of the documents retrieved that are actually relevant. More formally, given a query, we can divide the documents in a system into the following categories:

| | Relevant | Not relevant |
|---|---|---|
| Retrieved | $a$ | $b$ |
| Not retrieved | $c$ | $d$ |

and then define:

$$\text{recall} = \frac{|a|}{|a+c|} \quad \text{precision} = \frac{|a|}{|a+b|}$$

Both recall and precision can vary between 0 and 1. Theoretically speaking, there is no reason why both recall and precision cannot both be 1 (i.e., a system retrieves all and only the relevant documents), but in practice there is a trade-off between the two — as recall is increased, precision falls and vice-versa. As a result of this relationship, performance results for IR systems are usually stated in terms of average precision at various recall levels.

Some have attempted to combine the recall and precision measures into a single measure that describes how closely a system approaches the ideal of perfect recall and precision (see Meadow, 1992, p. 284 for a few examples), but most research results (e.g., the TREC conference, Harman, 1994) still use recall and precision.

### 2.3.2 Vector space models

One of the most successful approaches to IR has been the vector space model advocated by Salton (1989) and others. In this model, each document in a collection is represented by a vector of length $t$, where $t$ is the number of distinct word root forms (or *terms*) in the entire collection. The elements of the vector for a specific document are the weights for each of the terms in that document. Typically, the number of unique terms in the database of documents can be quite large. For example, Forsyth (1986) found that, over the course of 149 days, the number of unique terms in a database of newspaper articles was 108,587.

The weight for a specific term in a specific document is calculated by considering the frequency of the term in that particular document and the number of documents that the term appears in. The intuition behind this calculation is that the terms that are most significant in a document are those that appear *frequently* in the document, and *infrequently* in the rest of the database. This weighting approach is referred to as the *term frequency-inverse document frequency* or *tf·idf* weighting scheme. Typically, a normalization function is applied to the vector for a document, so that longer documents do not dominate shorter documents. These normalized document representations are unit vectors in a $t$-dimensional space.

An equation that incorporates both weighting and normalization to calculate $w_{ik}$, the weight of term $k$ in document $i$, is given in Salton and Allan (1993):

$$w_{ik} = \frac{tf_{ik} \cdot \log(N/n_k)}{\sqrt{\sum_{j=1}^{t}(tf_{ij})^2 \cdot (\log(N/n_j))^2}}$$

In this formula, $tf_{ik}$ is the frequency of term $k$ in document $i$, $N$ is the number of documents in the collection, $n_k$ is the number of documents in the collection that contain term $k$, and $t$ is the number of terms in all documents.

Documents that contain many of the same terms will have vectors that lie close together in $t$-space. The similarity of two documents can then be measured by taking the cosine of the angle between the vectors representing them. For two normalized vectors, the cosine of the angle between them is simply the dot product of the vectors.

This provides a measure of similarity between 0 and 1, with 1 indicating complete similarity. To retrieve documents that are similar to a given document, all that is required is to compute the similarity of the vector from the given document to all other document vectors and rank each document by its similarity to the given document.

This global (i.e., document level) restriction can be extended to a local restriction in order to defeat the problem of polysemy. If two documents show a sufficient similarity, they can then be broken down into pieces (usually sentences). Each piece of one document can then be compared to each piece of the other. If there is a common usage of words between these pieces of the document, then they are assumed to be using the same words in the same senses, and the documents should be considered related (this process is described fully by Salton et al., 1993).

### 2.3.3 Latent Semantic Indexing

The development of Latent Semantic Indexing (LSI) (Deerwester et al., 1990) was motivated by the need to address both synonymy and polysemy in IR systems. Deerwester et al. take the position that the term vector representing a document in a traditional vector space system is really an imperfect representation of the *concepts* contained in the document.

In LSI, a database of documents is originally represented by a $t \times N$ term-document matrix, where $t$ is the number of terms in the database, and $N$ is the number of documents. This is essentially the representation that is used in vector space systems. The goal of LSI is, given this term-document matrix, to determine the actual association between terms and documents by determining the patterns of occurrence of words. Berry and Dumais (1995) present the example of the synonyms *car* and *automobile*, which will tend to occur with many of the same words (e.g., *motor, model, engine,* etc.).

Using a technique called Singular Value Decomposition (SVD), this rather large term-document matrix can be reduced to a much smaller set of $k$ orthogonal factors (where $k \approx 200$). This set of factors is meant to represent the underlying concepts that are expressed in the database. Both the documents and the terms in the database can be represented as a linear combination of these $k$ factors. The idea is that similar words, such as *car* and *automobile* will be very close together in $k$-space. As with vector space systems, the similarity between documents (or terms) can be calculated by taking the dot product or cosine of their representative vectors. Queries can be represented as a weighted sum of the factors and the same cosine measure can be used to find the most-similar documents.

Because of this reduction in dimensionality, it is possible that documents that contain none of the query terms will be retrieved if the terms in the documents are synonyms of the query terms. The method performs less well in dealing with polysemy. Since each term is represented by a unique vector of weights for each factor, a polysemous term is represented as a sort of "average" across all senses. Despite this, the method performs reasonably well compared to SMART (a vector space IR system) on some standard test collections.

This reduction of a term vector to a "concept vector" is somewhat similar to the reduction that is made during lexical chaining, when a document is reduced to a collection of synsets. Of course, when using LSI, there is no way to interpret exactly what these factors mean. The method may be able to tell that *engine* and *car* co-occur, but not that one is part of the other. The regular relations built during lexical chaining have no analogue in LSI, since these relations can not be specified by simple co-occurrence.

### 2.3.4 Thesauri and IR

One of the most common proposals for overcoming the problem of synonymy is to use a thesaurus to expand the query with related terms. In the simplest case, these extra terms are simply synonyms of the words used in the query. This expanded query is then used while searching the database.

More complicated thesauri have been proposed for use in information retrieval. An early example is that of Gotlieb and Kumar (1968), who attempted to automatically define a set of concepts from the Library of Congress *Subject Headings*. They describe the set of semantic relatives of an index term $x$ as all of the terms $y$ such that $x$ contains a *see also* reference to $y$ or $y$ contains a *see also* reference to $x$.

These sets are used to define an association metric that can be used to build graphs of the relationships between index terms. Using graph-theoretic methods, Gotlieb and Kumar propose ways to group index terms into *sharp concepts* (corresponding to maximal complete subgraphs of the term graph) and to group sharp concepts into *diffuse concepts*. This attempt to reduce a set of terms to a smaller set of concepts is similar to the reductions made in both LSI and lexical chaining.

Forsyth (1986) has proposed what he calls a dictionary/thesaurus (or d/t) for information retrieval. The basic unit in his d/t is the word, and each word can have several kinds of relations to other words. These relations can be used to expand the terms in a query in more-general ways. Forsyth classifies the relations between words into three categories:

**Synonymy relations** Synonyms (or near synonyms) as well as antonyms are related.

**Hierarchical relations** These relations are the IS-A or HAS-A relations.

**Affinity relations** This is a more diffuse set of relationships meant to contain "related terms".

Interestingly enough, the structure of his proposed d/t is similar to that of the WordNet database, although WordNet specifies a much larger set of relations, and the basic unit is a set of synonyms rather than a single word.

In fact, Voorhees (1994) has used WordNet to perform term expansion on queries that were used in the TREC evaluations. Essentially she performed a sort of "reverse" lexical chaining operation on the words contained in the queries, determining what words from WordNet were related to the query terms and adding those to the query. She found that this term expansion had little effect on well specified queries, but that it had a significant effect on under-specified queries. It would be interesting to see how LSI would fare when used in a similar evaluation, but Voorhees focuses specifically on WordNet.

### 2.3.5 Computational linguistics and IR

While there has been much work that attempts to apply some of the techniques of computational linguistics (e.g., parsing and semantic interpretation) to information retrieval (Mauldin, 1991, Rau et al., 1989, Rau and Jacobs, 1991), the degree of success of such techniques has been much less than expected. The idea underlying most of this work has been that if a system can *understand* a text, then it will be better able to retrieve that text in response to a user's query. In most cases, the word *understand* as it is used here means "producing document and query representations more detailed than those used by traditional IR systems." Even IR researchers have noted the problem:

> It is generally agreed that new approaches must be introduced in information retrieval, if meaningful enhancements in retrieval effectiveness are to be obtained. ... Ultimately, any advanced information retrieval model must deal with the problem of language analysis, because the content of texts and documents necessarily controls the retrieval activities. (Salton et al., 1990, p. 73)

While some of the work has been quite successful in limited domains (e.g., Rau et al., 1989), there have never been any systems that produced results that were significantly better than traditional, word-based IR systems on typical IR problems. Furthermore, many of the systems that have been built have not been able to cope with the megabytes (or even gigabytes) of data that are being produced every day. Sparck Jones (1991) stresses that systems that employ techniques from computational linguistics must perform at least as well as the current systems, or else there is no reason to do all of the work involved in producing complex representations.

This is not to say that the task of building an efficient and effective IR system that uses techniques from computational linguistics is impossible, merely that it is very difficult. Rather than attempting to solve the entire problem at once, perhaps we should be focusing on smaller aspects and attempting to achieve incremental gains in performance, or focusing on different aspects of the IR problem, such as question-answering.

## 2.4 Manual hypertext construction

Much of the work in the area of hypertext has focused on authoring systems for the manual construction of hypertext (see, for example, Rada and Diaper (1991) for a discussion of some authoring systems). Needless to say, manual hypertext construction is a time-consuming and difficult task. It also seems that manually constructed hypertexts may not be useful in information retrieval or question-answering systems, because different authors will tend to insert different sets of links into the same document.

### 2.4.1 Inter-linker consistency

It is well known that human indexers display a distressing lack of consistency when assigning index terms to documents. That is, different indexers will often use different terms to describe the same document. For example, Furnas et al. (1987) found that their subjects agreed less than 20% of the time when choosing terms to describe objects. Ellis et al. (1994a) hypothesized that a similar effect would arise in the manual construction of hypertext, where the human linker must decide which paragraphs of a document are related. In order to test this hypothesis, they conducted a study in which subjects were asked to assign links between the paragraphs of technical documents. The inter-linker consistency could then be assessed by measuring the similarity between different hypertext versions of the same document.

In the first part of their experiment, five hypertext versions of each of five documents were produced by the subjects. Each version of each document was produced by a different subject, using an authoring system based on the Guide hypertext system. The paragraphs of the documents were used as the nodes of the hypertext. Two types of links between nodes were generated automatically:

1. Links between nodes that were linearly adjacent in the original document.
2. Links from the headings in a table of contents to the nodes that begin the corresponding sections.

The subjects were then asked to connect nodes whose contents were related somehow, that is, their links would represent conceptual associations between nodes. They were urged to define all such links that they could find, even if the link already existed (e.g., a link between two adjacent nodes). Nodes could be linked in two ways:

1. A *term* (a word or multi-word phrase) within one node could be connected to the beginning of another node, so that the target node would be the one most relevant to someone wishing more information about the term in the source node.

2. The whole of one node could be connected to the beginning of another node, so that the target node would be the most relevant to someone seeking more information about the subjects in the source node.

Ellis et al. divided the sets of links that the linkers created into three types of link set:

**Type 1** A link set of Type 1 included all of the links inserted into the document by the subject.

**Type 2** A link set of Type 2 excluded forward links that connected the whole of a source node to a target node that is physically adjacent to it.

**Type 3** A link set of Type 3 excluded all forward links, from both the whole of a source node and from a term in a source node, to a target node that is physically adjacent to it.

The hypertexts created by the subjects were converted to graphs using three different representations: adjacency matrices, distance matrices, and converted distance matrices. Ellis et al. then analyzed the similarity of the graph representations of each possible pair of hypertexts, to see how similar the graphs produced by different subjects were.

The similarities of the graph representations of the hypertexts were computed using 27 different similarity coefficients that have appeared in the IR literature over the years (see Ellis et al., 1994a, p. 43 for a complete list). These similarity metrics all work on two vectors, so they also considered several methods for converting the graph representation of a hypertext to a vector. Two of these methods worked directly on the matrix representations of the graphs. In the first, the elements of the matrix are placed in a single $n$-tuple. In the second, multiple $n$-tuples are used, one for each node in the graph. The rest of the methods depended on vectors of *node indices*. Each vector is composed of $n$ node indices, one for each node in the graph. These node indices represent certain topological characteristics of a graph, for example, one node index that they used is the in-degree of a node.

Their results were tables of similarity for each combination of:

1. The type of link set used (Type 1, 2, or 3).
2. The type of matrix representation used (adjacency, distance, or converted distance).
3. The type of vector used in the similarity calculations (matrix element or node index).
4. The similarity coefficient.

This produces a large number of tables, but the overall finding was that humans were inconsistent in assigning links between paragraphs. Generally, they found that the similarity between hypertexts was low and variable, with the most inconsistent results occurring when considering only Type 3 link sets. In fact, they found a significant difference ($p \leq 0.025$) between the similarity results for Type 1 and Type 3 link sets.

For example, figure 2.4 shows a histogram of similarity frequencies for all 50 hypertext pairs using the Dice coefficient of similarity and Type 3 link sets. Notice that the graph is highly skewed towards 0, indicating a *high* frequency of *low* similarity measures.

That human linkers are inconsistent is a very interesting (although not entirely unexpected) result, and shows that the task of constructing hypertexts is a difficult one. Despite this, there are a few aspects of the study that could be improved.

In total, there were only 50 hypertext pairs (10 for each of the five documents) to consider. This is a relatively small sample size, and it would be interesting to have seen more hypertext versions of each document. The results would have been more compelling if a single subject had constructed hypertext versions of each of the five documents. Unfortunately, constructing a hypertext is also a time-consuming process, and they were unable to convince their subjects to do more than one text.

It is also very possible that the types of documents used for the study had a significant effect on the inter-linker consistency. The documents were, in general, quite long (up to 347 nodes) and complicated. It is possible that inter-linker consistency may increase when considering

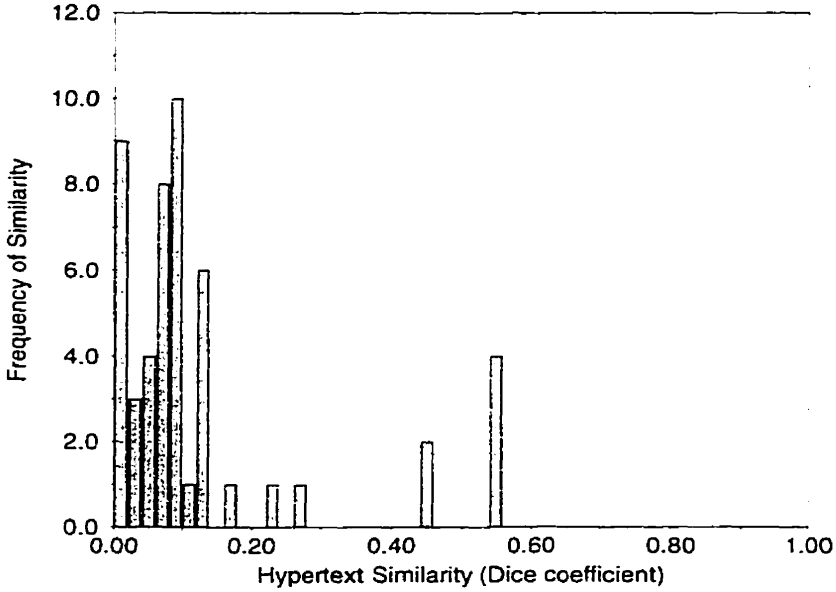


Figure 2.4: Histogram of similarity frequencies for technical documents, reproduced from Ellis et al. (1994).

shorter documents. The documents were also from diverse sources (Ph.D. theses, journal articles), some of which might not have had strict editorial control. Documents that are produced with stricter editorial and stylistic constraints might be easier to link, and perhaps human linkers would show a higher consistency. We will return to this question in chapter 3.

## 2.5 Automatic hypertext construction

When automatically constructing a hypertext, there are, in general, two types of links that can be built. First, there are *structural* links. Structural links reflect the hierarchical structure of many documents. For example, in a technical report, structural links could be built from the entries in the table of contents to the beginning of each section or subsection, from an entry in the references section to the point in the text where the reference is mentioned, or from an index entry to the places in the text where the indexed term is mentioned.

*Semantic* links, on the other hand, are those that relate portions of a document based on their semantic similarity, that is, these links connect the portions of a document that are about the same thing. For example, the introduction to a technical report could contain links from the paragraphs describing various aspects of the work to the sections where those aspects are explained in greater detail. Semantic links can be used to connect documents (or parts of documents) when there is no explicit relationship between them.

### 2.5.1 Structural links

While it seems that structural links would be relatively straightforward to create, problems may be encountered. In the best case, the document to be linked is available in electronic form and the logical structure of the document (e.g., sections, subsections, etc.) is indicated by some sort of document mark-up (e.g., SGML, LaTeX $2_\varepsilon$).

Furuta et al. (1989) describe their attempts to build the structural links in four different cases: a collection of eight scientific papers, a university course catalogue, a technical report abstract listing, and a dissertation abstract listing. Their experience runs the gamut from extensive editing of the source documents (in the case of the scientific papers) to almost entirely automatic detection of structural links (in the case of the technical report and dissertation abstract listings).

The main problem in constructing structural links lies in the fact that much of the formatting done in machine-readable documents does not reflect the logical structure of the document. For example, simply using a font size change to indicate the beginning of a section, rather than using an explicit tag such as `\section`, makes it much more difficult to determine where a section actually begins. This difficulty will probably dissipate as logical structuring features make their way into more document creation systems (i.e., commercially available word-processing software).

If the document does contain tags indicating the logical structure, the problem is then to build a pattern recognition engine to determine where each logical unit begins. Furuta et al. found that this might take as little as a week of effort. Once the logical units have been found, a variety of hypertext structures can be built using simple techniques. For example, in the case of the technical report and abstract listings, indices can be built by both author and title. Also, a back-of-the-book index may be used as a structure for the hypertext version of a document, if this is supported by the mark-up language.

Structural links can also be built across documents using references. Wilson (1990) developed the Justus suite of programs to convert traditional legal documents into an integrated hypertext database. The system detects (among other structural links) what she calls *location cross references* that point to different documents as well as another part of the same document. Fortunately, legal citation styles are very standard and can be automatically recognized.

While the process of determining the structural links in a document is more a matter of software engineering (i.e., writing the recognizers), it is nonetheless an important part of building a hypertext database of documents.

### 2.5.2 Semantic links

When we move from building strictly structural links towards building semantic links, the task becomes much more difficult. Without explicit clues to show how links should be built, we need to rely on more complicated techniques that take into account how language is used in a document or a set of documents. Indeed, there have been some doubts that such links could be discovered without resorting to full natural language processing of a text (see, for example, Bernstein, 1990 comments about building semantic links). Despite these doubts, there has been some work on automatically constructing semantic links within documents.

#### A link apprentice

Bernstein (1990) proposes what he calls a *link apprentice*. This is a software tool that can be used to examine the draft version of a hypertext and propose links that a human editor or author can either accept or reject. The apprentice that he proposes is a "shallow" one, considering only lexical equivalence. The apprentice was designed to operate in the Hypergate system, where, for each node in a hypertext, each word and each left-substring of a word are placed in a hash table for that node. These hash tables can then be used to compute a similarity (between 0 and 1) between nodes in an already-established hypertext. While an author is working on a particular node, the system scans the rest of the nodes in the hypertext for nodes that are similar to the current one. The top 20 most-similar nodes are then shown to the author.

The strength of this system is its efficiency. Bernstein reports a time of 6 seconds to process a 186-node hypertext. The problem is that the criteria for determining similarity are limited. There is no attempt to remove stop words from the nodes, and common word stems could cause a high similarity, even when words are not related. Even though these difficulties could be easily remedied, the real difficulty is that the apprentice is intended for "compact, independent hypertext documents" (Bernstein, 1990, p. 213) such as textbooks or training manuals, and would probably not scale up to a wider domain where there is a large amount of text to be linked and little opportunity for human involvement.

### An incremental approach to constructing hypertext

Chignell et al. (1990) have implemented a system that takes an incremental approach to automatic hypertext construction. As with Bernstein's system, their system is designed to produce a hypertext from a single document such as a technical manual. There are six steps in their incremental approach:

**Node preparation** The text is automatically segmented into nodes and each node is labeled. The structure of the text (i.e., the section and subsection information) can be exploited to determine what the nodes should be.

**Indexing** Index terms are assigned to each node, either through manual or automatic means.

**Link creation** The index terms for each node are used to compute the similarity between nodes. Nodes whose similarity exceeds a given threshold are linked.

**Organization** The nodes of the hypertext are organized by one of two methods:

1. Hierarchical organization through special link types such as INSTANCE-OF and PART-OF.
2. Emphasis of *landmarks*, nodes that are well connected in the hypertext. These landmarks can be used as entry points to topics in the hypertext.

**Link refinement** The usability of the hypertext thus constructed is tested in several ways. For example, the links may be tested to see whether they facilitate navigation. Links may be added or removed to improve the local and global coherence of the hypertext.

**Hypertext specification** The links and nodes of the hypertext are stored in a standard specification language that can be used to generate hypertexts for a number of hypertext viewing shells.

Chignell et al. also include a description of the conversion of a textbook from text to hypertext. In this case, each subsection of the book was placed in a node. The index used for computing node similarity was derived (manually) from the author and subject indices taken from the text. The similarity between two nodes $i$ and $j$, $\mathrm{sim}(i,j)$ is calculated using the inverse term frequency measure:

$$\mathrm{sim}(i,j) = \sum_{\{k|k\in i,k\in j\}} \frac{1}{N_k}$$

where $k$ is an index term that the two nodes share, and $N_k$ is the number of nodes that term $k$ appears in throughout the hypertext. This is a simplified version of the tf·idf metric that we showed in section 2.3.2. Similarities that exceed a set threshold (that depends on the size of the hypertext) indicate that two nodes should be linked. The links are then organized hierarchically according to the table of contents of the text.

It should be noted that the system described by Chignell et al. was a prototype, and some of the tasks which were carried out manually (e.g., building the index) could be done automatically. It is unclear how this system could be extended to handle a set of documents, rather than a single document. Also, shorter documents may defeat the statistical techniques used, since the number of nodes will be small and there might not be enough term repetition. Still, this approach should perform better than Bernstein's since it is based on strict term repetition rather than substring matching. It also requires a method to break the text into nodes. In the absence of a logical description (i.e., the table of contents), the system would have to resort to much smaller node sizes (e.g., paragraphs), which might decrease the likelihood of term repetitions, making it even more difficult to build the links between paragraphs.

### Unrestricted hypertext construction

More recently, Allan (1995) has been working on the automatic construction of hypertexts using the vector space model described in section 2.3.2. His work is significant in that it is intended to work on unrestricted collections of documents, rather than on single documents.

The similarity computation used in vector space IR systems lends itself very easily to building hypertext links between documents. From a query document, several kinds of links to a related document can be built:

- A link to the beginning of the most similar matching document or to the passages of that document that have the highest local similarity.
- A link between the passages of the query document and the matching documents that are the most similar.
- Links between the query document and all documents that show a sufficient similarity. The threshold could be set to 0 to link all similar documents.
- Links between documents that show global similarity, but fail the local similarity constraints.

Allan presents a method for visualizing the links between two documents as a graph. By considering these graphs, Allan develops methods so that hypertexts generated using some combination of the above link types can be simplified, and the links between documents and parts of documents can be automatically typed. In general, the procedure for describing the type of a link is as follows:

1. Decompose each document into parts. In Allan's examples, paragraphs are used, since they can usually be detected even when no mark-up language is used.
2. Compare each part of the first document to each part of the second document, noting which pairs have a non-zero similarity. This is the global similarity constraint.
3. For each such pair, apply a local similarity constraint by:
   (a) Breaking the two parts into sub-parts (sentences in this case).

(b) Compare each of the sub-parts of the parts as above. Note the highest sub-part similarity.

If there is at least one sub-part pair similarity that exceeds a threshold, mark that pair as "good", otherwise mark it as "tenuous".

4. If there are any "good" pairs that have a similarity over another (higher) threshold, mark them as "strong" and the others as "weak".
5. Simplify the connections between the documents' parts by merging nearby links.
6. Identify patterns within the simplified set of part links and use those patterns to identify the type of the link.

Links are merged by considering the distance between them. The distance is calculated in the following fashion: suppose that document $D_1$ contains two text sections $\alpha_1$ and $\beta_1$ and document $D_2$ contains two text sections $\alpha_2$ and $\beta_2$. Furthermore, suppose that there are two links $A$ and $B$ that connect, respectively, $\alpha_1$ to $\alpha_2$ and $\beta_1$ to $\beta_2$. We can then define the distance between $A$ and $B$ as the sum of the proportion of the document that lies between $\alpha_i$ and $\beta_i$. This is a real number that may vary between 0 and 2.

Link pairs with the smallest distances are merged first, and the result is what Allan calls a *meta-link* that connects a larger section of the two documents. If two pairs of links have the same distance, then one pair is selected by considering the relationship between the links, that is, what "shape" the links form. Merging continues until there is no pair of links with a distance smaller than a given threshold (which Allan sets at 0.10). Once the merging is complete, the final set of links is analyzed to detect patterns that will assist in the typing of the link. Allan specifies four measurements that are useful in identifying patterns:

**Convolution** How "parallel" were the links that made up a meta-link?

**Expansion** How much extraneous text was added at one endpoint during meta-link creation?

**Relative size** What proportion of two documents is included in a link?

**Absolute size** What size are the sections linked?

These measurements can be used to determine the following link types:

**Revision** Links documents with very little convolution and whose paragraphs remain in the same order.

**Summary/expansion** Links documents that have many strong paragraph links, but are also special because of what is not linked. One would expect that a summary document is largely composed of a smaller part of the expanded document.

**Equivalence** Links other strongly related documents that don't fall into the above two categories.

**Contrast** Links documents that have strong local similarities but weak global similarities.

**Tangent** Links documents that fail the global/local constraints.

**Comparison** Links that don't fall into any of the above categories.

Allan proposes an informal evaluation of the link typing process discussed above. Subjects (Computer Science graduate students) were given two encyclopedia articles that had been related by the algorithm and asked several questions to determine what they believed the relationship between the texts to be. Their answers could then be compared against the automatically generated link types. The results of the study were somewhat ambiguous. There was little consistency between the answers of the subjects, especially when determining the degree of relatedness of two texts. In general, the results seemed to show that the system performed well in choosing distinct passages that were well focused.

Despite the simplicity of the underlying vector space model, Allan's work is one of the best attempts at fully automatic hypertext construction on a large scale. Unfortunately, because of the underlying model, it has a few problems. Most notably, it requires strict term repetition to work. This is not much of a problem when dealing with large sections of text where term repetition will be common, but in smaller sections of text, the system may encounter problems[1]. The problem of polysemy has been moderately well handled by the global/local constraints on

[1] Allan has confirmed that this may indeed be the case (personal communication).

similarity measurement, at the cost of some efficiency. There has been no attempt to deal with synonymy, although a mechanism similar to Vorhees' (1994) could be used in this respect.

It is unfortunate that his link typing experiments proved inconclusive. The fact that his subjects were inconsistent in their judgments of the relatedness of two texts may simply be another facet of the inconsistency demonstrated by Ellis et al.

## 2.6 Models of hypertext search

While research in automatic hypertext generation is interesting, it is important to determine whether hypertext browsing is a viable method for performing IR tasks. In particular, we want to understand how browsing is incorporated into the search strategies of different classes of users. Furthermore, we need to consider what kinds of tasks are best performed using hypertext rather than a traditional IR system. In this section we will consider some of the empirical studies that have been conducted to answer these questions.

### 2.6.1 Paper versus electronic systems

Marchionini (1989) has investigated searcher behaviour in the transition from a print to an electronic version of an encyclopedia. Subjects in the experiment (high school students) performed three searches. The first was a "mental search" that was intended to gather information about their mental models for information seeking. Subjects were given a research problem and then were asked how they would begin searching for information to solve the problem. Specifically, they were asked what sources they would consult and what terms they would use to search these sources. They were also asked what they expected the results of these searches would be. They were asked why they had selected a particular source, and asked what their next source would be. These questions were repeated until the subject could provide no further sources.

The second search that the subjects performed was a print search. Students were asked to perform a search for information on a specific topic (possibly provided by the subject) using the print version of an encyclopedia. The terms that the subjects used to find articles and whether they used the index or went directly to articles were noted. Subjects were also questioned as to why they had taken particular actions. The searches were limited to 35 minutes.

The third search was performed using an electronic version of the same encyclopedia used for the second search. The subjects had been introduced to the electronic version previously, and had had the use of the Boolean connectives AND and OR demonstrated to them. The researchers gave no advice to the students, and time was reserved so that the subjects could be interviewed about the difference between the print and electronic versions of the encyclopedia.

The results of the experiment showed that there was little variation in the search outcome between the print and electronic versions of the encyclopedia. Variation occurred only in the category of "too many hits", which would seem to be a consequence of full-text searching as opposed to using the print encyclopedia's index. They did find that searches in the electronic version of the encyclopedia took almost twice as long as searches in the print version. In general, the subjects took little advantage of the electronic search features. Although two-thirds of the searches were performed using full-text matching, less than half of those used AND as a connective, and no subjects used the proximity features (e.g., NEAR) or the OR or NOT connectives.

The subjects also tended to ignore the complex screen displays of the electronic encyclopedia and accept default settings. The subjects made some use of the hypertext characteristics available in the system (e.g., jumping from one occurrence of a keyword to the next), but these aspects also seemed to cause some problems. For example, when an article was displayed, the first paragraph shown was the one which contained the first occurrence of a keyword. Subjects would then read from that point down, ignoring the text above. Subjects also demonstrated some "lost in hypertext" phenomena, such as trying to move up or down when at the top or bottom of an article.

### 2.6.2 The role of domain and search expertise

Marchionini et al. have also explored the role of domain and search expertise in full-text searching. (Marchionini et al., 1993) reports on several studies that have been conducted, specifically examining the roles of domain and search expertise in several fields (e.g., computer science, law). In general, domain experts focus on answers to their problems. They understand the problems and have expectations about the answers. They use technical terminology in their queries and devote large amounts of their search time to examining search results by scanning, reading, and assessing text. They are also capable of quick relevance assessments. Search experts, on the other hand, focus on query formulation, gathering documents, the structure of the database, and refining their queries. Texts are examined briefly in order to generate more query terms and to gain a better understanding of the problem. Their relevance judgments are more tentative than those of domain experts.

So, both domain and search experts use browsing as a part of their information-seeking strategies, although domain experts and novice searchers make more use of browsing (i.e., reading texts and scanning title lists). Marchionini et al. argue that this browsing lessens the cognitive load on the searcher. They do note however that browsing is often inefficient early in a search and takes more time than a focused search. Also, novices and domain experts may accept browsing as the default strategy if a system "invites" browsing. They recommend that multiple interfaces to a database be available in order to support both focused searches and browsing.

Tenopir and Shu (1989) have also found that users of a full-text information retrieval system (for general-interest magazines) often use browsing in their search strategies. Most users of such a system were searching for background information on a certain subject. Tenopir and Shu come to much the same conclusions as Marchionini et al.: users of an information retrieval system should be presented with a range of options for searching *and* browsing.

Hertzum and Frøkjær (1996), while investigating the effects of user interfaces in online documentation, found that printed manuals provide answers more quickly and more accurately, but that browsing was the fastest mode of searching and the mode that caused the fewest operational errors.

### 2.6.3 When hypertext is most useful

Rada and Murphy (1992) have conducted an experiment to determine the relationship between information-seeking tasks, user types, and tools for viewing hypertext. Their hypothesis was that a hypertext version of a textbook would help readers perform queries. They make a distinction between *search queries*, in which there is a single portion of the document that gives the answer (i.e., fact retrieval), and *browse queries*, in which multiple parts of the document must be consulted (i.e., complex question-answering).

In their study, a textbook was converted to several different hypertext representations (Emacs-Info, Guide, HyperTies, and MaxiBook). Subjects were classified as either experts (i.e., experts in hypertext software), trainees, or novices. Each expert was given four pairs of questions (each pair consisting of a search and a browse question) and each novice was given three pairs. The trainees were part of a course on hypertext, and were given questions from the course text to answer using each of the hypertext systems. Their comments on each of the systems were collected and analyzed.

The results showed that for the experts, search questions were answered more accurately and completely using the hypertext versions of the textbook, while browse questions were answered more accurately and completely using the paper versions of the textbook. There was also a significant difference in the search times between the hypertext and paper versions, with the hypertext searches taking longer. Novices performed both tasks more accurately and completely using the paper version, and also took more time with the hypertext version. Their results were better for the browsing questions than for the search questions.

This does not necessarily contradict the conclusions of Marchionini et al., nor those of Tenopir and Shu and Hertzum or Frøkjær, since it is true that the novice users did perform better on the browsing tasks. The fact that the novices preferred the paper version of the textbook to the hypertext version is somewhat troubling. This may be due to the fact that the hypertext was constructed using only structural links, and no semantic links. Also, this result is only for a (relatively) small hypertext. It would be interesting to see how the novices would have fared in a large (i.e., multi-thousand document) hypertext, where the use of the paper form would be problematic.

Lehto et al. (1995) have come to similar conclusions. In their study, users were given hypertext versions of two different texts. The first text was an annotated bibliography of warning-related issues, intended for practitioners and researchers interested in obtaining overviews of recent warnings-related research. In this case, the hypertext links were built using the author and subject indices, as well as a full-text search engine. The second text was a more traditional textbook on industrial ergonomics. In this case, two hypertexts were produced. The first hypertext used links based on full-text indexing, while the second used links based on the author's index and the table of contents.

In their first experiment, the participants were required to perform two types of tasks using the annotated bibliography: reading-to-do tasks (search queries) that required users to find and record which annotations contained relevant information for a very specific topic, and reading-to-learn tasks (browse queries) that required the user to become familiar with general safety related topics. They found that for the search queries, users of the hypertext answered more quickly and more accurately than users of the book. For the browse queries, book users provided more correct answers and took a slightly shorter time.

In their second experiment, users were given a set of 10 questions to answer using either the hypertext containing machine-generated links created by full-text indexing or the one containing manually-generated links that were created from the table of contents and the subject index. They found that responses were given more quickly and accurately using the manually-generated links.

This is an interesting result, and would seem to discourage us from using machine-generated links, but Lehto et al. recognize the difficulty of manually assigning links in large documents and, presumably, large document collections. Furthermore, this is a single result and further investigation of the conclusions is warranted. At any rate, Lehto et al. suggest providing links generated both manually and automatically. Considering the relatively simple ways in which the hypertext links were automatically generated, an improvement in automatic generation may provide better results.

# Chapter 3

# Testing inter-linker consistency

If we wish to automatically generate hypertext, then we need to be able to determine when we have built a "good" hypertext. One way to solve this problem is to take manually linked hypertexts, assume that they are "good", and then train our algorithm to produce similar hypertexts. There are two problems with this approach. Firstly, it is difficult to find a large number of manually-linked documents, since this process is extremely time-consuming. Secondly, Ellis et al.'s (1994a) results (reported in section 2.4.1) cast doubt on the consistency of such hypertexts.

Earlier, we noted some deficiencies in Ellis et al.'s study. Due to the time-consuming nature of the task, the number of hypertexts that they were able to collect was small (five hypertext versions of each of five documents, allowing only 50 pairs of different hypertexts). The nature of the documents linked (i.e., their length and complexity) might have also had an adverse effect on inter-linker consistency. This raises the question of how subjects would fare when presented with shorter documents that have undergone a strict editorial process and are written with a more regular structure. Ellis et al. themselves suggested that the experiment should be repeated under such circumstances, and this chapter details our efforts at replicating it.

## 3.1 Methodological issues

In the original study, Ellis et al. had their subjects place two different kinds of links between nodes: from a term in one node to the beginning of another or from an entire node to the beginning of another. In our replication, we allowed only the second type of link. We made this decision simply because of the nature of the text being linked. In the original study, the documents being linked were of a highly technical nature, and so such "definitional" links are more appropriate than they would be in a more general domain (such as newspaper articles).

Another difference is that the subjects in the original study used an authoring system based on the Guide hypertext system. In our study, the linking task was performed using pencil and paper. This saved us from having to tutor the subjects (some of whom had little computer experience of any kind) in an unknown system. It was also more natural for the subjects, who are used to reading newspaper stories on paper, and not on a computer screen.

Because we used a pencil-and-paper system, no links were automatically generated in the articles. In the original study, these links were built so that the subjects could navigate through the documents in a linear fashion, which was unnecessary in our case. Thus, we only concerned ourselves with what Ellis et al. called Type 3 link sets.

## 3.2 The task

Subjects were presented with three newspaper articles. These articles were not selected randomly; rather they were selected so that there would be a variation in topic, story structure, and length. One hard news story of 20 paragraphs, and two feature stories of 33 and 47 paragraphs were selected. The hard news article reported recent studies on the effect of acid rain on sugar maples, while the feature articles were about a bank scandal and white collar crime in Silicon Valley. For ease of reference, we will call these the "maple syrup" article, the "bank scandal" article, and the "Silicon Valley" article respectively.

The articles presented to the subjects were printed in two columns so that their format was similar to something that would be found in an actual newspaper. The paragraphs of the articles were numbered so that they could be referenced easily. The subjects were then given a worksheet and asked to write down pairs of numbers indicating which paragraphs they thought were related. In the instructions to the subjects, the term *related* was loosely defined as "paragraphs that share a similar topic or topics. Essentially, related paragraphs are 'about' the same subject." We felt that it was necessary to leave the definition of *related* somewhat vague, so as not to influence the subjects unduly.

Subjects were reassured that there were no "right" or "wrong" answers, and were urged to write down pairs of numbers for any paragraphs that they felt were related, even if the paragraphs were adjacent in the story. They were advised that it was acceptable not to include a paragraph in any pairs or to have one paragraph in many different pairs. We suggested to the subjects that they may wish to read the entire article before beginning to record pairs.

## 3.3 Results

The pairs of paragraphs that the subjects designated as related were used to build adjacency matrix representations. These matrices could then be used to calculate the similarity of the hypertexts in the same manner as Ellis et al. Table 3.1 shows the adjacency matrix from one subject for the maple syrup article.

Table 3.1: An adjacency matrix for the maple syrup article.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

### 3.3.1 Examining the data

In general, the number of links assigned by the subjects was much smaller than the number of links possible. Table 3.2 shows the number of links that each subject placed in each of the articles, along with the average number of links per paragraph. Table 3.3 provides a summary of the data.

Table 3.2: Link counts by subject and article.

| | Article | | | | | |
|---|---|---|---|---|---|---|
| | Bank scandal | | Maple syrup | | Silicon Valley | |
| Subject | Links | Avg. | Links | Avg. | Links | Avg. |
| A01 | 13 | 0.39 | 13 | 0.65 | 24 | 0.51 |
| A02 | 23 | 0.70 | 13 | 0.65 | 28 | 0.60 |
| A03 | 31 | 0.94 | 17 | 0.85 | 47 | 1.00 |
| A04 | 92 | 2.79 | 32 | 1.60 | 48 | 1.02 |
| A05 | 29 | 0.88 | 21 | 1.05 | 65 | 1.38 |
| A06 | 38 | 1.15 | 17 | 0.85 | 44 | 0.94 |
| A07 | 29 | 0.88 | 22 | 1.10 | 51 | 1.09 |
| A08 | 25 | 0.76 | 16 | 0.80 | 47 | 1.00 |
| A09 | 23 | 0.70 | 19 | 0.95 | 76 | 1.62 |
| A10 | 35 | 1.06 | 16 | 0.80 | 43 | 0.92 |
| A11 | 53 | 1.61 | 40 | 2.00 | 53 | 1.13 |
| A12 | 13 | 0.39 | 8 | 0.40 | 21 | 0.45 |
| A13 | 44 | 1.33 | 28 | 1.40 | 48 | 1.02 |
| A14 | 60 | 1.82 | 31 | 1.55 | 44 | 0.94 |

Table 3.3: Summary of link counts per article.

| Article | Number of Paragraphs | Min | Max | Mean | Mean Per Para. | Standard Deviation |
|---|---|---|---|---|---|---|
| Bank scandal | 33 | 13 | 92 | 36.3 | 1.01 | 21.0 |
| Maple syrup | 20 | 8 | 40 | 20.9 | 1.04 | 8.8 |
| Silicon Valley | 47 | 21 | 76 | 45.6 | 0.97 | 14.7 |

Paired $t$-tests show a significant difference ($p < 0.01$) in the number of links assigned to the bank scandal article and the maple syrup article. We also see a similar difference in the Silicon Valley and maple syrup articles. There is no significant difference in the numbers of links assigned in the bank scandal and Silicon Valley articles. If we consider the average number of links per paragraph, then we find no significant differences between any of the articles. So it appears that the subjects placed more links into longer articles, which is to be expected, but that across the three articles the average number of links per paragraph were about the same.

It is also interesting to consider where the majority of the links were placed. Table 3.4 shows a summary matrix which is the result of adding all of the adjacency matrices for the bank scandal article. Note the predominance of links near the diagonal, indicating very short distances for the links that the subjects placed into the articles. This predominance suggests that our results would be similar to those of Ellis et al., that is, the lowest consistency between linkers would be found when considering Type 3 link sets.

### 3.3.2 Similarity results

The result of each of the 14 subjects placing links between the paragraphs of each of the three articles is 14 hypertext versions of each of the articles. With 14 hypertext versions, there are 91 possible pairs of hypertexts for each of the articles, giving a total of 273 possible hypertext pairs for all articles. We computed graph similarities among all pairs of adjacency matrices using single $n$-tuple, multiple $n$-tuple, and node index representations of the adjacency matrices. Only Type 3 link sets were considered, since these sets demonstrate most clearly the non-linear links that the subjects produced.

Figure 3.1 shows a histogram of similarity frequencies for the maple syrup article. These similarities were calculated using the Dice coefficient of similarity and a single $n$-tuple representation of the adjacency matrix.

This is the shortest of the three articles, with only 20 paragraphs. It is also the article that had the highest mean similarity among the three articles when calculated under the above conditions. The mean similarity among all 91 hypertext pairs for the maple syrup article was 0.35, while the mean similarity was 0.22 and 0.29 for the bank scandal and Silicon Valley articles, re-

Table 3.4: Summary matrix for the bank scandal article.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 3 | 2 | 0 | 2 | 1 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 2 | 0 | 0 | 0 | 5 | 0 | 5 | 4 | 4 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 8 | 2 | 5 | 1 | 5 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 3 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 4 | 0 | 5 | 0 | 0 | 2 | 5 | 0 | 3 | 1 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 1 | 5 | 4 | 1 | 1 | 2 | 2 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 1 | 0 | 1 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 1 | 2 | 0 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 0 | 1 | 0 | 2 | 0 | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 1 | 3 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 8 | 1 | 5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| 22 | 1 | 0 | 3 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 |
| 24 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 3 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 7 |
| 26 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 0 | 0 | 0 |
| 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 4 | 0 | 0 | 0 |
| 29 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 32 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

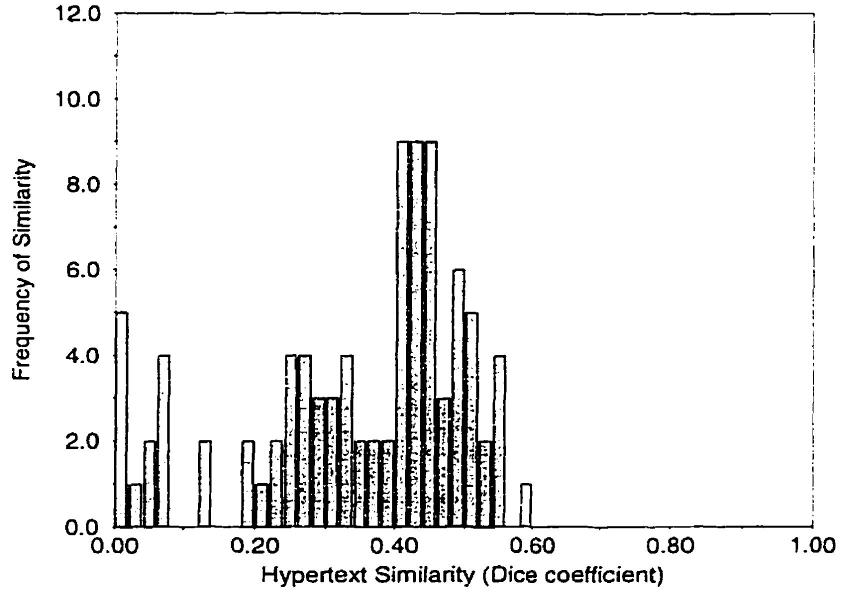


Figure 3.1: Histogram of similarity frequencies for the maple syrup article.

spectively. Figures 3.2 and 3.3 show the similarity frequency histograms for the bank scandal and Silicon Valley articles respectively. Notice that they are skewed more towards 0 than the graph in figure 3.1.

Figure 3.4 shows the similarity frequency histogram for all possible document pairs in our study. This graph can be compared to the similarity frequency histogram shown in figure 2.4, which gives the corresponding data from the original study. The mean similarity in this case in the original study was 0.116, with a standard deviation of 0.161. Thus, the 95% confidence interval for this mean was (0.0712, 0.161). In our study, the mean similarity across 273 document pairs was 0.285 and the standard deviation was 0.151. The 95% confidence interval for this mean is (0.267, 0.302) which does not overlap the 95% confidence interval from the original study. An unpaired $t$-test indicates that the difference in the means for the two experiments is significant at the $p < 0.01$ level.

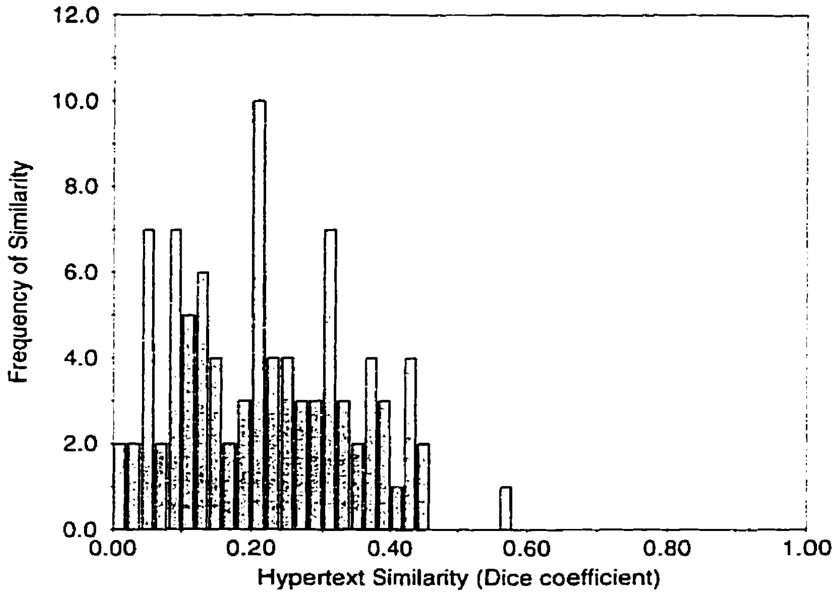


Figure 3.2: Histogram of similarity frequencies for the bank scandal article.

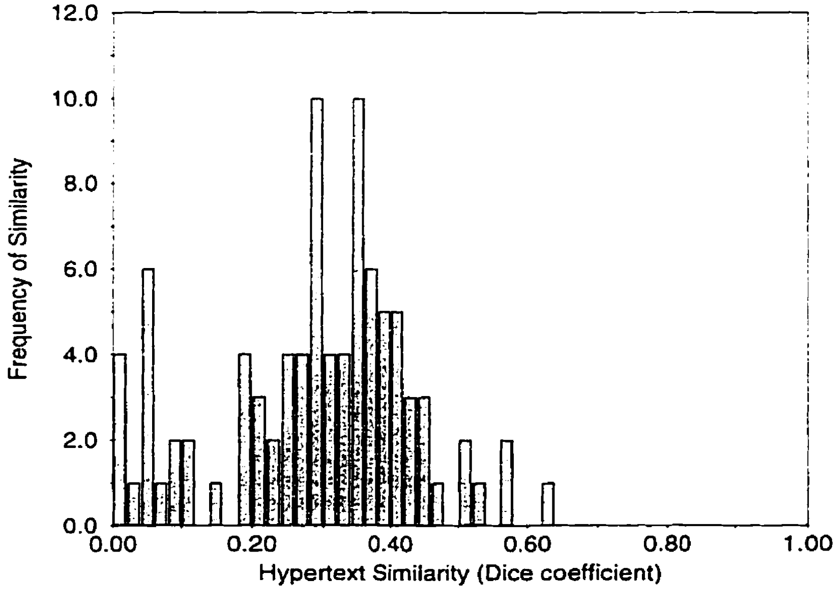


Figure 3.3: Histogram of similarity frequencies for the Silicon Valley article.

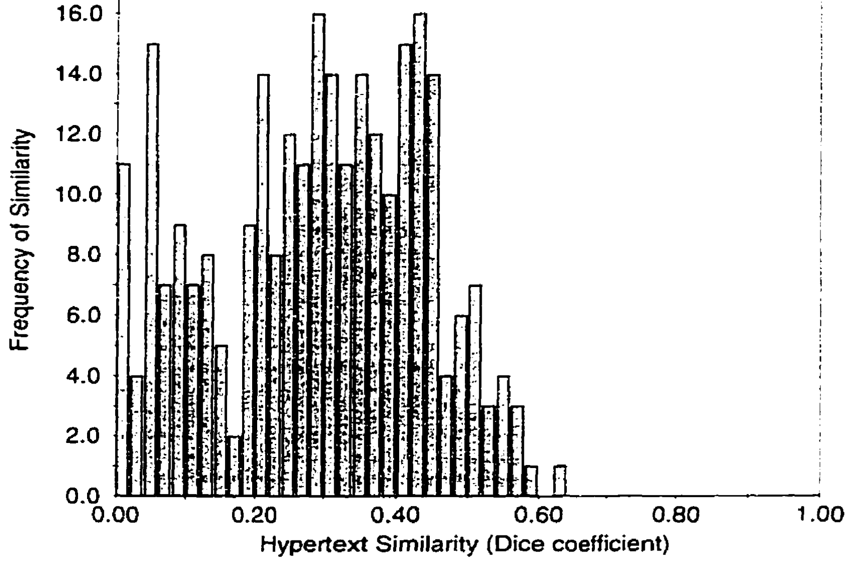


Figure 3.4: Histogram of similarity frequencies for all articles.

## 3.4 Discussion

So, it appears that our subjects performed more consistently than those in Ellis et al.'s study. This is especially interesting when considering the fact that our definition of "relatedness" was substantially less specific than theirs. We believe that the differences observed are due to two factors. The first is the length of the documents being linked. Our newspaper articles were significantly shorter than the texts linked by Ellis et al.'s subjects. As a result, our subjects were able to link all three articles in a single 90-minute sitting, rather than over the course of one or more days. The second factor that we believe affected our subjects' consistency was the nature of the documents being linked. Newspaper articles are strongly structured and well edited, which may have removed some of the ambiguity about which paragraphs were related. Unfortunately, the inter-linker consistency that we observed was still low — too low to consider using hand-linked articles to train our algorithm. Even if the consistency had been higher, the production of the large number of articles needed to train a system would be entirely too costly, even considering the fact that the articles are much shorter.

It is interesting to note that there were no significant differences in the average number of links per paragraph that the subjects assigned. This may simply indicate that the subjects were reluctant to write down as many links per paragraph as they wanted to, for fear of getting the "wrong" answer. It may, however, indicate that the discourse structure of newspaper articles is relatively straightforward, and that a given paragraph may only be related to a few other paragraphs. As this data is not available for Ellis et al.'s study, it is difficult for us to make comparisons.

Even though our subjects showed more consistency than those in Ellis et al.'s study, we still must contend with the fact that when humans read something, they bring to the task their own views of what is interesting and important. These biases will undoubtedly affect how they perform the task of linking related paragraphs. Studies of inter-indexer inconsistency have shown that consistency can be increased by using a controlled vocabulary of index terms (see, for example, Tarr and Borko, 1974). Unfortunately, there is no such "controlled vocabulary" of hypertext links, although our study seems to indicate that providing shorter, more strongly structured documents may have a similar effect. Building large-scale hypertext is still a relatively new task, and while such a "vocabulary" might eventually develop, it is difficult to tell when or if that will occur.

The kind of automatic hypertext generation methodology that we will discuss in the next chapter has the benefit that, even if the results are not perfect, the process is at least mechanistic and understandable.

# Chapter 4

# Linking within the article

As part of their work, Morris and Hirst (1991) demonstrated that the structure of the lexical chains in a document corresponds to the structure of the document (see section 2.2 above). In other words, the lexical chains will tend to delineate the parts of a document that are "about" the same topic. Due to the difficulty of building lexical chains by hand, they did not test whether this is the case for a large number of texts. If the lexical chains *do* indicate the structure of the document, then they are a natural tool to use when attempting to build a hypertext representation of a document. If we are using documents that have a strict structure, such as newspaper articles, then the chains should prove sufficient to build *intra-article* links, that is, hypertext links within an article.

As we said in section 2.1, newspaper articles are written so that one may stop reading at the end of any paragraph and feel as though they have read a complete article. For this reason, it is natural to choose to use paragraphs as the nodes in our hypertext. Figure 4.1 shows the first, second, fifth, and eighth paragraphs of a news article about the trend towards "virtual parenting" (Shellenbarger, 1995). As before, superscript numbers after a term indicate to which chain a term belongs. Table 4.1 shows the lexical chains contained in the article. Here, the numbers in parentheses indicate the number of times that a particular term appears in the article.

We will use this particular article to illustrate the process of building intra-article links. Before we begin, however, we should look at the structure of the article, in terms of how it talks about the phenomena of virtual parenting. We can do this on a paragraph by paragraph basis, as shown in table 4.2. There are several ways in which we could generate links between the paragraphs of this article, many of which would be useful and valid. We choose to consider how this article should be linked for someone who is trying to find out exactly what virtual

Table 4.1: Lexical chains in the virtual parenting article.

| C | Word | Syn | C | Word | Syn | C | Word | Syn |
|---|---|---|---|---|---|---|---|---|
| 1 | working (5) | 40755 | | | 21551 | | school (1) | 55261 |
| | ground (1) | 58279 | | | 21577 | | university (1) | 55299 |
| | field (1) | 57992 | | office (1) | 21928 | | company (1) | 54918 |
| | antarctica (1) | 58519 | | place (1) | 21928 | 11 | brochure (1) | 47300 |
| | michigan (1) | 57513 | | work (1) | 21919 | 12 | giving (1) | 19911 |
| | feed (1) | 53429 | | calling (1) | 21911 | | pushing (1) | 20001 |
| | chain (1) | 57822 | | business (3) | 21909 | | push (1) | 20001 |
| | hazard (1) | 77281 | | game (1) | 21910 | | high-tech (2) | 19957 |
| | risk (1) | 77281 | | homework (1) | 22348 | 13 | step (1) | 20667 |
| | young (2) | 24623 | | babysitting (1) | 22205 | | | 21665 |
| | need (1) | 58548 | | works (1) | 21890 | | travel (1) | 20661 |
| | parent (7) | 62334 | | bother (1) | 51139 | | promotion (2) | 20336 |
| | kid (3) | 60256 | | technology (2) | 23165 | | campaign (1) | 23228 |
| | child (1) | 60256 | | overuse (1) | 23173 | | expedition (1) | 20778 |
| | baby (1) | 59820 | | using (2) | 21236 | | petersburg (1) | 24516 |
| | wife (1) | 63852 | 4 | folk (1) | 54362 | | united_states (1) | 57412 |
| | adult (1) | 59073 | | family (4) | 54362 | | city (1) | 56043 |
| | traveller (3) | 59140 | 5 | left (1) | 20946 | | new_york (1) | 57551 |
| | substitute (1) | 63327 | | | 37680 | 14 | calm (1) | 42035 |
| | backup (1) | 63327 | | | 44572 | 15 | real (1) | 73220 |
| | computer (1) | 60118 | | | 55723 | | | 74629 |
| | expert (1) | 59108 | | | 56371 | 16 | headgear (1) | 36154 |
| | mark (1) | 60270 | 6 | reality (2) | 75601 | 17 | break (1) | 50935 |
| | worker (1) | 59145 | | | 75603 | | | 51123 |
| | speaker (1) | 63258 | | state (1) | 19695 | | separation (1) | 51004 |
| | advertiser (1) | 59643 | | excess (1) | 76985 | | going (1) | 51014 |
| | entrepreneur (1) | 60889 | | age (1) | 42122 | 18 | course (1) | 56574 |
| | engineer (1) | 59101 | 7 | inn (1) | 36320 | | trend (1) | 56574 |
| | sitter (1) | 59827 | 8 | middle (1) | 45633 | 19 | planning (1) | 23089 |
| | consultant (2) | 59644 | | kind (2) | 45529 | | arranging (1) | 23127 |
| | management_consultant (1) | 61903 | | form (1) | 45529 | 20 | urge (1) | 57698 |
| | man (1) | 61902 | | idea (1) | 45509 | 21 | good_night (1) | 48074 |
| | flight_attendant (1) | 63356 | 9 | call (2) | 19870 | | wish (1) | 48061 |
| 2 | residence (1) | 56129 | | | 20208 | 22 | phone (2) | 40017 |
| | home (2) | 56130 | | | 23590 | | cellular_phone (1) | 33808 |
| 3 | note (1) | 48602 | | | 23591 | | fax (2) | 35302 |
| | term (1) | 48631 | | | 46540 | | gear (1) | 32030 |
| | check (1) | 24363 | | | 46798 | | joint (2) | 36574 |
| | stay (1) | 24363 | | | 47837 | | junction (1) | 36604 |
| | promise (1) | 50589 | | | 48737 | | network (1) | 37247 |
| | example (1) | 48215 | | | 50172 | | system (2) | 32196 |
| | advice (1) | 48211 | | | 50445 | | audiotape (1) | 39983 |
| | voice (1) | 50135 | | | 50452 | | gadget (1) | 32428 |
| | video (3) | 46821 | | | 50455 | 23 | feel (1) | 22808 |
| | mail (2) | 48021 | | | 50456 | | kissing (1) | 22806 |
| | lullaby (1) | 21739 | 10 | management (2) | 55578 | 24 | newsletter (1) | 48253 |
| | singing (1) | 21733 | | professor (1) | 62638 | | account (1) | 48252 |
| | trick (1) | 21586 | | conference (1) | 55372 | 25 | little_league (1) | 55057 |
| | play (1) | 21240 | | meeting (1) | 55371 | | | |

**Working**$^{1}$ **parents**$^{1}$ **note**$^{3}$: From the **folks**$^{4}$ who brought you virtual **reality**$^{6}$ and the virtual **office**$^{3}$, now comes a new **kind**$^{8}$ of altered **state**$^{6}$ - virtual parenting.

Although no one is **pushing**$^{12}$ virtual-reality **headgear**$^{16}$ as a **substitute**$^{1}$ for **parents**$^{1}$, many technical ad **campaigns**$^{13}$ are promoting cellular **phones**$^{22}$, **faxes**$^{22}$, **computers**$^{1}$ and pagers to **working**$^{1}$ **parents**$^{1}$ as a way of bridging **separations**$^{17}$ from their **kids**$^{1}$. A recent **promotion**$^{13}$ by A T & T and **Residence**$^{2}$ **Inns**$^{7}$ in the **United States**$^{13}$, for **example**$^{3}$, suggests that **business**$^{3}$ **travellers**$^{1}$ with **young**$^{1}$ children use **video**$^{3}$ and **audiotapes**$^{22}$, **voice**$^{3}$ **mail**$^{3}$, videophones and E-mail to **stay**$^{3}$ connected, including **kissing**$^{23}$ the **kids**$^{1}$ **good night**$^{21}$ by **phone**$^{22}$.

When **Mark**$^{1}$ Vanderbilt, a **network**$^{22}$ **systems**$^{22}$ **engineer**$^{1}$, was **planning**$^{19}$ a scientific **expedition**$^{13}$ to **Antarctica**$^{1}$, he taught his **wife**$^{1}$ and three children to send and receive live **video**$^{3}$ **feeds**$^{1}$ over the Internet.

More **advice**$^{3}$ from **advertisers**$^{1}$: **Business**$^{3}$ **travellers**$^{1}$ can dine with their **kids**$^{1}$ by **speaker**$^{1}$-phone or "tuck them in" by cordless **phone**$^{22}$. Separately, a **management**$^{10}$ **newsletter**$^{24}$ recommends faxing your **child**$^{1}$ when you have to **break**$^{17}$ a **promise**$^{3}$ to be **home**$^{2}$ or **giving**$^{12}$ a **young**$^{1}$ **child**$^{1}$ a beeper to make him **feel**$^{23}$ more secure when **left**$^{5}$ alone.

Figure 4.1: Portions of an article about virtual parenting.

parenting is. In this case, links would probably be most useful from paragraph 2 (the definition of the term) to paragraphs 5, 6, 7, 8, and 9 (examples of and warnings about virtual parenting).

In their original work on lexical chaining, Morris and Hirst showed a mapping between the lexical chains contained in a document and the discourse intentions (i.e., the topics the writer intends to discuss) in the document. Unfortunately, they gave no easily implementable algorithm for determining this correspondence. Furthermore, they provided no way to determine the relatedness of two parts of the document. Our goal is to provide a method to make this determination. Because this has not been attempted before, we shall try to use techniques that are as simple as possible to begin with, and only turn to more complex techniques if necessary.

In general, our approach is similar to Morris and Hirst's in that we assume that the parts of a document that have the same lexical chains are about the same thing, but we are willing to consider that a particular unit of a document's structure may be indicated by the presence of many chains.

Table 4.2: Description of the paragraphs of the virtual parenting article

| Par | Chains | Topic |
|---|---|---|
| 1 | 1, 3, 4, 6, 8 | Introduction of the term *virtual parenting*. |
| 2 | 1, 2, 3, 6, 7, 12, 13, 16, 17, 21, 22, 23 | A definition of virtual parenting — parents using new communication technologies to keep in touch with their kids. |
| 3 | 1, 3, 4, 9, 10, 12, 13, 19, 20, 22 | How businesses are trying to cash in on the trend. |
| 4 | 1, 3, 4, 8, 10, 12, 15, 18, 21 22 | The trend is meeting the need of parents. |
| 5 | 1, 3, 13, 19, 22 | An example: live video over the Internet. |
| 6 | 1, 3, 10, 13, 14 | More examples: using email or recorded videos to keep in touch. |
| 7 | 1, 3, 4, 9, 11, 13, 17, 22, 24, 25 | Advice from communication companies: attend missed Little League games by cellular phone. |
| 8 | 1, 2, 3, 5, 10, 12, 17, 22, 23, 24 | More advice for parents: phone or fax your child when you're travelling. |
| 9 | 1, 3, 6, 12, 22 | A warning from the man who coined the term virtual parenting. |
| 10 | 1, 2, 3, 4, 8, 10, 13, 22 | A warning from someone who designed a system allowing parents to check up on their kids. |
| 11 | 1, 3, 8 | Conclusion: find the middle ground. |

## 4.1 Analyzing the lexical chains

We begin our analysis of an article's structure by determining how "important" each chain is to each paragraph in the article. By making this determination, we will be able to link together paragraphs that share sets of important chains. We judge the importance of a chain to a particular paragraph by calculating the fraction of the content words of the paragraph that are in that chain. We refer to this fraction as the *density* of that chain in that paragraph. The density of chain $c$ in paragraph $p$, $d_{c.p}$, is defined as:

$$d_{c.p} = \frac{w_{c,p}}{w_p}$$

where $w_{c,p}$ is the number of words from chain $c$ that appear in paragraph $p$ and $w_p$ is the number of content words (i.e., those words that are not stop words) in $p$. For example, if we consider paragraph 1 of our virtual parenting article, we see that there are two words from chain 1. We also note that there are 14 content words in the paragraph. So, in this case, the density of chain

1 in paragraph 1, $d_{1,1}$ is:

$$d_{1,1} = \frac{2}{14} = 0.14$$

Table 4.3: The chain density vectors for the virtual parenting article.

| | Paragraph | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Chain | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| 1 | 0.14 | 0.19 | 0.07 | 0.16 | 0.28 | 0.18 | 0.10 | 0.25 | 0.24 | 0.13 | 0.33 |
| 2 | | 0.02 | | | | | | 0.04 | | 0.03 | |
| 3 | 0.14 | 0.12 | 0.07 | 0.11 | 0.06 | 0.14 | 0.14 | 0.11 | 0.13 | 0.13 | 0.22 |
| 4 | 0.07 | | 0.11 | 0.05 | | | 0.03 | | | 0.03 | |
| 5 | | | | | | | | 0.04 | | | |
| 6 | 0.14 | 0.02 | | | | | | | 0.05 | | |
| 7 | | 0.02 | | | | | | | | | |
| 8 | 0.07 | | | 0.11 | | | | | | 0.03 | 0.11 |
| 9 | | | 0.04 | | | | 0.03 | | | | |
| 10 | | | 0.07 | 0.05 | | 0.11 | | 0.04 | | 0.03 | |
| 11 | | | | | | | 0.03 | | | | |
| 12 | | 0.02 | 0.04 | 0.05 | | | | 0.04 | 0.03 | | |
| 13 | | 0.06 | 0.04 | | 0.06 | 0.07 | 0.03 | | | 0.07 | |
| 14 | | | | | | 0.04 | | | | | |
| 15 | | | | 0.05 | | | | | | | |
| 16 | | 0.02 | | | | | | | | | |
| 17 | | 0.02 | | | | | 0.03 | 0.04 | | | |
| 18 | | | | 0.11 | | | | | | | |
| 19 | | | 0.04 | | 0.06 | | | | | | |
| 20 | | | 0.04 | | | | | | | | |
| 21 | | 0.02 | | 0.05 | | | | | | | |
| 22 | | 0.08 | 0.04 | 0.05 | 0.11 | | 0.07 | 0.07 | 0.08 | 0.03 | |
| 23 | | 0.02 | | | | | | 0.04 | | | |
| 24 | | | | | | | 0.03 | 0.04 | | | |
| 25 | | | | | | | 0.03 | | | | |
| Chain Words | 8 | 30 | 15 | 15 | 10 | 15 | 16 | 19 | 20 | 15 | 6 |
| Content | 14 | 48 | 27 | 19 | 18 | 28 | 29 | 28 | 38 | 30 | 9 |
| Density | 0.57 | 0.62 | 0.56 | 0.79 | 0.56 | 0.54 | 0.55 | 0.68 | 0.53 | 0.50 | 0.67 |

Similarly, we find that $d_{4,1} = 0.07$, and so on. The result of these calculations is that each paragraph in the article will have associated with it a vector of chain densities. Each of these vectors will contain an element for each of the chains in the article. These *chain density vectors* for our sample article are shown in figure 4.3. Note that an empty element in a vector indicates a density of 0, that is, it indicates that a particular paragraph contained no words from a particular chain.

## 4.2 Determining paragraph links

As we said earlier, the parts of a document that are about the same thing, and therefore related, will tend to contain the same lexical chains. Given the chain density vectors that we computed above, we need a method to determine the similarity of the sets of chains contained in each paragraph.

### 4.2.1 Weighting chain density vectors

Although the similarity between paragraphs can be calculated using the chain density vectors as they are computed from the paragraphs of the article, this does not take into account Morris and Hirst's intuition that some chains are more important (or stronger) than others. Thus, the chain density vectors can be weighted using one of three different weighing functions:

**Stairmand weighting** This strategy is due to Stairmand (1994). The weight for each chain in a document is computed by considering the distance between successive paragraphs that contain elements of the chain. This function will increase[1] the density for those chains that have many elements that occur close together.

**Chain length** Each element of the chain density vector is weighted by considering the total length of that particular chain, that is, the total number of elements in the chain (including term repetitions). By using this function, we will increase the density of each chain depending on the number of elements in the chain, the intuition being that long chains represent major aspects of an article, and so they should contribute more towards the decision to link two paragraphs.

**Overall density** Each element of the chain density vector is weighted by considering the density of that chain throughout the entire article (i.e., the number of elements of the chain divided by the total number of content words in the document.) This function increases the density for chains that are long with respect to the length of the document, that is, this is a measurement of relative chain length.

[1] Note that we are using the term "increase" only for simplicity's sake. Whether the weighting function increases or decreases the density of a particular chain depends on whether we are using an association coefficient or a distance coefficient, respectively, to calculate the similarity between density vectors.

### 4.2.2 Normalizing chain density vectors

We can also normalize the chain density vectors in two different ways:

**Unit length** The vectors are normalized so that their length is 1.

**Zero mean** The vectors are normalized so that the mean of the elements in the vector is 0.

Generally speaking, normalization is used to ensure that vectors representing large sections of a text are not necessarily more important than vectors representing shorter sections. This is important in IR systems such as SMART where the size of the documents in a database may vary considerably. It is most likely that this is less useful in the case of newspaper articles, since there will not be nearly as much variation in the length of paragraphs within a single article.

Although there is apparently no use for these normalization functions in a newspaper context, our experience demonstrates that they become necessary when paragraph size begins to exceed that typically found in newspaper articles. For example, in section 5.4 we will describe a test in which some of the articles were taken from magazines. In these cases, generating intra-article links with no normalization function led to an inordinately large number of links.

### 4.2.3 Calculating paragraph similarity

Once we have the set of (possibly weighted and normalized) chain density vectors, the second stage of paragraph linking is to compute the similarity between the paragraphs of the article by computing the similarity between the chain density vectors representing them. We can compute the similarity between two chain density vectors using any one of 16 similarity coefficients that we have taken from Ellis et al. (1994a). These 16 similarity coefficients include both distance coefficients (where smaller numbers indicate a greater similarity) and association coefficients (where larger numbers indicate a greater similarity). Table 4.4 gives the names and definitions of these functions.

We are assuming that we can choose freely among these coefficients, since they have all been used in the past to perform exactly the kind of task that we want to use them for, namely comparing the similarity of two text representations. Ellis et al. selected this subset of the similarity functions that have been discussed in the IR literature because they could show that there were no strong correlations in their values for a set of test documents.

Table 4.4: Functions for calculating paragraph similarity.

| Function Name | Formula | Range | Function Name | Formula | Range |
|---|---|---|---|---|---|
| Manhattan | $\sum \lvert x_i - y_i \rvert$ | 0 to ∞ | Russel/Rao | $\frac{\sum(x_i \cdot y_i)}{n}$ | 0 to ∞ |
| Mean Manhattan | $\frac{\sum \lvert x_i - y_i \rvert}{n}$ | 0 to ∞ | Sokal/Sneath | $\frac{\sum(x_i \cdot y_i)}{2\sum x_i^2 + 2\sum y_i^2 - 3\sum(x_i \cdot y_i)}$ | 0 to 1 |
| Euclidean | $\sqrt{\sum(x_i - y_i)^2}$ | 0 to ∞ | Kulczynski (1) | $\frac{\sum(x_i \cdot y_i)}{\sum x_i^2 + \sum y_i^2 - 2\sum(x_i \cdot y_i)}$ | 0 to ∞ |
| Mean Euclidean | $\frac{\sqrt{\sum(x_i - y_i)^2}}{n}$ | 0 to ∞ | Ochial | $\frac{\sqrt{\sum(x_i \cdot y_i)}}{\sqrt{\sum x_i^2 \cdot \sum y_i^2}}$ | 0 to 1 |
| Mean Squared Euclidean | $\frac{\sum(x_i - y_i)^2}{n}$ | 0 to ∞ | Kulczynski (2) | $\frac{\frac{\sum(x_i \cdot y_i)}{2}(\sum x_i^2 \cdot \sum y_i^2)}{\sum x_i^2 + \sum y_i^2}$ | 0 to ∞ |
| Bray/Curtis | $\frac{\sum \lvert x_i - y_i \rvert}{\sum(x_i + y_i)}$ | 0 to 1 | Forbes | $\frac{n\sum(x_i \cdot y_i)}{\sqrt{\sum x_i^2 \cdot \sum y_i^2}}$ | 0 to ∞ |
| Jaccard | $\frac{\sum(x_i \cdot y_i)}{\sum x_i^2 + \sum y_i^2 - \sum(x_i \cdot y_i)}$ | 0 to 1 | Fossum | $\frac{n\sum(x_i \cdot y_i) - 1/2}{\sum x_i^2 \cdot \sum y_i^2}$ | 0 to ∞ |
| Dice | $\frac{2\sum(x_i \cdot y_i)}{\sum x_i^2 + \sum y_i^2}$ | 0 to 1 | Simpson | $\frac{\sum \min(x_i, y_i)}{\min(\sum x_i, \sum y_i)}$ | 0 to 1 |

Once we've decided on a similarity metric, we can compute the similarity of each pair of chain density vectors, giving us a symmetric $p \times p$ matrix of similarities, where $p$ is the number of paragraphs in the article. From this matrix we can calculate the mean and the standard deviation of the paragraph similarities.

Table 4.5 shows the $11 \times 11$ similarity matrix for the virtual parenting article. This particular similarity matrix was calculated using the Dice association coefficient with no weighting and no normalization. Since we used an association metric, larger numbers indicate a greater similarity (i.e., the vectors are closer together). Note that only the upper half of the matrix is shown, and that the diagonal entries are all 1.0 (i.e., a paragraph is perfectly similar to itself).

Table 4.5: An 11 × 11 similarity matrix for the virtual parenting article, calculated using the Dice coefficient of similarity.

| Par | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.00 | 0.70 | 0.54 | 0.67 | 0.56 | 0.65 | 0.65 | 0.64 | 0.78 | 0.73 | 0.71 |
| 2 | | 1.00 | 0.57 | 0.71 | 0.88 | 0.83 | 0.84 | 0.90 | 0.93 | 0.89 | 0.76 |
| 3 | | | 1.00 | 0.59 | 0.48 | 0.64 | 0.67 | 0.53 | 0.52 | 0.72 | 0.39 |
| 4 | | | | 1.00 | 0.64 | 0.67 | 0.62 | 0.72 | 0.72 | 0.73 | 0.71 |
| 5 | | | | | 1.00 | 0.73 | 0.65 | 0.89 | 0.90 | 0.72 | 0.77 |
| 6 | | | | | | 1.00 | 0.72 | 0.81 | 0.80 | 0.88 | 0.75 |
| 7 | | | | | | | 1.00 | 0.73 | 0.76 | 0.86 | 0.60 |
| 8 | | | | | | | | 1.00 | 0.93 | 0.78 | 0.82 |
| 9 | | | | | | | | | 1.00 | 0.80 | 0.85 |
| 10 | | | | | | | | | | 1.00 | 0.71 |
| 11 | | | | | | | | | | | 1.00 |

| | |
|---|---|
| Number of pairs: | 55 |
| Average similarity: | 0.72 |
| Std. Deviation: | 0.12 |

### 4.2.4 Deciding on the links

The next step is to decide which paragraphs should be linked, on the basis of the similarities computed in the previous step. We make this decision by looking at how the similarity of two paragraphs compares to the mean paragraph similarity across the entire article. Each similarity between two paragraphs $i$ and $j$, $s_{i,j}$, is converted to a z-score, $z_{i,j}$ using the well-known formula:

$$z_{i,j} = \frac{s_{i,j} - \mu}{\sigma}$$

where $\mu$ is the mean similarity and $\sigma$ is the standard deviation. Thus, each similarity is converted to a measure indicating how many standard deviations away from the mean it is. If two paragraphs are more similar than a threshold given in terms of a number of standard deviations, then a link is placed between them. The result is a symmetric adjacency matrix where a 1 indicates that a link should be placed between two paragraphs.

This $z$-score metric of similarity is meant to capture our intuition that we want to link paragraphs that are "very similar". The problem is that how similar two paragraphs are will depend on the context in which they occur. Articles with a lot of large chains spread throughout them will tend to display higher inter-paragraph similarity scores. If we set a simple threshold to determine which paragraphs to link, then in cases such as this we will tend to link almost all pairs of paragraphs. This is clearly not the right thing to be doing, as this would severely disrupt the reader. What we would like to do is to link only those paragraphs whose similarity significantly deviates from the average. The $z$-score measure that we have proposed is a traditional method for determining how much a single number stands out from the mean.

It should be noted that the use of $z$-scores to determine which paragraphs should be linked carries with it the implicit assumption that the paragraph similarities are normally distributed. In order to test this assumption, we collected the inter-paragraph similarity measures from approximately 1,400 randomly selected articles. Kolmogorov-Smirnov tests show that the inter-paragraph similarities for most of the articles show no significant deviation from the normal distribution. Thus, we feel that the use of $z$-scores is reasonably well justified.

Continuing with our example, consider $s_{1,2} = 0.70$. We know that the mean paragraph similarity is 0.72 and that the standard deviation in paragraph similarity is 0.12. We compute $z_{1,2}$ in the following way:

$$z_{1,2} = \frac{s_{1,2} - \mu}{\sigma} = \frac{0.70 - 0.72}{0.12} = -0.17$$

So, $s_{1,2}$ is 0.17 standard deviations *closer* to 0 than the mean. If we are using a threshold of 1.0, paragraphs 1 and 2 will *not* be linked, since in this case $z_{1,2}$ would have to be greater than 1.0 (since higher scores are better.) If, on the other hand, we consider $s_{2,5} = 0.88$, then we would have $z_{2,5} = 1.33$, and for a threshold of 1.0, we would link paragraphs 2 and 5. Figure 4.6 shows the adjacency matrix that is produced when a $z$-score threshold of 1.0 is used to compute the links from the similarity matrix in table 4.5.

We can visualize this adjacency matrix as a set of links between the paragraphs as in figure 4.2. This set of links shows exactly the kind of connections that we wanted for this article. The second paragraph (the definition) is linked to paragraphs 5 (an example), 8 (advice), and 9 (a

Table 4.6: Adjacency matrix for the virtual parenting article.

| Par | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 |  | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 |
| 3 |  |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 |  |  |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 |  |  |  |  | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| 6 |  |  |  |  |  | 0 | 0 | 0 | 0 | 1 | 0 |
| 7 |  |  |  |  |  |  | 0 | 0 | 0 | 1 | 0 |
| 8 |  |  |  |  |  |  |  | 0 | 1 | 0 | 0 |
| 9 |  |  |  |  |  |  |  |  | 0 | 0 | 1 |
| 10 |  |  |  |  |  |  |  |  |  | 0 | 0 |
| 11 |  |  |  |  |  |  |  |  |  |  | 0 |

warning). Furthermore, the fifth paragraph is linked to paragraphs 8 and 9.

### 4.2.5 Examining a connection

At this point we should step back and look at the relations between the words in the linked paragraphs. For example, consider the link that was built between paragraphs 2 and 8. This connection was built on the strength of the seven chains that they have in common: chains 1, 2, 3, 12, 17, 22, and 23. Figure 4.3 shows these two paragraphs with only words from these chains highlighted in bold. Terms which are repeated across the two paragraphs are shown in italics. Thus, bold italic terms are both in one of these chains and repeated.

While there is a small amount of term-repetition between these paragraphs (e.g., *cellular phone*, *parent*), standard IR methods would not have enough data available to make the connection. The lexical chains, on the other hand, connect together synonyms such as *kid* and *child*. More-distant connections are also made between the paragraphs, such as the fact that phones, cellular phones, and faxes are all communication media, or the fact that there is a relation between the words *parent* and *child*. This extra information allows the linker to make the connection between these two paragraphs and build a link between them.

As we have noted, the process of lexical chaining is not perfect, and so we must accept some errors (or at least bad decisions) for the benefits that we get. In our sample article, for example, chain 1 is a conglomeration of words that would have better been separated into different

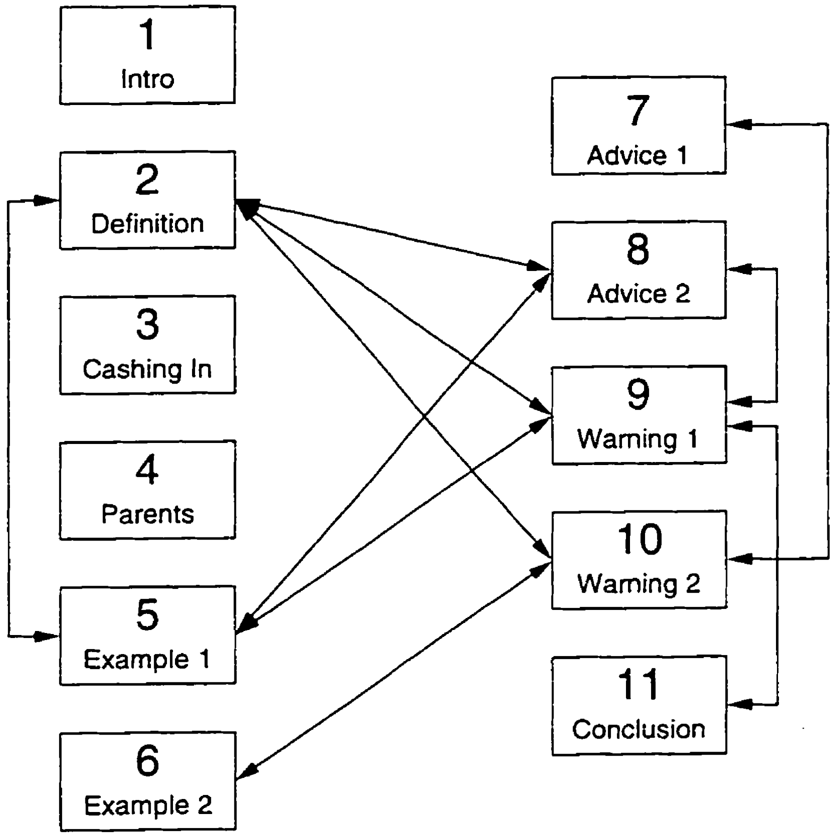


Figure 4.2: Links between paragraphs for the virtual parenting article.

Although no one is **pushing**$^{12}$ virtual-reality headgear as a **substitute**$^{1}$ for **parents**$^{1}$, many technical ad campaigns are promoting *cellular* ***phones***$^{22}$, **faxes**$^{22}$, **computers**$^{1}$ and pagers to **working**$^{1}$ **parents**$^{1}$ as a way of bridging **separations**$^{17}$ from their ***kids***$^{1}$. A recent promotion by A T & T and **Residence**$^{2}$ Inns in the United States, for **example**$^{3}$, suggests that ***business***$^{3}$ ***travellers***$^{1}$ with **young**$^{1}$ children use **video**$^{3}$ and **audiotapes**$^{22}$, **voice**$^{3}$ **mail**$^{3}$, videophones and E-mail to **stay**$^{3}$ connected, including **kissing**$^{23}$ the **kids**$^{1}$ good night by **phone**$^{22}$.

More **advice**$^{3}$ from **advertisers**$^{1}$: ***Business***$^{3}$ ***travellers***$^{1}$ can dine with their ***kids***$^{1}$ by **speaker**$^{1}$-*phone* or "tuck them in" by cordless ***phone***$^{22}$. Separately, a management newsletter recommends faxing your **child**$^{1}$ when you have to **break**$^{17}$ a **promise**$^{3}$ to be **home**$^{2}$ or **giving**$^{12}$ a **young**$^{1}$ **child**$^{1}$ a beeper to make him **feel**$^{23}$ more secure when left alone.

Figure 4.3: Paragraphs 2 and 8 of the virtual parenting article.

chains. This is a side effect of the current implementation of the lexical chainer, but even with these difficulties, we are able to perform useful tasks.

### 4.2.6 Generating a hypertext representation

Once the linker decides which paragraphs should be linked, a representation of the hypertext that can be used for browsing needs to be produced. We have decided to use HTML as our hypertext representation, since it is an open standard and relatively easy to use. This is not to say that HTML is the only possible (or even the best) representation, and we have taken care to ensure that the hypertexts that our method produces will be usable in other hypertext systems. For example, in appendix A we show two hypertexts that were rendered into a form suitable for inclusion in this thesis.

In the current system, there are two ways to output the HTML representation of an article. The first simply displays all of the links that were computed during the last stage of the process described above. The second is more complicated, showing only some of the links. The idea is that links between physically adjacent paragraphs should be omitted so that they do not clutter the hypertext, making it more difficult to use.

The process for generating the HTML is as follows: for each paragraph in the story, we first test whether the current paragraph is the destination of a link from some other paragraph. If it is, then an HTML anchor is generated with the same name as specified in the source paragraph.

The body of the paragraph is then output.

At this point, if we are using the first method for displaying the links, then the appropriate row of the adjacency matrix is scanned, and a link is output for each entry that contains a 1.

If we are using the second method, then links are generated in the following way: first we scan through the appropriate row of the adjacency matrix, looking for the first entry that is 0, in order that we not link to directly adjacent paragraphs. We continue scanning until we encounter a 1, and then output a link for that paragraph and then scan until we reach another 0. The process repeats until each of the other paragraphs has been considered. The result is that the text is broken into "chunks" that are connected by links.

### Choosing anchors

Once the linker makes the decision that a link should be present in the hypertext being displayed, it is necessary to select an *anchor* to represent the link on the page. The anchor is the text that the user will use to decide whether this is a link that they would like to follow. There is relatively little direction about how to build anchors for intra-article links, and several strategies suggest themselves

We could place the anchors in the text so that they surround the words that connect the two paragraphs. This is problematic for two reasons. First, given the density of the lexical chains in the text, and depending on the number of links that are generated, there is a good chance that the user will be looking at "blue" text, text that is *all* links. While this problem can be remedied to some extent using HTML, these anchors would give very little indication about where the link would lead: to the same word somewhere else or to a similar word? The second problem with this strategy is that the same words may participate in links to more than one paragraph. In this case, it would be necessary for the user to select the target at the time that she clicks on the link, a task that would unnecessarily interrupt the browsing process (and also be somewhat difficult to represent in HTML).

It seems more reasonable to separate the anchors from the text of the paragraphs. In the case of our system, the anchor text selected for these separate links is the first few words of the destination paragraph. This is a relatively straightforward anchoring strategy that has some problems of its own, most notably that pronouns in the anchor text are not resolved, leading to confusion about where a link leads. Still, this strategy seems to be a better one than placing the links within the text of the paragraph.

If the links are placed outside the text of the paragraph, then we must decide how to display them to the user. Currently, our system displays the links for a paragraph directly after the text of the paragraph. This is relatively intrusive, and it might be better to place the links in a separate frame that would track the user's motion through the hypertext. The benefit of our present method is that it is displayable on a wide range of Web browsers, something that cannot be said for a frame-based solution.

## 4.3 Selecting representative hypertexts

The previous sections detailed our method for the generation of intra-article links, but do not answer an important question: How do we choose a set of parameters (a similarity coefficient, a weighting function, a normalization function, and a $z$-score threshold) for generating these links?

Clearly, the choice of a specific set of parameters will produce a particular set of paragraph links. We have discussed the 16 similarity metrics available, the choice of four weighting functions (including the choice of *no* function), and the choice of three normalization functions. The $z$-score threshold is a real number, but our examinations have demonstrated that it seems best to select thresholds between 1.0 and 2.0 in increments of 0.1, giving us 11 possible similarity thresholds. Given these possibilities, we are capable of generating $4 \times 3 \times 16 \times 11 = 2112$ hypertexts. Obviously, not all of these will be distinct, since for many articles, there are less than 2112 possible pairs of paragraphs.

Fortunately, upon closer examination, the problem is not nearly this complex. As we've mentioned previously, the normalization functions will not be very useful in a newspaper domain, since these kinds of functions are generally meant to prevent the vectors associated with larger paragraphs from "overwhelming" those associated with shorter paragraphs. In newspaper articles, there will be not nearly as much variation in paragraph size as there is in magazine articles. Furthermore, many of the similarity metrics include something very similar to normalization so that they will generate similarities between 0 and 1. So, if the normalizations will have no effect or if they are already accounted for, we can leave them out of consideration (at least for newspaper articles).

The z-score threshold can obviously take on a large number of values, but for the most part, the value of this threshold will affect a very visible factor in the hypertext: the number of links. Given the way we've developed the linking methodology, as the z-score threshold increases we will eliminate more and more pairs of paragraphs as possible candidates for linking, since their z-score will not exceed the increased threshold. This is clearly something straightforward enough that it could be put under the control of the user through the use of some sort of sliding control between "More links" and "Less links" with appropriate scores at either end of the interval. If we do leave this threshold to the user's taste, then we will need to ensure that any such control will work in a consistent way, no matter what article it is used for.

Having dealt with normalization and the similarity threshold, we are left with the question of which similarity metric and weighting function to use. Our 16 similarity functions and 4 weighting schemes give us 64 possible hypertexts from a single article. Of course, some of these may be the same. Even if there are many duplicate hypertexts, we still have the problem of judging which ones are "good". Unfortunately, we would need to examine a very large number of hypertexts in order to do this, and the task may be fruitless in any event, since making this judgment seems to be another aspect of the problems encountered by Ellis et al. and Allan, as discussed in sections 2.4.1 and 2.5.2.

Most systems that compute document similarity do so using some variation of the Dice coefficient (e.g., the cosine measure used in vector space systems). Ellis et al., however, showed that there were no strong correlations among any of the 16 similarity coefficients that we are using. There does not seem to be any *a priori* way to select among the various similarity coefficients.

It is left to us then to decide how we can reduce this space of possible hypertexts to a set of *representative* hypertexts; that is, given the 64 possible combinations of a similarity metric and a weighting function, can we determine which combinations will produce similar hypertexts? We can use the method of Ellis et al. to compute the pairwise similarity between all of the hypertext versions of an article and then can then cluster the hypertexts on the basis of their similarity. By doing this for a large number of articles, we should be able to use the results to determine if there is a large number of co-occurrences between any of the 64 combinations.

The idea underlying this computation is that if two hypertexts are highly similar (in the sense that they have most of the same links), then clearly our algorithm for generating intra-article links is insensitive to whatever variation there might be in the similarity or weighting function. If we can find these insensitivities, then we can reduce our problem space to a more manageable size. If we could reduce the number of parameter sets to four or five, then evaluation of which is "best" (or which one people would prefer) would be relatively straightforward.

We performed this clustering operation for a random sample of 97 articles from the *Globe and Mail* of 1992. The average number of paragraphs for these articles was 10.13, and the average initial number of hypertexts (after equivalent hypertexts had been removed from consideration), was 20.2. After the clustering operation, the average number of representative sets was 4.31. Unfortunately, the co-occurrence counts for the pairs of similarity function and weighting function show no obvious pattern of co-occurrence — the distribution of pairs among clusters is relatively uniform.

We would like to submit all of these possible hypertexts to experiment to see which are "best", but this would be prohibitively expensive, especially in light of the fact that we have not determined yet whether the kind of intra-article links that we are proposing is useful in information retrieval tasks. In chapter 6 we shall tackle this question.

# Chapter 5

# Linking between articles

While it is useful to be able to build links within articles, for a large scale hypertext, links also need to be placed between articles. You will recall from section 2.2 that the output of the lexical chainer is a list of chains, each chain consisting of one or more words. Each word in a chain has associated with it one or more synsets. These synsets indicate the sense of the word as it is being used in this chain. An example of the kind of output produced by the chainer is shown in table 5.1, which shows the chains extracted from an article (Gadd, 1995b) about cuts in staff at children's aid societies due to a reduction in provincial grants. As before, the numbers in parentheses show the number of occurrences of a particular word. Table 5.2 shows another set of chains, this time from an article (Gadd, 1995a) describing the changes in child-protection agencies, due in part to budget cuts.

It seems quite clear that these two articles are related, and that we would like to place a link from one to the other. It is also clear that the words in these two articles display both of the linguistic factors that affect IR performance, namely synonymy and polysemy. For example, the first set of chains contains the word *abuse*, while the second set contains the synonym *maltreatment*. Similarly, the first set of chains includes the word *kid*, while the second contains *child*. The word *abuse* in the first article has been disambiguated by the lexical chainer into the "cruel or inhuman treatment" sense, as has the word *maltreatment* from the second article. We once again note that the lexical chaining process is not perfect: for example, both texts contain the word *abuse*, but it has been disambiguated into different senses.

Although the articles share a large number of words, by missing the synonyms or by making incorrect (or no) judgments about different senses, a traditional IR system might miss the relation between these documents or rank them as less related than they really are. Aside from

Table 5.1: Lexical chains from an article about cuts in children's aid societies.

| C | Word | Syn |
|---|---|---|
| 1 | drop (1) | 42930 |
|  | fall (1) | 42930 |
|  | shortfall (1) | 42938 |
|  | deficit (1) | 42938 |
| 2 | aid (3) | 72660 |
|  | support (2) | 72660 |
|  | grant (1) | 72663 |
| 3 | society (7) | 54351 |
|  | group (1) | 19698 |
|  | mother (1) | 62088 |
|  | parent (4) | 62334 |
|  | kid (1) | 60256 |
|  | recruit (1) | 62769 |
|  | employee (2) | 60862 |
|  | worker (2) | 59145 |
|  | computer (1) | 60118 |
|  | teen-ager (2) | 59638 |
|  | provincial (3) | 62386 |
|  | face (1) | 59111 |
|  | spokesman (1) | 63287 |
|  | insolvent (1) | 59869 |
|  | annual (1) | 64656 |
| 4 | ron (1) | 49609 |
| 5 | ontario (1) | 56918 |
|  | canadian (1) | 58424 |
|  |  | 59296 |
|  | burlington (1) | 57612 |
|  | union (3) | 57424 |
| 6 | record (1) | 73286 |
|  | budget (2) | 73288 |
|  | pay (1) | 72709 |
|  | question (1) | 48679 |
|  |  | 50328 |
|  |  | 50336 |
|  | information (1) | 48081 |
| 7 | staff (3) | 55303 |
|  | public (1) | 54349 |
|  | high (2) | 55689 |
| 8 | program (3) | 45706 |
|  | plan (1) | 45706 |
|  | attribute (1) | 45567 |
|  | basis (1) | 45366 |
| 9 | cut (4) | 20950 |
|  | reduction (1) | 20949 |
|  | pay_cut (1) | 20952 |
|  | hire (1) | 24218 |
|  | decision (1) | 20204 |
|  | call (1) | 20208 |
|  | travel (1) | 20661 |
|  | running (1) | 20709 |
| 10 | saying (1) | 50294 |
|  | interview (2) | 50268 |
| 11 | wednesday (1) | 79629 |
| 12 | per_cent (3) | 75017 |
|  | proportion (1) | 75012 |
| 13 | cope (1) | 36156 |
|  | john (1) | 40190 |
|  | board (2) | 79392 |
| 14 | receiving (1) | 19907 |
|  | addition (1) | 19858 |
| 15 | nothing (1) | 74685 |
|  | year (1) | 79808 |
|  |  | 79819 |
|  |  | 79820 |
|  | birth (1) | 79543 |
|  | start (2) | 80111 |
|  | oct (1) | 79867 |
|  | week (2) | 79505 |
|  |  | 79506 |
|  | yesterday (4) | 79599 |
|  | day (2) | 79595 |
|  | night (1) | 79596 |
|  |  | 79646 |
| 16 | subdivision (1) | 21139 |
|  |  | 39145 |
|  |  | 47219 |
|  |  | 55646 |
|  |  | 56540 |
| 17 | funding (1) | 23765 |
| 18 | number (2) | 47893 |
|  | issue (1) | 47893 |
|  | monthly (1) | 47883 |
| 19 | durham (2) | 30254 |
| 20 | region (2) | 56394 |
|  | outside (1) | 56323 |
|  | front_line (1) | 56193 |
|  | home (2) | 55932 |
|  |  | 56234 |
|  | response (2) | 64129 |
|  | process (1) | 73369 |
|  | reducing (1) | 73441 |
|  | pressure (1) | 64434 |
| 22 | treatment (1) | 23905 |
|  | management (1) | 23903 |
|  | government (1) | 23871 |
| 23 | working (1) | 40755 |
|  | extra (1) | 33311 |
| 24 | spending (1) | 23855 |
| 25 | social (2) | 55184 |
| 26 | million (1) | 74742 |
| 27 | try (1) | 22561 |
|  | seeking (1) | 22571 |
|  | acting (1) | 21759 |
|  | services (1) | 21922 |
|  | work (3) | 21919 |
|  | risk (2) | 22613 |
|  | care (1) | 22204 |
|  | social_work (1) | 24180 |
|  | slowdown (1) | 23640 |
|  | abuse (3) | 21214 |
|  | child_abuse (1) | 21215 |
|  | neglect (1) | 21235 |
| 28 | living (1) | 75629 |
|  | standing (1) | 75573 |
|  | complaint (1) | 76270 |
|  | agency (1) | 75786 |
|  | stress (1) | 76799 |
|  |  | 76906 |
| 29 | suck (2) | 22767 |
| 30 | think (1) | 45337 |
| 31 | family (3) | 54362 |
|  | people (3) | 54363 |
| 32 | executive_director (2) | 60922 |
|  | manager (1) | 59634 |
| 33 | times (1) | 79443 |
| 34 | money (1) | 73198 |
|  | stake (1) | 72746 |
| 35 | crude (1) | 78956 |
| 36 | empty (1) | 35183 |
| 37 | layoff (2) | 20457 |
| 38 | norm (1) | 46113 |
|  |  | 75184 |

Table 5.2: Lexical chains from a related article.

| C | Word | Syn | C | Word | Syn | C | Word | Syn |
|---|---|---|---|---|---|---|---|---|
| 1 | canadian (1) | 58424 | | prostitute (1) | 62660 | 6 | numbers (1) | 21560 |
| | river (1) | 58309 | | provincial (2) | 62386 | 7 | give (1) | 42565 |
| | rapid (1) | 58321 | | welfare_worker (1) | 63220 | 8 | laws (1) | 47389 |
| | britain (1) | 57004 | | lorelei (1) | 61833 | 9 | onus (1) | 45505 |
| | country (1) | 56080 | | god (1) | 58615 | 10 | say (4) | 77086 |
| | ontario (4) | 56918 | 4 | protection (2) | 22672 | 11 | better (1) | 43058 |
| | toronto (2) | 56919 | | care (5) | 22721 | | | 43059 |
| | vancouver (1) | 56906 | | preservation (2) | 22676 | | bad (2) | 43062 |
| | canada (1) | 56897 | | judgment (1) | 22881 | 12 | draw (1) | 20012 |
| | new_brunswick (1) | 56909 | | act (1) | 19697 | | pulling (1) | 20010 |
| | ottawa (1) | 56920 | | behaviour (1) | 24235 | | leaving (1) | 19749 |
| | support_system (1) | 55819 | | | 24236 | | sending (1) | 20030 |
| 2 | wit (1) | 48647 | | making (1) | 23076 | | support (3) | 20171 |
| | play (1) | 48668 | | calling (1) | 21911 | | proof (1) | 20169 |
| | abuse (4) | 48430 | | services (2) | 21922 | | getting (1) | 19854 |
| | cut (4) | 48431 | | prevention (1) | 23683 | 13 | recurrence (1) | 51047 |
| | criticism (1) | 48406 | | supply (1) | 23596 | 14 | single (1) | 74692 |
| | recommendation (1) | 48310 | | providing (3) | 23596 | | number (3) | 73854 |
| | case (1) | 48682 | | maltreatment (2) | 21214 | | factor (1) | 73861 |
| | problem (1) | 48680 | | child_abuse (2) | 21215 | | million (1) | 74742 |
| | question (3) | 48679 | | investigation (1) | 22142 | | year (2) | 79808 |
| 3 | child (10) | 60256 | | research (1) | 22143 | | | 79819 |
| | parent (9) | 62334 | | investigating (1) | 22142 | | | 79820 |
| | mother (3) | 62088 | | work (1) | 21885 | | period (1) | 79429 |
| | daughter (1) | 60587 | | aid (9) | 22204 | | week (1) | 79506 |
| | foster_home (1) | 54374 | | social_work (1) | 24180 | | | 79661 |
| | society (5) | 54351 | | risk (1) | 22613 | | day (1) | 79635 |
| | at_home (1) | 55170 | | dispute (1) | 24051 | | | 79842 |
| | social (1) | 55184 | | intervention (1) | 24317 | | years (4) | 80023 |
| | function (1) | 55154 | | fail (1) | 19811 | | month (1) | 79847 |
| | expert (3) | 59108 | 5 | agency (5) | 75786 | | hour (1) | 79949 |
| | human (1) | 19677 | | prison (2) | 75540 | | summer (1) | 79991 |
| | guardian (1) | 59099 | | situation (1) | 75502 | | half (1) | 80080 |
| | official (1) | 62223 | | want (1) | 77120 | | old (3) | 79446 |
| | worker (1) | 59145 | | poverty (3) | 77119 | | past (1) | 79444 |
| | neighbour (1) | 62152 | | need (1) | 77122 | | future (1) | 79448 |
| | youngster (1) | 60255 | | condition (1) | 75493 | | set (1) | 54454 |
| | kid (2) | 60255 | | decline (1) | 76848 | | rate (1) | 80186 |
| | natural (1) | 62139 | | neglect (4) | 76852 | 15 | name (1) | 54366 |
| | lawyer (2) | 61725 | | difficulty (1) | 76792 | | family (8) | 54362 |
| | professional (1) | 62636 | | stress (1) | 76799 | | | |

(cont'd)

Table 5.2: Lexical chains from a related article (cont'd).

| C | Word | Syn | C | Word | Syn | C | Word | Syn |
|---|---|---|---|---|---|---|---|---|
| 16 | call (1) | 19870 | | | 57880 | 38 | system (4) | 45139 |
| | | 20208 | | | 62738 | | plan (1) | 45520 |
| | | 23590 | 27 | day_care (1) | 24188 | | november (1) | 79869 |
| | | 23591 | 28 | normal (1) | 44921 | | reason (1) | 45459 |
| | | 46540 | 29 | per_cent (1) | 75017 | | lead (1) | 45488 |
| | | 46798 | 30 | produce (1) | 52869 | | evidence (2) | 45475 |
| | | 47837 | 31 | child_support (1) | 72806 | | aim (1) | 45996 |
| | | 48737 | | cost (1) | 72821 | | | 46001 |
| | | 50172 | 32 | major (1) | 61881 | | experience (1) | 46011 |
| | | 50445 | 33 | school (1) | 55261 | | part (1) | 45631 |
| | | 50452 | | university (1) | 55299 | | end (3) | 45634 |
| | | 50455 | | professor (1) | 62638 | | total (1) | 45605 |
| | | 50456 | 34 | led (1) | 36879 | 39 | keeping (1) | 22674 |
| 17 | budget (1) | 73288 | 35 | rock (1) | 57716 | | supervision (1) | 23908 |
| | | 73362 | | type (1) | 40411 | 40 | headline (1) | 47032 |
| 18 | high (1) | 56231 | | bob (1) | 32045 | 41 | tragedy (1) | 50939 |
| | place (1) | 56524 | | | 36895 | | breakdown (1) | 51097 |
| 19 | profile (1) | 47606 | | level (1) | 35493 | 42 | crack (2) | 34491 |
| | life (1) | 47603 | | | 35495 | | cocaine (1) | 34123 |
| 20 | executive_director (1) | 60922 | | home (2) | 35090 | 43 | putting (1) | 21871 |
| 21 | matthew (1) | 64046 | | housing (2) | 36932 | 44 | alcoholic (1) | 59668 |
| | john (1) | 64019 | 36 | sweeping (1) | 20525 | 45 | harm (2) | 51359 |
| 22 | sword (1) | 39915 | | reform (1) | 20562 | | dwindling (1) | 51367 |
| 23 | wish (1) | 51618 | | overhaul (1) | 20596 | 46 | metro (1) | 37269 |
| | desire (1) | 51606 | | killing (1) | 20412 | 47 | positive (1) | 38232 |
| 24 | health (1) | 76967 | | death (1) | 20414 | 48 | things (1) | 72559 |
| | welfare (8) | 76965 | | shift (3) | 20873 | 49 | authorities (1) | 54501 |
| 25 | education (1) | 45224 | | move (1) | 20650 | | court (1) | 55432 |
| | special_education (1) | 45230 | | rise (1) | 20839 | | united_states (3) | 55495 |
| | study (1) | 45212 | | movement (1) | 20650 | | work_force (1) | 54965 |
| 26 | rip (1) | 21119 | | approach (1) | 20651 | | institute (2) | 55680 |
| | | 51285 | 37 | rear (1) | 56391 | | turner (1) | 63644 |

the problems of synonymy and polysemy, we can see that there are also more-distant relations between the words of these two articles. For example, the first set of chains contains the word *maltreatment* while the second set contains the related word *child abuse* (a kind of maltreatment).

Our aim is to build hypertext links between articles that will account for the fact that two articles that are about the same thing will tend to use similar (although not necessarily the same) words. These *inter-article* links can be built by determining how links could be built between the words of the chains from the two articles. By using the lexical chains extracted from the articles, rather than just the words, we can account for the problems of synonymy and polysemy, and we can take into account some of the more-distant relations between words.

## 5.1 Comparing chains across documents

Once we have extracted the lexical chains from a document, we can consider how the words that make up these chains are related to the chains extracted from another document. This comparison can be seen as exactly the same sort of operation that was done during the initial chaining of both documents, that is, this comparison is a kind of "cross-document" chaining.

The main difference from chaining within a document is that in cross-document chaining, we want to restrict the chaining algorithm so that only extra strong and strong relations are allowed. We enforce such a restriction for two reasons. First, allowing regular relations between words will introduce too many spurious connections. For example, in table 5.2, chain 38 contains the words *November* and *evidence*. This is clearly not the kind of relation that we would like to build in general. We allow it at the article level so that intra-article links can be built more easily.

The other reason is that the bulk of the time spent in lexical chaining is devoted to finding regular relations, since this involves performing a complicated graph traversal in WordNet. This is not a problem when dealing with small amounts of text (as in the original chaining of a document), but becomes problematic when we wish to perform chaining operations on large numbers of texts in real-time.

Along with the restriction on the types of relations between words, we will need to ensure that there is a certain minimum number of links between the chains of two documents before we can say that the documents are related. We require multiple connections so that polysemy does not lead us to place a link where there should not be one.

Consider the following case: Suppose that we allow two chains from two different documents to be related on the strength of only one link. It is possible that two chains containing the word *bank*, for example, could be related, even though one chain uses bank in the "financial" sense, and one uses it in the "river" sense. This can be resolved by considering what synsets are associated with a word, but consider the case where we have the word *union* in two different articles. Even if both articles use the word in the "labour movement" sense, one article may be about the police union, while the other is about the auto workers union. We require multiple connections because the probability that multiple words are co-ambiguous is relatively quite small.

## 5.2 An initial approach

If we wish to link two articles using their lexical chains, taking into consideration the above criteria, then there is a straightforward solution. Given two sets of chains, we can determine the number of connections between them using the following algorithm:

```
Algorithm 1: Cross-document chaining.
Input: $C_1$ and $C_2$, chain sets from different documents
Output: The number of strong and extra strong links between the articles
RELATED($C_1, C_2$)
    foreach chain $c_1$ in $C_1$
        foreach chain $c_2$ in $C_2$
            foreach word $w_1$ in $c_1$
                foreach word $w_2$ in $c_2$
                    if $w_1 = w_2$ and $w_1$ and $w_2$ share a synset then
                        extra_strong++
                    else if $w_1$ and $w_2$ share a synset or $w_1$ has a synset that is a
                    single link from a synset of $w_2$ then
                        strong++
```

Once we have determined the number of strong and extra strong connections between two chain sets, we can decide whether they should be related.

The main strength of this algorithm is its simplicity. It is easy to implement and understand. It also has the desirable property that documents that contain the same term can only be related when the two words share the same synset (i.e., when the words are used in the same sense). Salton et al. (1993) have used a local/global criteria for document similarity in order to solve this problem, but this is a natural side effect of the lexical chaining process.

Unfortunately, this approach also has some rather debilitating weaknesses. Due to the hierarchical structure of WordNet, it is very easy to find documents that have a large number of related words, even when the documents are completely unrelated. When a word in a chain is in synsets that are near the top of WordNet's hierarchy, there are a large number of synsets that are a single IS-A or INCLUDES link away. Very general words like *human* can be linked to a large number of other words. This is especially a problem when the articles in question are long, since there is more opportunity for such connections.

The other main weakness is that this approach is extremely time consuming. Clearly we need to compare each word in $C_1$ with each word in $C_2$, which takes $O(n^2)$ time (if the number of words in each set of chains is comparable). At steps 5 and 7 in the above algorithm, we need to search a list of synsets of which $w_1$ and $w_2$ are members (usually not very large) and a list of synsets that are one link away from one of $w_1$ or $w_2$'s synsets. This second list can be quite large, for example, the word *human* has 165 synsets that are one link away from one of its synsets. So, if $m$ is the number of linked synsets, then to do the comparisons between words requires $O(m^2)$ time, not counting the time to do the comparison of the word strings. If $m$ is of the same order as $n$, then we are dealing with a very inefficient algorithm.

Our calculations indicate that, using this method, it would take approximately six years to determine all possible inter-article links for one year of the *Globe and Mail*. If we attempt to do this in real-time, and simply search through a year of articles to find links from a particular article, we can reduce the time to approximately one hour. Unfortunately, this is still unacceptable.

The problem is that there is no straightforward, global description for a document, so each set of chains must be treated as a special case. In traditional vector space IR systems the term weight vector provides such a global description. This vector is the same length for each document, and a particular element of the vector is used for the weight of a particular term in every document. Lexical chaining, on the other hand, is more fluid. It is highly unlikely that two documents will contain the same set of lexical chains. In the vector space model, it is a simple decision to say whether two documents have a term in common; all that is required is to check the term weight vector. Discovering related documents is as simple as taking the dot product of two vectors. It is quite difficult to say that two documents have related chains, since it is necessary to try to relate each of the words in the two chains of interest.

In order to build a system that is reasonably efficient, we need to devise a simple, global representation for the lexical chains which retains the properties of disambiguation and linking-by-relation as the method described above, while at the same time dealing with the problem of spurious links.

## 5.3 Synset weight vectors

In considering the simple algorithm shown above, we noted that much of the work being done was simply determining whether two words have a synset in common or whether a synset of one word is one link away from a synset of the other word. Our first step will be to make this process more efficient.

### 5.3.1 Simple synset vectors

We can represent each chain in a document by two vectors. Each vector will have an element for each synset in WordNet. An element in the first vector will contain the number of occurrences of that particular synset in the words of the chains contained in the document. An element in the second vector will contain the number of occurrences of that particular synset when it is one link away from a synset associated with a word in the chains. We will call these vectors the *member* and *linked synset vectors,* or simply the member and linked vectors, respectively.

We can then compute the relatedness of two chains $C_1$ and $C_2$ by measuring three similarities (shown by the lines in figure 5.1):

1. The similarity of the member vectors of $C_1$ and $C_2$;
2. The similarity of the member vector of $C_1$ and linked vector of $C_2$; and
3. The similarity of the linked vector of $C_1$ and the member vector of $C_2$.

Clearly, the first similarity measure (which we call the *member-member* similarity) is the most

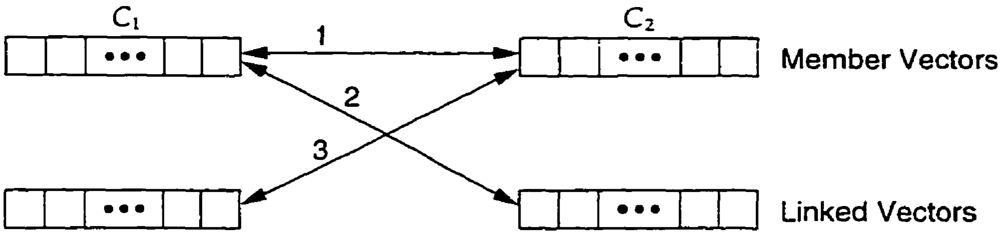


Figure 5.1: Computing chain similarity.

important, as it will capture extra strong (i.e., term repetition) relations as well as strong relations between synonymous words. The last two measures (called the *member-linked* similarities) are less important as they capture strong relations that occur between synsets that are one link away from each other.

If we enforce a threshold on these measures of relatedness, we can capture our requirement for multiple connections, since each element of the vectors will contribute only a small part of the overall similarity. We can calculate this similarity for all pairs of chains from two articles, and if there are a certain number of pairs that are more similar than our threshold, we can then say that the two articles should be linked. We have also removed the necessity for performing actual string comparisons on the words contained in the two sets of chains.

Unfortunately, this method still has some efficiency problems. It will be necessary to compute the similarities for all pairs of chains in the two articles. It would be more efficient if the member and linked vectors were built at the article level, rather than at the chain level.

It is reasonable to assume that, if we build the member vectors at the chain level, then they will be nearly disjoint (i.e., they will tend not to have synsets in common). This is a side-effect of the lexical chaining process: if two words share a synset, then they would likely have been placed in the same chain. So, at the article level, calculating the similarity between member vectors will be as effective as calculating the similarity between the pairs of member vectors at the chain level.

The linked synset vectors for the various chains will, in all likelihood, have many synsets in common, especially when chains include words such as *human*, as we showed above. As strong relations due to IS-A or INCLUDES relations are less important, the overlap may not seem to pose much of a difficulty. In reality, this overlap means that the linked vectors will be populated with high-frequency synsets that will contribute enough to the similarity calculation to introduce links where there should be none. In addition to this, we will still have the problem of a longer article's vectors, with many more synsets, overwhelming a shorter article's vectors. To solve these problems, we look to traditional vector space approaches to IR.

### 5.3.2 Synset weight vectors

As we said in section 2.3.2, in the vector space model for IR, documents are represented by weighted term vectors. The weight of a particular term in a particular document is not based solely on the frequency of that term in the document, but also on how frequently that term appears throughout the database. The terms that are the most heavily weighted in a document are the ones that appear frequently in that document but infrequently in the entire database.

The equation from Salton and Allan (1993) used to compute term weights will serve equally well when computing weights for synsets:

$$w_{ik} = \frac{sf_{ik} \cdot \log(N/n_k)}{\sqrt{\sum_{j=1}^{t}(sf_{ij})^2 \cdot (\log(N/n_j))^2}}$$

Here, $w_{ik}$ is the weight of *synset* $k$ in document $i$, $sf_{ik}$ is the frequency of synset $k$ in document $i$, $n_k$ is the number of documents that contain synset $k$, and $N$ is the number of documents in the entire collection.

In our case, rather than calculate a single set of weights incorporating the frequencies of both member and linked synsets, the weights are calculated independently for the member and linked vectors. We do this because the linked vectors introduce a large number of synsets that do not necessarily appear in the original chains of an article, and should therefore not influence the frequency counts of the member synsets. Thus, we make a distinction between strong relations that occur due to synonymy, and ones that occur due to IS-A or INCLUDES relations.The similarity between documents is then determined by calculating the three similarities between member and linked vectors discussed above.

These synset weight vectors can be seen as a *conceptual* or *semantic* representation of the content of an article, as opposed to the traditional IR method of representing a document by the words that it contains. This representation also addresses both synonymy and polysemy. Synonymy is taken care of by virtue of the fact that all of the synonyms for a word will be collected in the same synset, and therefore represented in the same element of the synset vectors. Because of the disambiguation performed by the lexical chainer, a word will be represented only by synsets (i.e., senses) that are appropriate in the context of the article. Only these synsets will appear in the weighted synset vectors, solving (to some extent) the problem of polysemy.

As a side-effect of representing documents by the synsets that they contain, we reduce the size of the vectors needed to represent each document. For a database of four months of the *Globe and Mail* we find that there are 31,360 distinct synsets in the member vectors and 46,612 distinct synsets in the linked vectors. Thus, the combined size of the two vectors necessary to represent an article (77,962) is substantially smaller than the more than 108,000 unique terms that Forsyth (1986) says we can expect. This reduction in dimensionality is similar to the reduction that we see in Latent Semantic Indexing, although their reduction is even more substantial than ours (from 108,000 terms to 200 factors).

### 5.3.3 Building inter-article links

Once we have built a set of synset weight vectors for a collection of documents, the process of building links between articles is relatively simple. Given an article that we wish to build links from, we can compute the similarity between the article's synset weight vectors and the vectors of all other documents. If the member-member similarity of two articles is higher than a given threshold, then we can calculate the two member-linked similarities and place a link between the two documents. We can rank the links using the sum of the three document similarities that we compute. Our work shows that a threshold of 0.15 will include most related documents while excluding many unrelated documents. In section 4.2.4 we discussed the fact that the distributions of inter-paragraph similarities seemed to be close to normal. No such claim can be made for the distribution of inter-article similarities. In fact, in a sample of approximately 500,000 inter-article similarities calculated from 20 different articles, only 584 met or exceeded our threshold of 0.15.

By using such a strenuous threshold, we enforce our constraint that there must be multiple connections between the chains of the documents. This is almost exactly the methodology used in vector space IR systems such as SMART, with the difference being that for each pair of documents we are calculating three separate similarity measures. By using the sum of the three similarities as our ranking criterion, we are taking full account of not only the terms and synonyms that the documents have in common, but also how many more distantly related terms that they share. The sum of the three similarities can lie, theoretically, anywhere between 0 and 3. In practice, the sum is usually less than 1. For example, the average sum of the three similarities when running the vectors of a single article against 5,592 articles is 0.039.

This method is also much more efficient than the methods that we discussed in the previous sections. For a database of approximately 30,000 articles and a threshold of 0.15, it takes approximately 1.2 seconds to build all the links from a single document. This is certainly more in line with the demands of a system that must perform in real-time.

### 5.3.4 How related words affect linking

Now that we have settled on a method for building inter-article links, we can see how the two sets of chains shown in table 5.1 and table 5.2 are handled. Tables 5.3 and 5.4 give information about the member and linked vectors that represent these two articles.

Table 5.3: Lengths of the vectors in the example articles.

| Article | Vector | Length | Article | Vector | Length |
|---|---|---|---|---|---|
| 1 | Member | 128 | 2 | Member | 215 |
| 1 | Linked | 574 | 2 | Linked | 1481 |

Table 5.4: Similarities of the vectors in the example articles.

| | Article 1 | |
|---|---|---|
| Article 2 | Member | Linked |
| Member | 0.224 | 0.096 |
| Linked | 0.079 | — |

If we are using a linking threshold of 0.2, then we will place a link between these articles. The sum of the similarities for these two articles is 0.399. Approximately 23% of the member-member similarity of these articles is accounted for by synsets from which the articles do not share exactly the same words. This proportion of the similarity is sufficiently large that, if it were removed, the member-member similarity of these articles would fall below the linking threshold that we had set.

## 5.4 A preliminary test of inter-article links

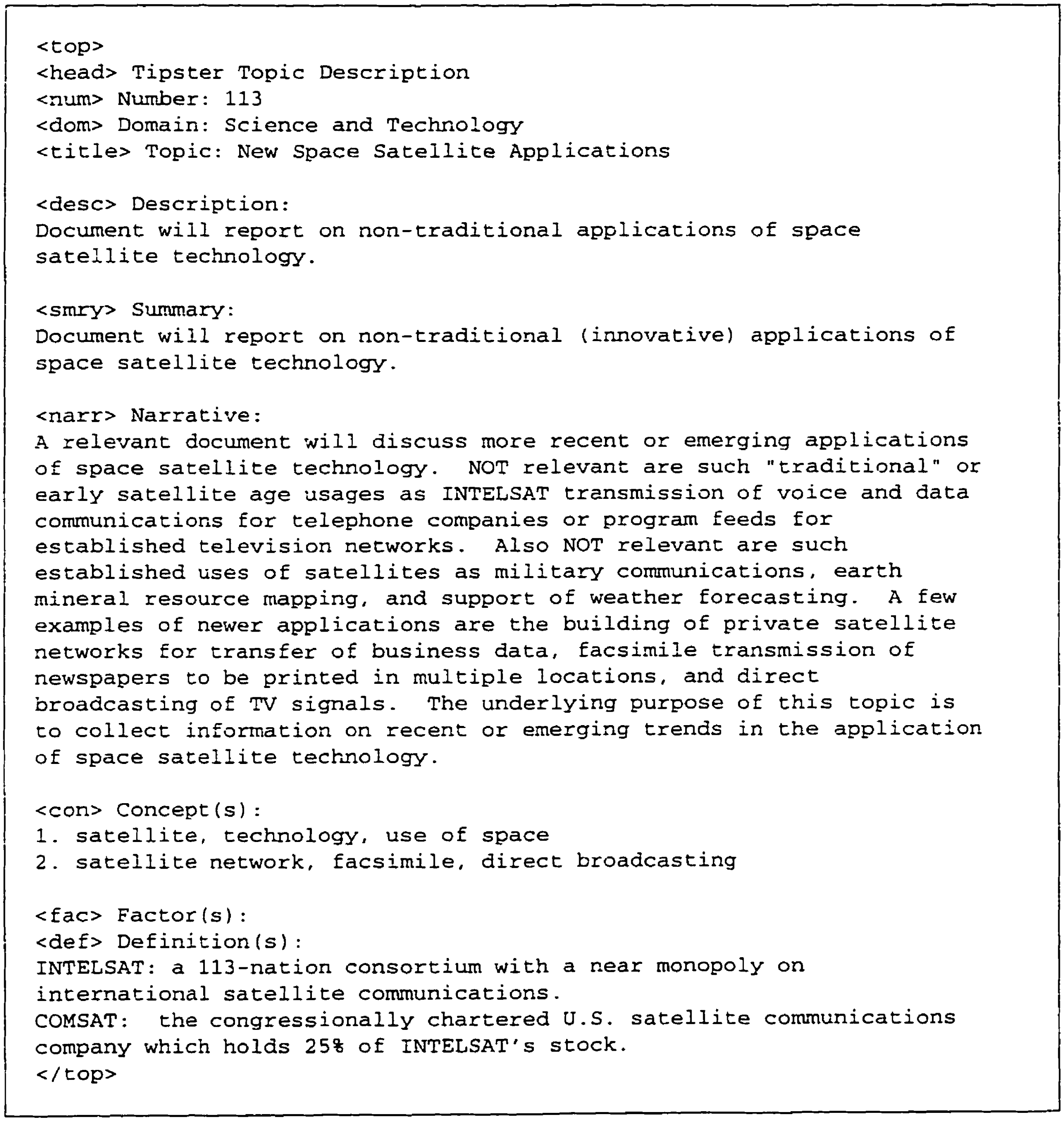
There is certainly a need for an evaluation to test how well our machine-generated links perform when being used for IR tasks such as question-answering. Before we perform such an evaluation, however, we need to ensure that our links are in fact working on a larger scale than the single example shown in the previous sections. We can perform this "sanity check" by testing our linker against a set of reference queries. If the results are favourable, then we may proceed to a full scale evaluation.

Our test involves taking a set of articles that are known to be related and seeing what connections are made between them. Such a set can be taken from the data used for the Text Retrieval Conference (TREC) (Harman, 1994). The object of TREC is a head-to-head evaluation of IR systems. Participating sites are provided with approximately 2 GB of data comprising Associated Press wire stories, six years of the Wall Street Journal, San Jose Mercury News articles, Ziff-Davis magazine articles, U.S. Department of Energy abstracts, U.S. Federal Register articles, and U.S. Patent abstracts.

TREC participants are given a set of *topics* which specify an information requirement. These topics are used in training the IR systems. A sample topic is shown in figure 5.2. Participants are also provided with relevance judgments, detailing which documents are relevant to which topics. From this set of judgments we can select a set of articles to use in a preliminary evaluation of our inter-article linking methodology. We wish to determine whether articles that are relevant to the same topic will be linked, while articles that are relevant to different topics will not be linked.

### 5.4.1 Selecting topics

For our evaluation, we selected six topics from the 50 available. Table 5.5 shows the descriptions of each topic. Notice that each of the topics fall into one of two distinct groups, those



```
<top>
<head> Tipster Topic Description
<num> Number: 113
<dom> Domain: Science and Technology
<title> Topic: New Space Satellite Applications

<desc> Description:
Document will report on non-traditional applications of space
satellite technology.

<smry> Summary:
Document will report on non-traditional (innovative) applications of
space satellite technology.

<narr> Narrative:
A relevant document will discuss more recent or emerging applications
of space satellite technology.  NOT relevant are such "traditional" or
early satellite age usages as INTELSAT transmission of voice and data
communications for telephone companies or program feeds for
established television networks.  Also NOT relevant are such
established uses of satellites as military communications, earth
mineral resource mapping, and support of weather forecasting.  A few
examples of newer applications are the building of private satellite
networks for transfer of business data, facsimile transmission of
newspapers to be printed in multiple locations, and direct
broadcasting of TV signals.  The underlying purpose of this topic is
to collect information on recent or emerging trends in the application
of space satellite technology.

<con> Concept(s):
1. satellite, technology, use of space
2. satellite network, facsimile, direct broadcasting

<fac> Factor(s):
<def> Definition(s):
INTELSAT: a 113-nation consortium with a near monopoly on
international satellite communications.
COMSAT:  the congressionally chartered U.S. satellite communications
company which holds 25% of INTELSAT's stock.
</top>
```

Figure 5.2: A sample topic from TREC.

about satellite systems, and those about cancer treatments. If our linking methodology works perfectly, then we would expect that documents that are relevant to one topic would never be linked to documents relevant to a different topic. Unfortunately, this may be too much to expect, especially given that some documents are relevant to more than one of these topics. A more realistic expectation would be that documents relevant to the "satellite" topics are not linked to the "cancer" topics.

Table 5.5: Descriptions of topics used for evaluation.

| Topic | Description |
|---|---|
| 113 | Document will report on non-traditional applications of space satellite technology. |
| 114 | Document will provide data on launches worldwide of non-commercial space satellites. |
| 121 | Document will discuss the life and death of a prominent U.S. person from a specific form of cancer. |
| 122 | Document will report on the research, development, testing, and evaluation (RDT&E) of a new anti-cancer drug developed anywhere in the world. |
| 123 | Document will report on studies into linkages between environmental factors or chemicals which might cause cancer, and/or it will report on governmental actions to identify, control, or limit exposure to those factors or chemicals which have been shown to be carcinogenic. |
| 124 | Document will report on innovative approaches to preventing or curing cancer. |

For our evaluation, we excluded documents from the Department of Energy, Patent Office, and Federal Register corpora, since they are not newspapers or magazines. We were left with 2406 documents relevant to one or more of these topics.

### 5.4.2 Clustering documents

Rather than computing the similarity of all document pairs, a computationally expensive task, we decided to use a clustering technique to find groups of documents that could be linked to one another. The clustering technique used is the same as that used in the SMART system. This technique requires only $O(n)$ time, as opposed to the $O(n^2)$ time for computing all document similarities. The algorithm is as follows:

**Algorithm 2:** Clustering articles.
**Input:** $W$, a file containing the weighted synset vectors for a collection of articles and $T$, a threshold
**Output:** $C$, an array of document clusters

```
CLUSTER($W$, $T$)
    nextcluster = 0
    foreach vector $v$ in $W$
        maxsim = 0
        bestcluster = nextcluster
        foreach cluster $c$ in $C$
            if $v \cdot c >$ maxsim and $v \cdot c \geq T$
                maxsim = $v \cdot c$
                bestcluster = $c$
        bestcluster += $v$
        if bestcluster == nextcluster then nextcluster++
```

### 5.4.3 Clustering runs

We performed three separate runs of the clustering algorithm, using thresholds of 0.1, 0.15, and 0.2. The results of these clusterings is shown in tables 5.6 through 5.8. We distinguish four kinds of clusters in the results:

**Unit** A "cluster" containing a single document.

**With Same Topic** A cluster containing more than one document where all the documents are relevant to a single topic.

**With Similar Topics** A cluster containing more than one document where the documents are relevant to topics in the same group.

**With Different Topics** A cluster containing documents relevant to topics in different groups.

The percentage measures indicate the percentage of the documents relevant to each topic that are included in the clusters.

It should be noted that this clustering method is dependent on the order in which the vectors are added. In order to make sure that this was not the case in this instance, we reclustered the documents using a randomized order. The results of these clusterings is shown in tables 5.9 through 5.11. It seems that the order in which the documents were clustered was not significant.

### 5.4.4 Discussion of results

One thing that is easily discernible from these tables is that the similarity function for synset weight vectors works as expected, that is, higher thresholds result in less connections. As the threshold increases, the number of vectors clustered into the *Unit* or *With Same Topic* categories increases, while the number of vectors clustered from different groups decreases. In both cases, at the 0.2 level, the majority of the documents are clustered either with documents relevant to the same topic, or documents in the same group of topics.

The number of clusters produced is quite high in all cases. This is to be expected, since documents that may be relevant to a particular topic may not be entirely related to each other, leading to a low similarity score. In fact, we begin to see that the clusters divide up the set of all documents relevant to a topic into subsets centered around a particular subject. For example, using the randomly ordered vectors with a threshold of 0.2, two clusters are formed containing articles about high-definition television. All of these articles are classified as relevant to topic 113, but they do form a sub-topic that is recovered during clustering.

It is also worth investigating why some articles are clustered with articles that are clearly not related. For example, when using a threshold of 0.2, an article describing the launch of a satellite (from topic 114), is clustered with articles from topic 123 on the strength of a single word that was poorly disambiguated: *bill*. When weighting the documents, the synsets containing the word *bill* occur infrequently throughout the database, but frequently in these documents, so it is given a very high weight. This weight is sufficient to link the two documents on the strength of a single common word. Problems such as this should dissipate when we use a larger database.

This experiment has also shown that it is possible to link articles across newspapers, as many of the clusters contained articles from the Associated Press, Wall Street Journal, and San Jose Mercury News corpora. It is also worth noting that our methodology seemed to work just as well for the Ziff corpus, which contains some magazine-style articles as long as 77 paragraphs.

Table 5.6: Clustering TREC articles with a threshold of 0.1.

| | Unit | | With Same Topic | | With Similar Topics | | With Other Topics | |
|---|---|---|---|---|---|---|---|---|
| Topic | Clusters | Percent | Clusters | Percent | Clusters | Percent | Clusters | Percent |
| 113 | 29 | 5.9% | 63 | 63.3% | 115 | 8.2% | 80 | 22.7% |
| 114 | 12 | 3.9% | 9 | 29.9% | 115 | 44.4% | 67 | 21.9% |
| 121 | 70 | 13.3% | 94 | 56.7% | 56 | 19.0% | 41 | 11.0% |
| 122 | 10 | 6.1% | 5 | 7.4% | 32 | 58.9% | 16 | 27.6% |
| 123 | 48 | 8.1% | 53 | 48.8% | 62 | 34.2% | 25 | 8.9% |
| 124 | 30 | 9.4% | 8 | 6.9% | 75 | 69.9% | 25 | 13.8% |

Number of clusters: 626

Table 5.7: Clustering TREC articles with a threshold of 0.15.

| | Unit | | With Same Topic | | With Similar Topics | | With Other Topics | |
|---|---|---|---|---|---|---|---|---|
| Topic | Clusters | Percent | Clusters | Percent | Clusters | Percent | Clusters | Percent |
| 113 | 111 | 22.7% | 81 | 56.7% | 111 | 8.4% | 56 | 12.2% |
| 114 | 30 | 9.6% | 29 | 53.1% | 111 | 23.8% | 52 | 13.5% |
| 121 | 206 | 39.1% | 81 | 45.2% | 45 | 11.8% | 16 | 4.0% |
| 122 | 30 | 18.4% | 14 | 25.8% | 28 | 44.8% | 6 | 11.0% |
| 123 | 104 | 17.4% | 71 | 46.0% | 52 | 28.7% | 22 | 7.9% |
| 124 | 71 | 22.3% | 13 | 17.9% | 69 | 53.3% | 19 | 6.6% |

Number of clusters: 1008

Table 5.8: Clustering TREC articles with a threshold of 0.2.

| | Unit | | With Same Topic | | With Similar Topics | | With Other Topics | |
|---|---|---|---|---|---|---|---|---|
| Topic | Clusters | Percent | Clusters | Percent | Clusters | Percent | Clusters | Percent |
| 113 | 180 | 36.7% | 78 | 45.9% | 81 | 4.7% | 29 | 4.7% |
| 114 | 54 | 17.4% | 45 | 62.1% | 81 | 15.4% | 28 | 4.8% |
| 121 | 302 | 57.3% | 73 | 33.0% | 28 | 7.0% | 13 | 2.7% |
| 122 | 51 | 31.3% | 18 | 33.1% | 25 | 33.7% | 2 | 1.8% |
| 123 | 168 | 28.2% | 87 | 51.7% | 38 | 17.3% | 13 | 2.5% |
| 124 | 112 | 35.1% | 22 | 27.3% | 52 | 35.7% | 5 | 1.9% |

Number of clusters: 1300

Table 5.9: Randomly clustering TREC articles with a threshold of 0.1.

| | Unit | | With Same Topic | | With Similar Topics | | With Other Topics | |
|---|---|---|---|---|---|---|---|---|
| Topic | Clusters | Percent | Clusters | Percent | Clusters | Percent | Clusters | Percent |
| 113 | 29 | 5.9% | 65 | 70.6% | 121 | 7.1% | 81 | 16.3% |
| 114 | 12 | 3.9% | 8 | 25.4% | 121 | 35.4% | 71 | 35.4% |
| 121 | 59 | 11.2% | 90 | 54.6% | 67 | 21.6% | 43 | 12.5% |
| 122 | 10 | 6.1% | 6 | 19.0% | 33 | 62.6% | 12 | 12.3% |
| 123 | 54 | 9.1% | 47 | 44.0% | 59 | 31.0% | 27 | 15.9% |
| 124 | 33 | 10.3% | 6 | 5.0% | 76 | 74.0% | 25 | 10.7% |

Number of clusters: 621

Table 5.10: Randomly clustering TREC articles with a threshold of 0.15.

| | Unit | | With Same Topic | | With Similar Topics | | With Other Topics | |
|---|---|---|---|---|---|---|---|---|
| Topic | Clusters | Percent | Clusters | Percent | Clusters | Percent | Clusters | Percent |
| 113 | 119 | 24.3% | 81 | 54.5% | 102 | 8.4% | 56 | 12.9% |
| 114 | 26 | 8.4% | 30 | 58.8% | 102 | 17.4% | 53 | 15.4% |
| 121 | 199 | 37.8% | 87 | 46.3% | 43 | 11.8% | 20 | 4.2% |
| 122 | 25 | 15.3% | 19 | 38.0% | 27 | 42.9% | 5 | 3.7% |
| 123 | 111 | 18.6% | 73 | 48.7% | 44 | 26.5% | 20 | 6.2% |
| 124 | 72 | 22.6% | 17 | 12.2% | 67 | 59.2% | 18 | 6.0% |

Number of clusters: 1017

Table 5.11: Randomly clustering TREC articles with a threshold of 0.2.

| | Unit | | With Same Topic | | With Similar Topics | | With Other Topics | |
|---|---|---|---|---|---|---|---|---|
| Topic | Clusters | Percent | Clusters | Percent | Clusters | Percent | Clusters | Percent |
| 113 | 185 | 37.8% | 76 | 45.5% | 74 | 3.7% | 27 | 4.9% |
| 114 | 57 | 18.3% | 45 | 60.8% | 74 | 15.1% | 26 | 4.5% |
| 121 | 304 | 57.7% | 72 | 34.2% | 22 | 5.3% | 12 | 2.5% |
| 122 | 49 | 30.1% | 19 | 32.5% | 24 | 35.6% | 2 | 1.8% |
| 123 | 174 | 29.2% | 78 | 49.0% | 34 | 18.5% | 14 | 2.5% |
| 124 | 114 | 35.7% | 26 | 27.3% | 49 | 35.4% | 4 | 1.6% |

Number of clusters: 1300

## Chapter 6

# Evaluating a linking methodology

Clearly, methodologies such as the one that we have presented in the previous two chapters require evaluation. In this chapter, we will describe the design and results of a study that was undertaken to test our linking methodology.

We will not attempt to answer the question of whether browsing is a useful way of performing IR tasks, as it seems clear from the work discussed in section 2.6 that browsing is a viable and necessary component of any IR system. Rather, we will be asking the question: Is our hypertext linking methodology superior to other methodologies that have been proposed (e.g., that of Allan, 1995)? The obvious way to answer the question is to test whether the links generated by our methodology will lead to better performance when they are used in the context of an appropriate IR task.

The null hypothesis for our tests is simply that there is no significant difference between the hypertext links generated by our method and those generated by another methodology — one could perform IR tasks equally well using either kind of links. Our research hypothesis is that our method provides a significant improvement, because it is based on semantic similarity of concepts rather than strict term repetition.

## 6.1 Experimental Design

### 6.1.1 The task

We selected a question-answering task for our study. We made this choice because it appears (as we saw in section 2.6.3) that this kind of task is well suited to the browsing methodology that hypertext links are meant to support. This kind of task is also useful because it can be performed easily using *only* hypertext browsing. This is necessary because in the interface used for our experiment, no query engine was provided for the subjects.

It may be argued that the restriction to strict hypertext browsing creates an unnatural setting for the study and that in any real system, users would at least be able to perform a keyword search. This may be true, but if we had included a query engine, then it is possible that any results that we obtained would pertain more to the use of queries rather than browsing or to how well users can form queries. By making the restriction, we tested just the hypothesis in which we were interested: is a semantically-based approach to hypertext link generation better than a strict term-repetition approach? If we can make a determination one way or the other, then we will be able to draw conclusions about how hypertext links should be built in a system that provides both querying and browsing.

### 6.1.2 The questions and the database

The most difficult part of performing an evaluation of any IR or hypertext system is developing reasonable questions and then determining which documents from the test database contain the answers. Several test collections have been developed over the years that can be used by anyone who wishes to compare the performance of her IR system to others. The most recent, and certainly the largest, of these collections is the TREC collection, which we discussed in section 5.4.

Figure 5.2 showed a sample topic that we used in our preliminary evaluation of the inter-article linking methodology. Notice that the section labeled "Narrative" provides an English description of which documents are relevant and which are not. We used this section as the basis of our test questions. From the 50 available topics, we selected three that were appropriate for our evaluation and used them to develop the questions shown in table 6.1. We specifically excluded from consideration the topics that were used for our preliminary test of inter-article linking, in order to avoid possible confounding of the experimental results.

There were approximately 1996 documents that were relevant to the topics from which these questions were created. We read these documents and prepared lists of answers for the questions. Our test database consisted of these articles combined randomly with approximately

Table 6.1: Questions used in evaluation of linking methodology.

| Number | Answers | Question |
|---|---|---|
| Test | N/A | List the names of as many premiers of Canadian provinces as you can find. Be sure to include the name of the province. |
| 1 | 61 | List all the drug brand names that you can find, if you can also list the name of a generic substitute for the drug *or* the chemical name of the drug. |
| 2 | 56 | List the names of as many people as you can find that are identified as "terrorists". You should *not* include the names of terrorist groups. |
| 3 | 34 | List the names of biotechnology companies that have participated in mergers or joint ventures. You should list the names of all participants in the merger or joint venture. |

29,000 other articles selected randomly from the TREC corpus. The combination of these articles provided us with a database that was large enough for a reasonable evaluation and yet small enough to be easily manageable.

### 6.1.3 Whose links to use?

We considered two possible methods for generating inter-article hypertext links. The first is our own method, described in chapter 5. The second method uses a vector space IR system called Managing Gigabytes (MG) (Witten et al., 1994) to generate links by calculating document similarity. We used the MG system to generate links in a way very similar to that presented in Allan (1995).

Links from a source article were built by passing the entire text of the source article to the MG system as a "query". MG builds the term vector representing this query after removing stop words and stemming the words in the query. This query vector was compared against the document vectors stored in the MG database, and the top 150 related articles were returned and used as the targets of the inter-article hypertext links. The MG system provided most of the same capabilities as the SMART system used by Allan. We used the MG system because it was much more easily integrated into our other software. For simplicity's sake, we will call the links generated by our technique *HT links* and the links generated by the MG system *MG links*.

At this point we considered two approaches to testing the effectiveness of these two sets of links. The first was to set two experimental conditions: one using HT links and the other using MG links. This is a very typical experimental strategy, and certainly viable in this case. The problem was that such a design would have required a large number of subjects to be tested in each condition to ensure that the study was valid.

The second method was, at each stage during a subject's browsing, to combine the sets of links generated by the two methods. This results in a single experimental condition where the system must keep track of how each inter-article link was generated. By using this strategy, the subjects "vote" for the system that they prefer by choosing the links generated by that system. Of course, the subjects are not aware of which system generated the links that they are following — they can only decide to follow a link by considering the article headlines displayed as anchors. We can, however, determine which system they "voted" for by considering their success in answering the questions they were asked. If we can show that their success was greater when they followed more HT links, then we can say that they have "voted" for the superiority of HT links. A similar methodology has been used previously by Nordhausen et al. (1991) in their comparison of human and machine-generated hypertext links.

The two sets of inter-article links can be combined by simply taking the *unique* links from each set, that is, the links that we take are those that appear in only one of the sets of links. Of course, we would expect the two methods to have many links in common, but it is ifficult to tell how these links should be counted in the "voting" procedure. By leaving them out, we test the differences between the methods rather than their similarities. Of course, by excluding the links that the methods agree on we are reducing the ability of the subjects to find answers to the questions that we have posed for them. This appears to be a necessary difficulty of this method and, as we shall see, the number of correct answers that the subjects found was generally quite low, but it was nonetheless sufficient to compare the two methodologies.

The intra-article links that were presented to the users were generated by the methodology described in chapter 4. Because there was no other method for generating these links, the subjects were presented only with links generated by our method, using the Mean Euclidean distance metric with no weighting or normalization of the chain density vectors and a $z$-score threshold of 1.0. This set of parameters was selected as one that had produced "good" sets of links during the testing of the system.

### 6.1.4 The evaluation system

The evaluation system used a front-end written in Java combined with a back-end written in C++. Although we have discussed the use of our system over the World-Wide Web, we found it necessary to use a non-Web-based system to perform the evaluation. This was mostly due to the difficulty in obtaining sufficient logging information (e.g., what links were followed?) from a Web browser.

The system works by sending requests to three servers, as shown in figure 6.1. When a user clicks on a link to another article, three requests are sent out:

1. A request for HT links, which is sent to the "HT Link Server".
2. A request for MG links, which is sent to the "MG Link Server".
3. A request for the text of the article, including intra-article links. This request is sent to the "Article Server".

The interface of the system was quite straightforward. It consisted of a single screen similar to the one shown in figure 6.2 The main part of the screen showed the text of a single article. The subjects could navigate through the article by using the intra-article links, the scroll bar, or the page up and down keys. The buttons to the left of the article could be used for navigating through the set of articles that had been visited (the *Previous Article* and *Next Article* buttons) or navigating within an article (the *Back* button would return to the point from which an intra-article link was taken).

At the bottom of the screen was a list of the articles from the database that were related to the article displayed. The anchor text for these links was the headline of the article that the user would jump to when the link was clicked on. In order to leverage the subjects' experience with Web browsers such as Netscape Navigator, all hypertext links were shown in blue, while all regular text appeared in black. To ease navigation difficulties (i.e., "Have I been here before?"), links that had already been traversed (both intra- and inter-article) were shown in magenta.

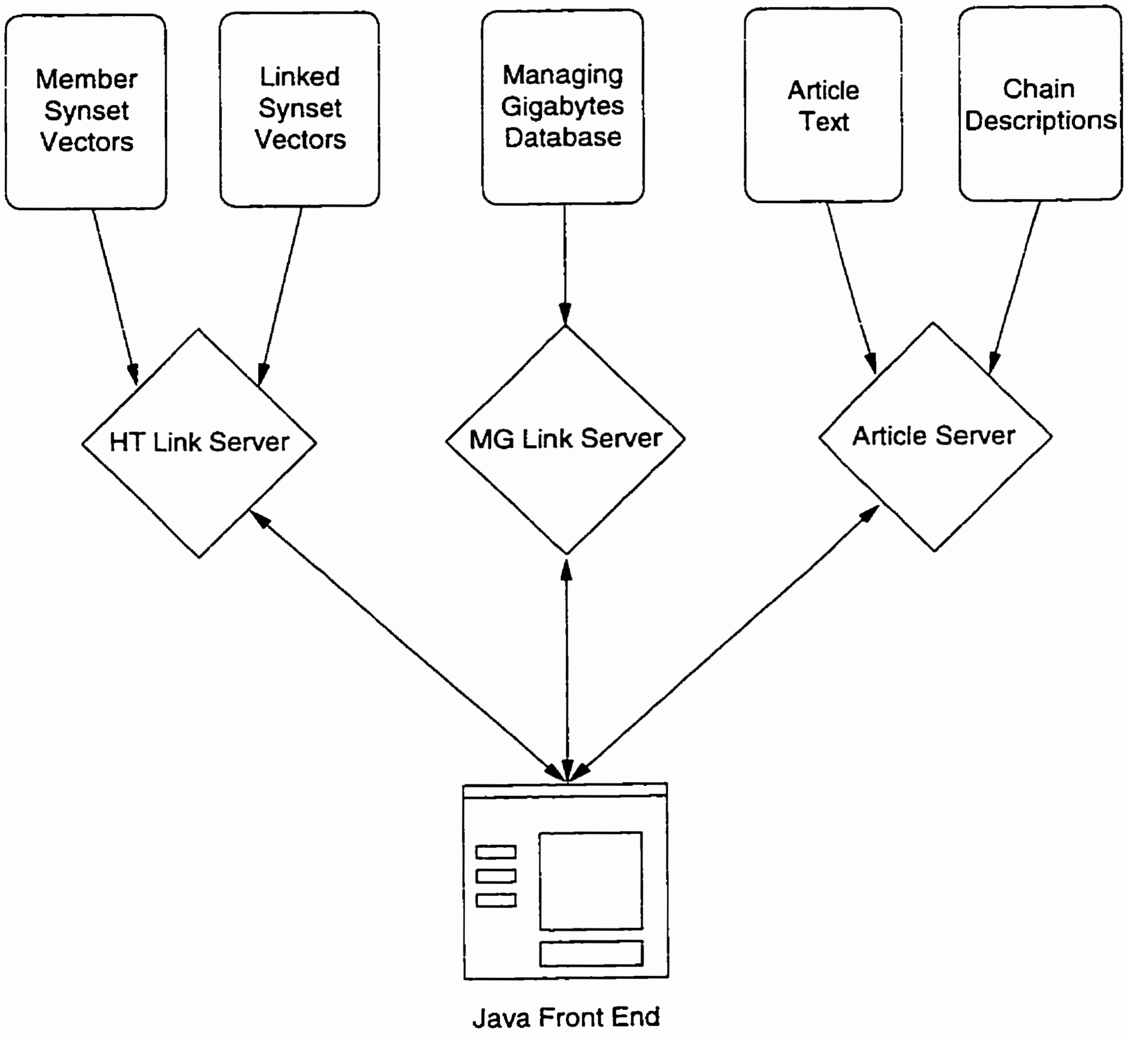
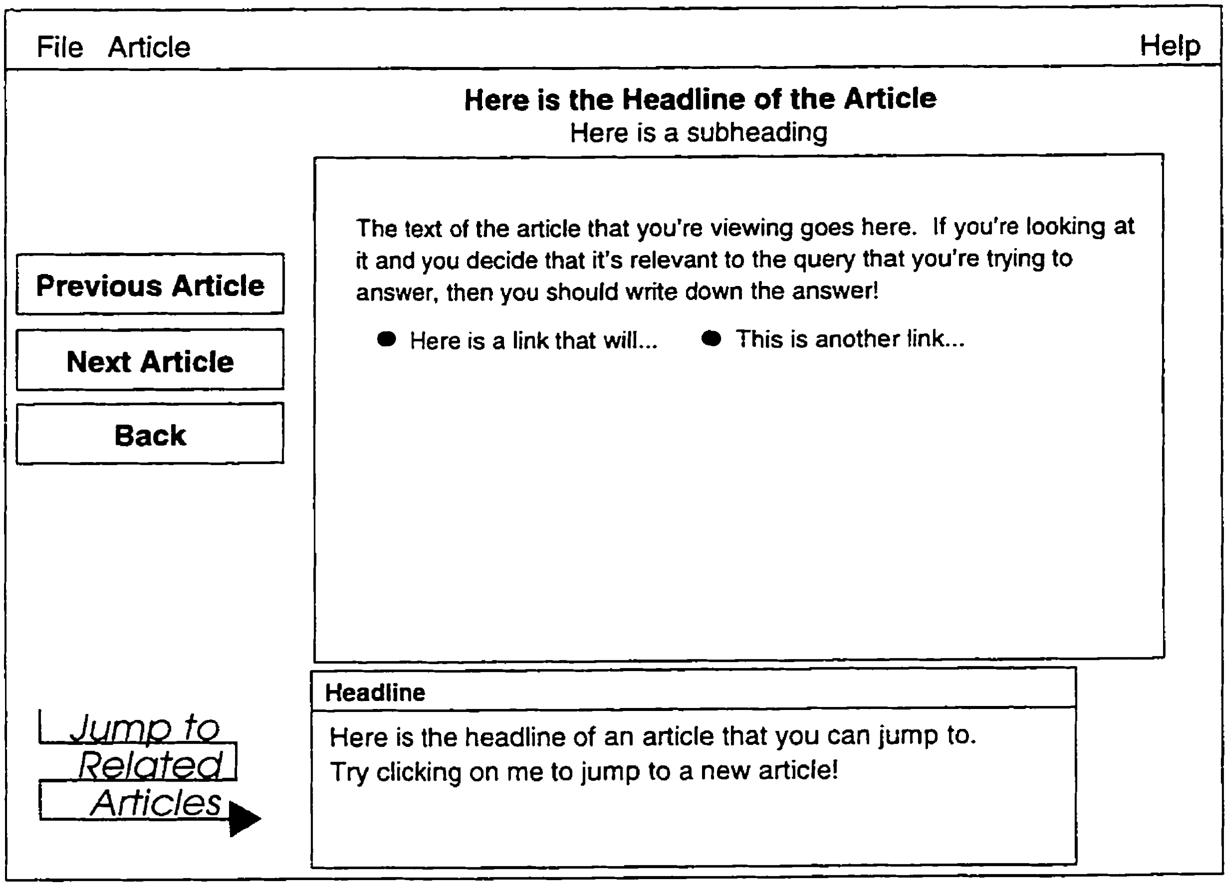


Figure 6.1: The structure of the system used for the evaluation.



**Here is the Headline of the Article**

Here is a subheading

The text of the article that you're viewing goes here. If you're looking at it and you decide that it's relevant to the query that you're trying to answer, then you should write down the answer!

- Here is a link that will...
- This is another link...

Here is the headline of an article that you can jump to. Try clicking on me to jump to a new article!

Figure 6.2: The interface of the evaluation system.

### 6.1.5 Performing searches

To begin, subjects were given a set of instructions on using the system (shown in appendix B), and were allowed to ask questions about the interface. The subjects were all provided with the "test" question and allowed 5 minutes to become familiar with the properties of the system. Once comfortable, the subjects were given the rest of the questions one by one. The time for each question was limited to 15 minutes so that subjects would not spend inordinate amounts of time on one query and then give the others short shrift. The order in which questions were given was varied among the six possible orders across all of the subjects who performed the task.

Each search began on a "starter" page that contained the text of the appropriate TREC topic as·the "article" and the list of articles related to the topic shown (this was computed by using the text of the topic as the initial "query" to the database). Subjects were expected to traverse the links, writing down whatever answers they could find.

As the subjects browsed through the database of articles, the links that they followed within and between articles were automatically logged. In addition, any scrolling motions within an article were recorded (e.g., using the scrollbar or the page up and down keys). When a subject left one article to go to another, the amount of time spent on the article was recorded.

After they had finished answering the questions, the subjects were given a short questionnaire to fill out. This questionnaire is shown in appendix C.

## 6.2 Analysis

### 6.2.1 An initial look at the system

Given the evaluation system described above, we note that for a particular starting point, the hypertext that our subjects could navigate is completely determined. To simplify somewhat, we can view this hypertext as a tree whose root is the starting point for a particular question. Before we begin the analysis of the experimental data, we should explore whether there is any difference between the trees that are generated by the two methodologies.

For each method it is a relatively straightforward task to generate the hypertext tree. We can do this in a breadth-first manner, and note at which level in the tree documents containing answers occur. This level tells us how long the path is from the root node to the document in question. A paired $t$-test can then be used to see if there is a significant difference in the path lengths to the answers.

We built the trees generated by both methodologies for each question that we gave to the subjects. The results were that for question 1, the path lengths were significantly shorter for the MG tree; for question 2, the path lengths were significantly shorter for the HT tree; and there was no significant difference in path lengths for question 3. Thus we can say that there are some objective differences between the methods under examination.

### 6.2.2 Examining the data

We tested 27 subjects during the course of the evaluation. However, our analysis will only include 23 subjects. Some changes were made after the first day of the evaluation in order to improve the reliability of the Java front-end, resulting in significantly fewer disruptive system crashes. In one case during the first day, the system crashed five times during the course of one 15-minute question. More importantly, the way in which inter-article links were displayed was changed. In addition to the system changes, we corrected a grammatical error in one of the questions, and slightly modified the instructions that were provided to the subjects. Because of these changes, we decided that it would be best if the results from the first day were removed from consideration during the analyses, since those subjects were not operating under the same set of experimental conditions as the others.

The data for the remaining 23 subjects are shown in table 6.2 and a summary is shown in table 6.3. In these tables, the variable name $L_{MG}$ refers to the number of MG links followed, $L_{HT}$ refers to the number of HT links followed, $L_I$ refers to the number of intra-article links followed, and $Ans$ refers to the number of correct answers found.

The number of both inter- and intra-article links followed was, on average, quite small and variable. As we expected, the number of correct answers found was also low and variable. On average, the subjects showed a slight bias for HT links, choosing 52.1% HT links and 47.9% MG links. This is interesting, especially in light of the fact that, for all the articles the subjects

Table 6.2: Data collected during question answering tasks

| Trial | HT Links ($L_{MG}$) | Percent | MG Links ($L_{HT}$) | Percent | Intra ($L_I$) | Answers ($Ans$) |
|---|---|---|---|---|---|---|
| s05/q1 | 1 | 14.3 | 6 | 85.7 | 1 | 3 |
| s05/q2 | 5 | 62.5 | 3 | 37.5 | 5 | 4 |
| s05/q3 | 7 | 53.8 | 6 | 46.2 | 0 | 5 |
| s06/q1 | 10 | 52.6 | 9 | 47.4 | 11 | 6 |
| s06/q2 | 11 | 61.1 | 7 | 38.9 | 11 | 8 |
| s06/q3 | 7 | 43.8 | 9 | 56.2 | 2 | 3 |
| s07/q1 | 6 | 85.7 | 1 | 14.3 | 1 | 3 |
| s07/q2 | 5 | 62.5 | 3 | 37.5 | 0 | 5 |
| s07/q3 | 5 | 50.0 | 5 | 50.0 | 4 | 6 |
| s08/q1 | 9 | 60.0 | 6 | 40.0 | 0 | 2 |
| s08/q2 | 9 | 69.2 | 4 | 30.8 | 0 | 3 |
| s08/q3 | 4 | 40.0 | 6 | 60.0 | 0 | 0 |
| s09/q1 | 8 | 72.7 | 3 | 27.3 | 0 | 3 |
| s09/q2 | 6 | 40.0 | 9 | 60.0 | 1 | 8 |
| s09/q3 | 9 | 37.5 | 15 | 62.5 | 0 | 4 |
| s10/q1 | 8 | 47.1 | 9 | 52.9 | 17 | 4 |
| s10/q2 | 9 | 69.2 | 4 | 30.8 | 12 | 5 |
| s10/q3 | 6 | 42.9 | 8 | 57.1 | 15 | 3 |
| s11/q1 | 9 | 42.9 | 12 | 57.1 | 5 | 7 |
| s11/q2 | 8 | 80.0 | 2 | 20.0 | 1 | 16 |
| s11/q3 | 8 | 57.1 | 6 | 42.9 | 1 | 7 |
| s12/q1 | 5 | 29.4 | 12 | 70.6 | 16 | 2 |
| s12/q2 | 10 | 71.4 | 4 | 28.6 | 3 | 0 |
| s12/q3 | 1 | 7.1 | 13 | 92.9 | 4 | 3 |
| s13/q1 | 1 | 50.0 | 1 | 50.0 | 7 | 1 |
| s13/q2 | 1 | 50.0 | 1 | 50.0 | 11 | 0 |
| s13/q3 | 8 | 53.3 | 7 | 46.7 | 1 | 0 |
| s14/q1 | 2 | 33.3 | 4 | 66.7 | 3 | 1 |
| s14/q2 | 3 | 33.3 | 6 | 66.7 | 8 | 4 |
| s14/q3 | 7 | 70.0 | 3 | 30.0 | 0 | 1 |
| s15/q1 | 9 | 60.0 | 6 | 40.0 | 5 | 5 |
| s15/q2 | 11 | 57.9 | 8 | 42.1 | 2 | 5 |
| s15/q3 | 13 | 65.0 | 7 | 35.0 | 0 | 2 |
| s16/q1 | 4 | 23.5 | 13 | 76.5 | 0 | 5 |
| s16/q2 | 9 | 75.0 | 3 | 25.0 | 3 | 7 |

(cont'd)

Table 6.2: Data collected during question answering tasks (cont'd)

| Trial | HT Links<br>$(L_{MG})$ | Percent | MG Links<br>$(L_{HT})$ | Percent | Intra<br>$(L_I)$ | Accuracy<br>$(Ans)$ |
|---|---|---|---|---|---|---|
| s16/q3 | 8 | 44.444 | 10 | 55.556 | 2 | 6 |
| s17/q1 | 2 | 18.182 | 9 | 81.818 | 0 | 3 |
| s17/q2 | 8 | 53.333 | 7 | 46.667 | 0 | 5 |
| s17/q3 | 8 | 57.143 | 6 | 42.857 | 7 | 5 |
| s18/q1 | 3 | 30.000 | 7 | 70.000 | 14 | 2 |
| s18/q2 | 5 | 71.429 | 2 | 28.571 | 11 | 6 |
| s18/q3 | 6 | 42.857 | 8 | 57.143 | 3 | 3 |
| s19/q1 | 11 | 68.750 | 5 | 31.250 | 8 | 6 |
| s19/q2 | 6 | 50.000 | 6 | 50.000 | 8 | 6 |
| s19/q3 | 5 | 45.455 | 6 | 54.545 | 8 | 0 |
| s20/q1 | 6 | 85.714 | 1 | 14.286 | 1 | 6 |
| s20/q2 | 4 | 100.000 | 0 | 0.000 | 8 | 4 |
| s20/q3 | 2 | 25.000 | 6 | 75.000 | 0 | 5 |
| s21/q1 | 10 | 50.000 | 10 | 50.000 | 7 | 10 |
| s21/q2 | 10 | 50.000 | 10 | 50.000 | 7 | 11 |
| s21/q3 | 12 | 50.000 | 12 | 50.000 | 1 | 8 |
| s22/q1 | 9 | 52.941 | 8 | 47.059 | 12 | 8 |
| s22/q2 | 19 | 79.167 | 5 | 20.833 | 23 | 9 |
| s22/q3 | 5 | 33.333 | 10 | 66.667 | 6 | 2 |
| s23/q1 | 7 | 63.636 | 4 | 36.364 | 0 | 2 |
| s23/q2 | 14 | 73.684 | 5 | 26.316 | 1 | 2 |
| s23/q3 | 7 | 53.846 | 6 | 46.154 | 0 | 5 |
| s24/q1 | 2 | 22.222 | 7 | 77.778 | 17 | 3 |
| s24/q2 | 7 | 70.000 | 3 | 30.000 | 13 | 6 |
| s24/q3 | 1 | 8.333 | 11 | 91.667 | 10 | 0 |
| s25/q1 | 7 | 50.000 | 7 | 50.000 | 7 | 2 |
| s25/q2 | 9 | 60.000 | 6 | 40.000 | 0 | 2 |
| s25/q3 | 9 | 60.000 | 6 | 40.000 | 0 | 11 |
| s26/q1 | 7 | 58.333 | 5 | 41.667 | 3 | 6 |
| s26/q2 | 6 | 66.667 | 3 | 33.333 | 5 | 7 |
| s26/q3 | 12 | 70.588 | 5 | 29.412 | 0 | 3 |
| s27/q1 | 4 | 40.000 | 6 | 60.000 | 8 | 5 |
| s27/q2 | 4 | 40.000 | 6 | 60.000 | 3 | 4 |
| s27/q3 | 5 | 41.667 | 7 | 58.333 | 0 | 0 |

Table 6.3: Summary statistics for experimental results.

| Data | Min | Max | Mean | Std. Dev. |
|---|---|---|---|---|
| $L_{HT}$ | 1 | 19 | 6.87 | 3.44 |
| $L_{MG}$ | 0 | 15 | 6.32 | 3.20 |
| $L_I$ | 0 | 23 | 4.97 | 5.41 |
| $Ans$ | 0 | 16 | 4.48 | 2.98 |

visited, 50.4% of the links available were MG links, while 49.6% were HT links. A paired $t$-test, however indicates that this difference is not significant.

We can also combine $L_{HT}$ and $L_{MG}$ in a ratio that we will call $L_R$. Because $L_{MG} = 0$ in some cases, we will define $L_R$ in the following way:

$$L_R = \begin{cases} \frac{L_{HT}}{L_{MG}} & \text{when } L_{MG} > 0 \\ L_{HT} & \text{when } L_{MG} = 0 \end{cases}$$

If $L_R > 1$, then a subject followed more HT links than MG links. An interesting question to ask is: did subjects with significantly higher values for $L_R$ find more answers? With 23 subjects each answering 3 questions, we have 69 values for $L_R$. If we sort these values in decreasing order and divide the resulting list at the median, we have two groups with a significant difference in $L_R$. An unpaired $t$-test then tells us that the differences in $Ans$ should occur by chance with $p < 0.1$. This is certainly unlikely enough that there may be some relationship between the number and kinds of links that a subject followed and his or her success in finding answers to the questions pose. In the following sections, we will explore this relationship using regression analyses. In fact, there are two cases that we wish to consider. In the first, we look at only the inter-article links that the subjects followed. In the second, we include the intra-article links as well.

### 6.2.3 Inter-article links

In the first case, we will consider solely the relationship between the kinds of inter-article links that the subjects used (i.e., HT versus MG links). We can use a multivariate regression model with two independent variables, $L_{MG}$ and $L_{HT}$, to express the relationship between HT links, MG links, and the number of correct answers found. The dependent variable in our analysis is

*Ans*, the number of correct answers found by the subject. For each subject, we will have three measurements of the independent and dependent variables corresponding to the three questions that they answered.

Note that we are using the number of correct answers that the subjects found as our dependent variable. It may be argued that a more appropriate measure would be the percentage of the possible answers that they found — essentially the *recall* of the correct answers. This would be a valid concern for an evaluation in which the subjects were allowed to look for answers until they felt they had found them all. In our task, however, searches were limited to 15 minutes and the speed of the system tended to limit the number of answers that a subject could find. Indeed, the subjects found significantly ($p < 0.05$) more answers for question 2 than for questions 1 and 3. There was no significant difference in the number of answers between questions 1 and 3, even though question 1 has nearly twice as many possible answers as question 3. If we were to use the percentage of correct answers found, then we would artificially lower the subjects' scores.

**A standard regression**

Using the data from table 6.2, our regression model gives us the following equation for deriving the number of correct answers found from the number of each type of link followed:

$$Ans = 2.08 + 0.33 \cdot L_{HT} + 0.03 \cdot L_{MG} \quad (R^2 = 0.14)$$

So, at least at first glance, it seems that by following an HT link, a user would derive a greater benefit (in terms of the number of correct answers found) than she would get from traversing an MG link. Unfortunately, the analysis is not that simple. We also need to ask ourselves what the possibility is that the independent variables that we have chosen are actually unrelated to the dependent variable. We can test this hypothesis with an ANOVA analysis of the linear regression to see how much of the difference between the observed and fitted values of *Ans* is attributable to the regression and how much to simple error. The ANOVA table is shown in table 6.4.

For the calculated value of $F$, we can reject the initial hypothesis that $L_{MG}$ and $L_{HT}$ are unre-

Table 6.4: ANOVA analysis for a regression model with an intercept.

| Source of Variation | Sum of Squares | df | Mean Square | Calculated $F$ | $p$ |
|---|---|---|---|---|---|
| Regression | 87.13 | 2 | 43.56 | 5.55 | 0.01 |
| Error | 518.09 | 66 | 7.85 | | |

lated to *Ans* with $p < 0.01$. Now, if our dependent variable is related to our independent variables, then we still need to ask what range of values we can reasonably expect the coefficients of our independent variables to take on. Table 6.5 shows the 95% confidence intervals for these coefficients, which provides an estimate of this range.

Table 6.5: 95% confidence intervals for a model with an intercept.

| Parameter | Value | Standard Error | $t$ | $p$ | Low | High |
|---|---|---|---|---|---|---|
| Constant | 2.08 | 0.98 | 2.11 | 0.02 | 0.11 | 4.04 |
| $L_{HT}$ | 0.33 | 0.10 | 3.30 | 0.00 | 0.13 | 0.52 |
| $L_{MG}$ | 0.03 | 0.11 | 0.24 | 0.41 | −0.19 | 0.24 |

Here, the column labeled $t$ is the $t$-score associated with the hypothesis $H_0$: the coefficient in question is 0. The alternative hypothesis is that the coefficient is greater than 0. The column labeled $p$ is the probability that $H_0$ is true. For this model, we can safely reject $H_0$ for the coefficient of $L_{HT}$ with $p < 0.05$. We can also reject $H_0$ for the constant in our equation. This is surprising, as we told the subjects to record only those answers that they found in the database, and not those that they already knew. In addition, there were no answers on any of the "starter" pages for the questions. So, if a subject followed no links, then they should have been unable to find any answers and *Ans* should therefore have been 0. Interestingly, we cannot reject $H_0$ for $L_{MG}$, meaning that the coefficient may be 0.

The columns labeled *Low* and *High* give the endpoints of the 95% confidence interval for the values of each of the coefficients. Notice that the confidence intervals for the coefficients of $L_{MG}$ and $L_{HT}$ overlap significantly. This leads us to the conclusion that it is possible that, for this model, the coefficient of $L_{MG}$ may be greater than the coefficient of $L_{HT}$ some of the time, if, in fact, the coefficient of $L_{MG}$ is not 0. Thus, for this case, we cannot reject our null hypothesis that the number of answers that a user will find does not depend on which kind of links that they follow.

### Removing the constant

In the previous model, we noted that we could not necessarily say that the constant term was 0, even though this was to be expected. Also, we were unable to say that the coefficient of $L_{MG}$ was greater than 0. This would seem to be a useful result for us, since we could say that following MG links has no benefit. However, as we are proposing an alternative method, we feel that we should give the MG method of generating links the benefit of the doubt in this case. So, we propose another regression model, in which we ensure that the fitted value of the constant is its theoretical value of 0. This model results in the equation:

$$Ans = 0.46 \cdot L_{HT} + 0.17 \cdot L_{MG} \quad (R^2 = 0.09)$$

which shows a smaller benefit than the previous model for the selection of an HT link over an MG link. The ANOVA analysis in table 6.6 shows that our independent variables are related to our independent variable and that with $p \leq 0.05$, we can safely assume that the number of links followed is related to the number of answers found.

Table 6.6: ANOVA analysis for a regression model without an intercept.

| Source of Variation | Sum of Squares | df | Mean Square | Calculated $F$ | $p$ |
|---|---|---|---|---|---|
| Regression | 52.19 | 2 | 26.10 | 3.11 | 0.05 |
| Error | 553.02 | 66 | 8.38 | | |

Table 6.7: 95% confidence intervals for a model without an intercept.

| Parameter | Value | Standard Error | $t$ | $p$ | Low | High |
|---|---|---|---|---|---|---|
| $L_{HT}$ | 0.46 | 0.08 | 5.96 | 0.00 | 0.31 | 0.62 |
| $L_{MG}$ | 0.17 | 0.08 | 2.01 | 0.02 | 0.00 | 0.34 |

The 95% confidence intervals for the model coefficients are shown in table 6.7. Notice that the standard errors for the coefficients have dropped when compared to the ones in table 6.5, and that we can now safely reject the hypothesis that the coefficients of the model parameters are 0 for all of the coefficients. Unfortunately, there is still an overlap in the confidence intervals for the coefficients of $L_{HT}$ and $L_{MG}$, so we cannot reject our null hypothesis in this case. We do note, however, that the overlap is relatively small. By inspection, we find that the confidence intervals begin overlapping at approximately the 92.5% level. This overlap may be accounted for by some of the factors to be discussed in section 6.4.

### 6.2.4 A two-dimensional model

Rather than casting our data as a three-dimensional regression problem, we could instead consider the question of how the ratio of HT links to MG links, $L_R$, and the number of correct answers, *Ans*, are related. If we can show that the regression line for these two variables has positive slope, then we will know that increasing the number of HT links that a user takes will increase his or her number of correct answers.

This model gives us the following equation for the regression line:

$$Ans = 3.65 + 0.56 \cdot L_R \qquad (R^2 = 0.05)$$

Figure 6.3 shows a scatter plot of the values and the regression line. Notice that the intercept is quite high, almost at the average for the data that we collected. An ANOVA analysis similar to those above, however, shows us that $L_R$ is related to *Ans* with $p < 0.07$. Table 6.8 shows the 95% confidence intervals for the parameters of this model. From this table, we see that we can reject the hypothesis that the coefficient of $L_R$ is 0 with $p < 0.05$. We note, however, that a very small portion of the 95% confidence interval is negative, indicating that some of the time, we could expect a greater benefit from following MG links rather than HT links.

Table 6.8: 95% confidence intervals for a two-dimensional model of all data.

| Parameter | Value | Standard Error | $t$ | $p$ | Low | High |
|---|---|---|---|---|---|---|
| Constant | 3.65 | 0.56 | 6.52 | 0.00 | 2.53 | 4.77 |
| $L_R$ | 0.56 | 0.30 | 1.90 | 0.03 | −0.03 | 1.16 |

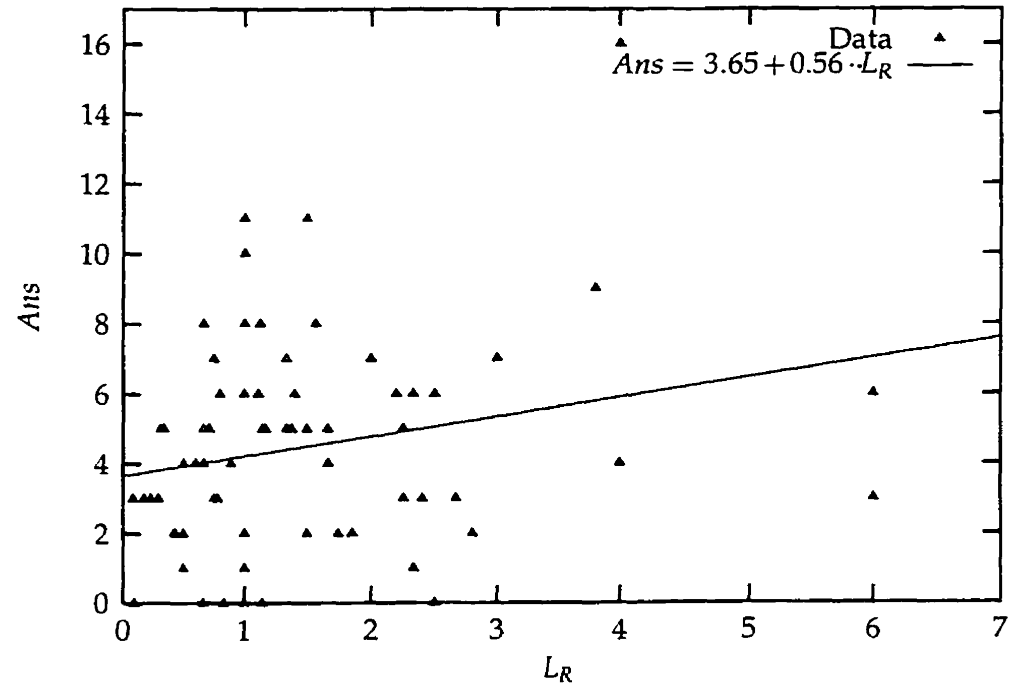


Figure 6.3: Data and regression line for all questions.

### Data by question

Figure 6.3 shows that the regression line from our model is not a particularly good fit to our highly variable data. It is worthwhile to look at the data and regression lines computed for each separate question. The scatter plots for these data sets are shown in figures 6.4 through 6.6.

Paired $t$-tests show that the subjects found significantly more answers ($p < 0.05$) for question 2 than for questions 1 and 3. Interestingly, question 2 also showed the greatest benefit for subjects following HT links, with a slope of 0.93 for the regression line. The ANOVA analysis for the regression model of question 2 also showed the greatest amount of variation that was due to the regression and not to the residual. Although the ANOVA analyses of these models indicate that none of them are significant (the model for question 2 comes the closest with $p < 0.25$), they may offer clues about what kinds of questions should be used for evaluations like the one that we have performed.

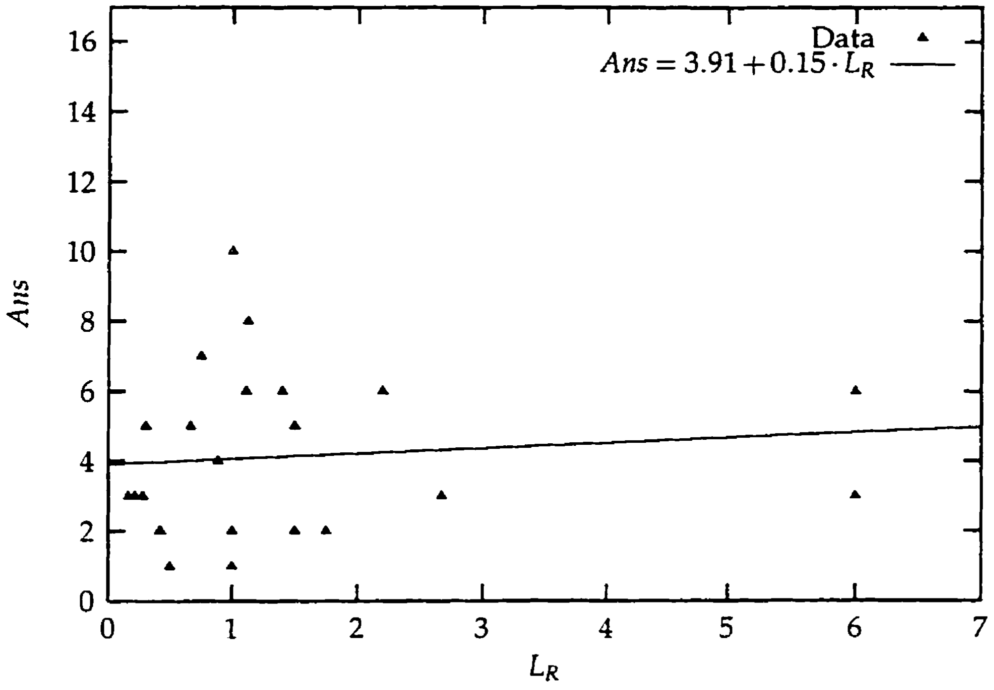


Figure 6.4: Data and regression line for question 1.

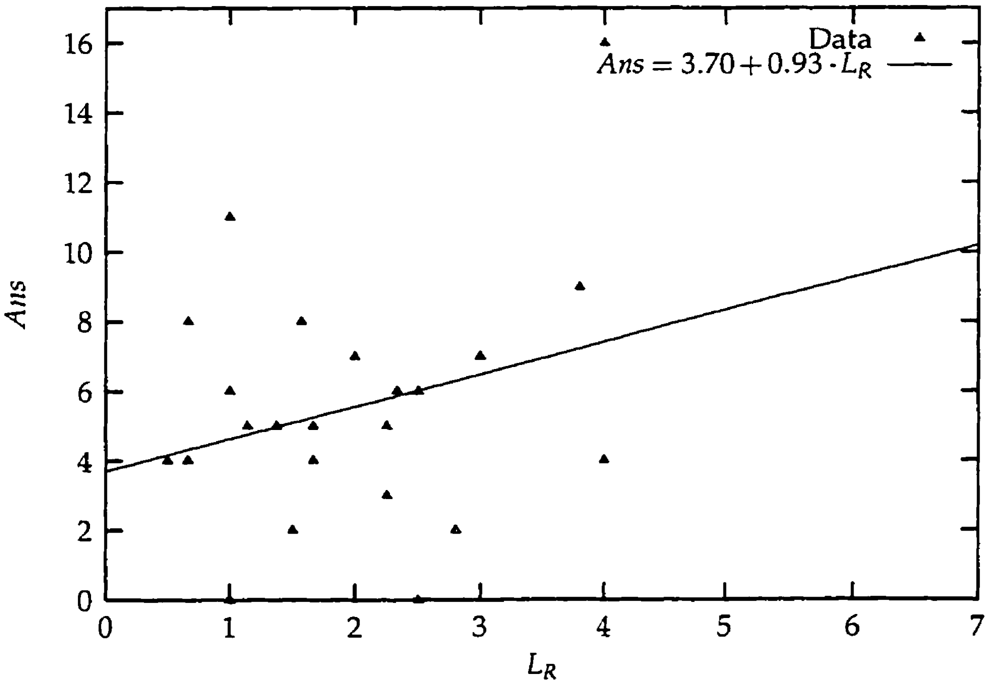


Figure 6.5: Data and regression line for question 2.

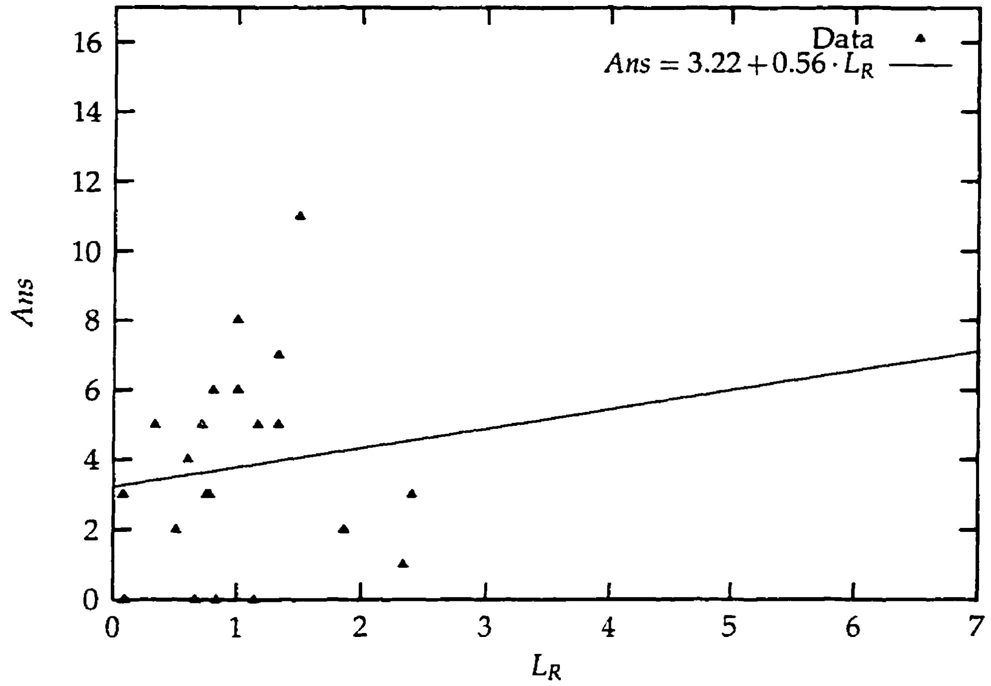


Figure 6.6: Data and regression line for question 3.

### Data by experience

We can also ask how a subject's success is affected by their degree of previous experience in using hypertext. Question 5 of the questionnaire given to the subjects asked how often they browse the Web. We can take their answer to this as an indication of their experience using hypertext. We divide the subjects into two groups. The first group, which we will call the *Low Web* group, circled 1, 2, or 3 in response to this question, indicating that they use the Web less than three times a week. The second group (the *High Web* group) circled 4 or 5, indicating that they use the Web three or more times a week. An unpaired $t$-test shows that the High Web group (12 subjects) chose significantly more ($p < 0.01$) inter-article links than the Low Web group (11 subjects). This difference indicates that these subjects are probably more comfortable in a hypertext environment than the other subjects, and adapted more quickly to the interface used for the task.

When we look at the numbers of each kind of hypertext links followed by each group, we see that the High Web group chose significantly more HT links than the Low Web group ($p < 0.01$). There was no significant difference in the number of MG links chosen by the two groups.

Within each group, we find that the High Web group chose significantly ($p < 0.05$) more HT links than MG links, while there was no such significant difference in the Low Web group. There is also a significant difference ($p < 0.01$) in the number of answers found by the two groups, with the High Web group finding more correct answers.

If we consider transforming our ratio measure by taking its inverse, $\frac{1}{L_R}$, then we see a significant ($p < 0.05$) difference in the ratios between the High and Low Web groups. Thus, we can see a set of subjects (the High Web group) who found significantly more answers *and* followed significantly more HT links, indicating the advantage of HT links over MG links.

As with our other data sets, we can build two-dimensional regression models for each of these groups. Figures 6.7 and 6.8 show the data and regression lines for the Low and High Web groups, respectively. Although only the model for the Low Web group is significant, we see that the slope of the regression line for the Low Web group is steeper than that for the High Web group, indicating that the Low Web group benefited more from following HT links than did the High Web group.

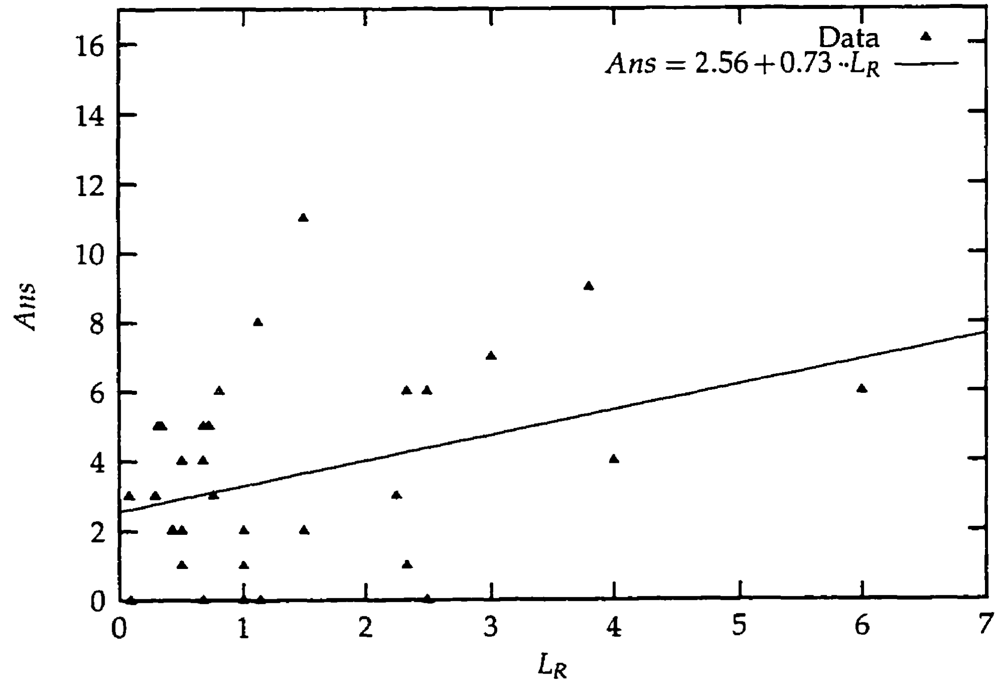


Figure 6.7: Data and regression line for Low Web group.

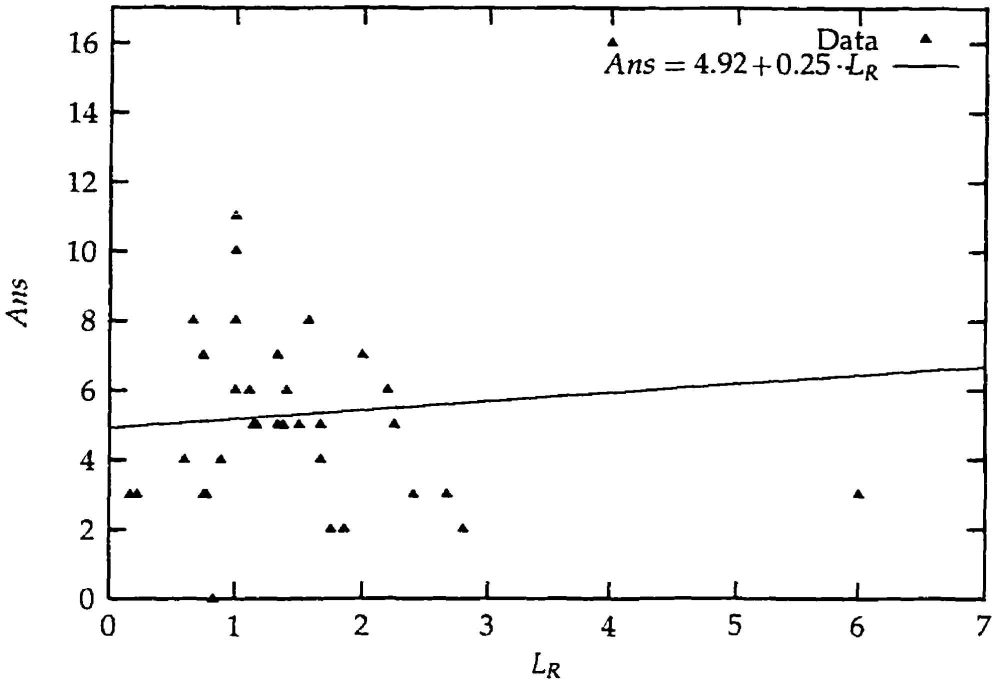


Figure 6.8: Data and regression line for High Web group.

### 6.2.5 Viewed answers

In the analyses that we've performed to this point, we have been using the number of correct answers that the subjects provided as our dependent variable. We have also mentioned that the reason we are using this dependent variable is that the subjects were limited in the amount of time that they could spend on each search. We can mitigate this effect by introducing a new dependent variable, $Ans_V$, or the number of *viewed answers*.

The number of viewed answers for a particular question is simply the number of answers that were contained in articles that a subject visited while attempting to answer a question. These answers need not have been written down. We are merely saying that, given more time, the subjects might have been able to read the article more fully and find these answers. This idea is analogous to the use of *judged* and *viewed recall* by Golovchinsky (1997) in his studies.

For the data collected from our study, a paired $t$-test indicates that there is a significant difference ($p \approx 0$) between $Ans_V$ and $Ans$, so we could investigate a two-dimensional regression model using $Ans_V$ as the dependent measure; however, such a model is not significant. We must then return to a three-dimensional model incorporating separate terms for $L_{MG}$ and $L_{HT}$.

Such a model is highly significant when considering the ANOVA analysis shown in table 6.9 and gives us the following equation:

$$Ans_V = 0.70 \cdot L_{HT} + 0.26 \cdot L_{MG} \qquad (R^2 = 0.22)$$

Table 6.9: ANOVA analysis for a regression model using viewed answers.

| Source of Variation | Sum of Squares | df | Mean Square | Calculated $F$ | $p$ |
|---|---|---|---|---|---|
| Regression | 293.43 | 2 | 146.71 | 9.14 | 0.00 |
| Error | 1059.18 | 66 | 16.05 | | |

which shows a greater benefit for HT links over MG links. The 95% confidence intervals for this model, however, do show a very small overlap (less than 1% of the interval for $L_{HT}$) between the coefficients of $L_{MG}$ and $L_{HT}$, as we see in table 6.10. This overlap precludes us from claiming significance for this result, but it may be accounted for by some of the factors that we will discuss in section 6.4.

Table 6.10: 95% confidence intervals for coefficients in a model using viewed answers.

| Parameter | Value | Standard Error | $t$ | $p$ | Low | High |
|---|---|---|---|---|---|---|
| $L_{HT}$ | 0.70 | 0.11 | 6.57 | 0.00 | 0.49 | 0.92 |
| $L_{MG}$ | 0.26 | 0.12 | 2.28 | 0.01 | 0.03 | 0.50 |

### 6.2.6 Inter- and intra-article links

While we're primarily interested in how well our inter-article linking works compared to other methods, we are also interested in seeing how the use of intra-article links affected the number of correct answers that a user found. We can begin answering this by proposing a regression model in which the independent variables are $L_{MG}$, $L_{HT}$, and $L_I$ and the dependent variable is *Ans*. For simplicity's sake, we will show only the model in which the constant has been fixed at 0.

This model gives us the following relationship between the three types of links and the number of correct answers:

$$Ans = 0.44 \cdot L_{HT} + 0.15 \cdot L_{MG} + 0.06 \cdot L_I \quad (R^2 = 0.10)$$

As with the model discussed above, there is still a greater benefit in selecting an HT link over an MG link. The coefficient of $L_I$ although quite small, is positive, indicating some benefit from following intra-article links. The ANOVA analysis for this model, shown in table 6.11, indicates that our independent variables are indeed related to our dependent variables. The 95% confidence intervals of the model coefficients in table 6.12 show that, as with the models discussed above, we can reject our null hypothesis with respect to the inter-article links, but the probability is high that the coefficient of $L_I$ is 0 ($p > 0.18$).

Table 6.11: ANOVA analysis for a regression model including all link types.

| Source of Variation | Sum of Squares | df | Mean Square | Calculated $F$ | $p$ |
|---|---|---|---|---|---|
| Regression | 59.19 | 3 | 19.73 | 2.35 | 0.08 |
| Error | 546.03 | 65 | 8.40 | | |

Table 6.12: 95% confidence intervals for coefficients in a model using all three link types.

| Parameter | Value | Standard Error | $t$ | $p$ | Low | High |
|---|---|---|---|---|---|---|
| $L_{HT}$ | 0.44 | 0.08 | 5.55 | 0.00 | 0.28 | 0.60 |
| $L_{MG}$ | 0.15 | 0.09 | 1.70 | 0.05 | −0.03 | 0.32 |
| $L_I$ | 0.06 | 0.06 | 0.92 | 0.18 | −0.07 | 0.18 |

Thus we are led to conclude that intra-article links had no across-the-board effect on *Ans* for this particular question-answering task. This conclusion seems to be borne out by the subjects' answers on the post-task questionnaire. The average score on the question "Were the links *within* the articles useful?" was 2.9, between "Not really" and "Somewhat". Separate regression models for the High and Low Web groups including the number of intra-article links and using *Ans* as the dependent variable were not significant, and in any case the probability that the coefficient of $L_I$ is 0 in these models is still very high.

When we consider $Ans_V$ as our dependent variable, the model for the High Web group is still not significant, and there is still a high probability that the coefficient of $L_I$ is 0. For our Low

Web group, who followed significantly more intra-article links than the High Web group, the model that results is significant (as we can see from table 6.13) and has the following equation:

$$Ans_V = 0.58 \cdot L_{HT} + 0.21 \cdot L_{MG} + 0.21 \cdot L_I \quad (R^2 = 0.41)$$

Table 6.14 shows the 95% confidence intervals for this model. We see that the coefficient of $L_I$ is always positive, indicating some effect on $Ans_V$ from intra-article links. We also see that the probability that this coefficient is 0 is less than 0.02. We note, however, that for this model we cannot claim that the coefficient of $L_{HT}$ is always greater than the coefficient of $L_{MG}$. This is not too surprising in light of the fact that the High Web group chose significantly more HT links than did the Low Web group.

Table 6.13: ANOVA analysis for Low Web group including all link types.

| Source of Variation | Sum of Squares | df | Mean Square | Calculated $F$ | $p$ |
|---|---|---|---|---|---|
| Regression | 240.59 | 3 | 80.20 | 6.71 | 0.00 |
| Error | 346.37 | 29 | 11.94 | | |

Table 6.14: 95% confidence intervals for coefficients in a model using all three link types and viewed answers.

| Parameter | Value | Standard Error | $t$ | $p$ | Low | High |
|---|---|---|---|---|---|---|
| $L_{HT}$ | 0.58 | 0.13 | 4.37 | 0.00 | 0.31 | 0.85 |
| $L_{MG}$ | 0.21 | 0.13 | 1.62 | 0.06 | −0.05 | 0.47 |
| $L_I$ | 0.21 | 0.10 | 2.19 | 0.02 | 0.01 | 0.40 |

In addition to the number of intra-article links that subjects followed, we also recorded the scrolling motions that they made, using either the scroll bar or the page up and down keys. The number of scrolling motions (15075) far exceeded the number of intra-article links taken (343), indicating that the subjects were browsing the articles using the scrollbars rather than by using the intra-article links.

## 6.3 Other results

While the models that we have been discussing in this chapter were the main objectives for which we conducted this study, some of the data that were collected lead us to some interesting discoveries. In this section, we will present some of the things that we discovered, although we will not be making any claims about the statistical significance of these artifacts.

### 6.3.1 Size of the database

Earlier in this chapter we mentioned that our database consisted of some 30,000 articles, most of which were not relevant to the questions that we gave to the subjects. In fact, the subjects only ever saw 591 of the articles. The size of the database that we used may, in fact, have been a confounding factor in the experiment, as the main complaint from the subjects was that the system was "too slow". The speed at which articles were retrieved may have affected how many links a subject could traverse in the 15 minutes allotted for each question, and therefore limited the number of answers that they could find.

### 6.3.2 Preference for early links

The subjects showed a great preference for links in the "first page" of links to other articles. Each "page" showed 13 links, and the average link position selected by the users was 11.4. In table 6.15 we show the number of links followed by the page on which they occurred.

Table 6.15: Distribution of the position of selected links.

| Page | Links used | Percentage |
|---|---|---|
| 1 | 724 | 79.6 |
| 2 | 112 | 12.3 |
| 3 | 42 | 4.6 |
| 4 | 13 | 1.4 |
| $> 4$ | 19 | 2.1 |
| Total | 910 | 100 |

So it might not matter what the recall of a link generator is (i.e., whether it linked to all relevant articles) as long as the *most* related articles appear at the top of the list. In fact, the above table suggests that some relatively time-intensive post-processing should be done on the retrieved set of articles to move the most-relevant ones to the top.

## 6.4 Discussion

The most important conclusion that we can draw from the study is that the inter-article hypertext links generated by the method described in this thesis were not ignificantly better than links generated by a competing methodology for a question-answering task such as the one we posed to our subjects.

Having said this, however, we note that the probability of results such as those we achieved occurring by chance are less than 0.1. In addition, we can demonstrate at least one partition of our subjects (the Low and High Web groups) such that the only significant differences between them were the number of HT links followed and the number of answers found. This would seem to indicate some benefit from following HT links over MG links. For these reasons, we therefore conclude that it is necessary to replicate this evaluation in order to gain more evidence about the relationships between the number and kinds of inter-article links followed and the number of correct answers found.

Another interesting conclusion we draw is that, in general, the intra-article links did not have any benefit for the question-answering task that we designed. Only the Low Web group showed a significant benefit from using intra-article links, and then only when considering the number of viewed answers. This result is probably an indication of the novice's need for tools that make using unfamiliar information systems easier.

We believe that there were several factors that affected the study, some of which might have reduced the effectiveness of our methods, leading to our inconclusive results.

### 6.4.1 Implementation factors

We believe that there are several problems with the *implementation* of the current system that, when fixed, would allow our method to perform even more effectively.

### The evaluation system

Foremost among these factors was the speed of the system. Even though we could generate links from an article in less than two seconds, many of the subjects felt that the system was "too slow." The speed of the system tended to limit the number of articles that a user could actually read in the 15 minutes alloted for each question. This factor was mitigated by the fact that once an article had been visited, the hypertext links leading from it were stored so that subsequent visits would be almost instantaneous.

Several subjects noted after they had finished their tasks that they did not feel that they could judge where an intra-article link would take them. Clearly, some more study is needed as to what would constitute good intra-article link anchors. As we discussed in section 4.2.6, using the first few words of the target paragraph as the anchor text is a compromise position. One possibility is to allow the user a way to "peek" at more of the target paragraph. This would be relatively easy to implement.

### The lexical chainer

The current implementation of the lexical chainer, upon which all of our work is based, has some deficiencies, as we noted in section 2.2.1. Of these, probably the most damaging is that words that do not appear in WordNet can never be included in a chain. This excludes a large class of words that are important in the newspaper domain, namely proper nouns. These words can never be used in a lexical-chain-based comparison of document similarity, even if they appear in both documents. We do believe, however that this difficulty can be remedied, as we shall discuss in the next chapter.

Perhaps a more subtle problem is that we rely on the lexical disambiguation performed by the chainer to solve the problem of polysemy. There are two ways in which a failure in this mechanism will negatively affect our document-linking capabilities. First, the chainer can incorrectly disambiguate a word, choosing a single, incorrect synset to represent it. This incorrect synset is then used in building the weighted synset vectors used for document comparison. When the vector for the document containing the incorrect synset is compared to other document vectors, some portion of the similarity of the documents will be missed. Unfortunately, there is no way to tell whether the chainer has incorrectly disambiguated a word, and we have no data on the average number of incorrect disambiguations per document.

The second kind failure of the disambiguation mechanism is when it does not work at all (or works very badly), leaving a word that is represented by several synsets, each of which is counted when building the weighted synset vectors. This can result in spurious document connections. For example, during the evaluation, the "starter" document for question 1 contained the word *piece*, a word that is in 11 WordNet synsets. This word was not disambiguated at all. Another, totally unrelated article, suffered the same fate. On the basis of the weights of these 11 synsets, the member-member similarity of these articles was 0.477. This led to these articles being linked with a highly ranked connection!

Clearly we would like to avoid this sort of spurious connection. It is less obvious how we could avoid such things happening, but it is interesting to note that, in this particular case at least, the member-linked similarities for the two articles were both 0. A threshold on the two member-linked similarities, in addition to the threshold of 0.15 on the member-member similarities may be enough to solve this problem. In the longer term, we believe that a more cautious approach to lexical chaining may be needed, that is, an approach that may take more time, but is less likely to make these sorts of errors.

### 6.4.2 Task factors

Question-answering is a very "fuzzy" task to choose for an evaluation such as we have performed. In the IR community, the process of evaluation is generally carried out in a totally automated fashion, using collections of documents and queries with known sets of relevant articles. Of course, we could perform similar evaluations (as we have shown in section 5.4), but we are more interested in seeing how the hypertexts that we build can be used by people to perform a specific task.

Designing the questions for a task to be performed by people is not an exact science, and so we have to assume that the subjects had at best an imperfect understanding of the questions that they were supposed to answer, even though the average response on the questionnaire to "I understood the questions I was supposed to answer" lay between "Agree" and "Strongly agree." This variation in understanding would obviously cause a variation in the answers that the subjects recorded. The way to avoid this seems to be to pose questions that require as little interpretation as possible on the part of the subject.

The subjects performed best on question 2, where the idea was simply to find the names of terrorists. This is a relatively straightforward task, and requires little interpretation, since most of the names in the database are actually identified as terrorists in the articles. In the case of the other two questions, however, some subjects seemed to have some real difficulty. For example, in more than one case, subjects answering question 3 reported only the name of the biotechnology company involved in a merger, rather than the names of all companies involved. In other cases, some subjects seemed to have difficulty distinguishing the name of a drug manufacturer from the name of the drug that they manufacture. This underscores the need for pilot testing in such evaluations.

### 6.4.3 The influence of the domain

As we noted in section 2.1, newspaper articles are written so that one can stop reading them at the end of any particular paragraph. This property of news articles may account for the performance of our intra-article links in this evaluation. If news articles are written to be skimmed, then it is likely that people will skim them. Since people will be more familiar with a newspaper than with a hypertext system and since the subjects were aware that they were reading newspaper articles, they likely read them as they would read articles in the paper. This might not have been a winning strategy for the task that we asked the subjects to perform, because if it had been, then we would probably not have found a significant difference between the number of correct answers and the number of viewed answers (although the time restrictions would account for part of this). We did, however, find that the Low Web group had some benefit from the intra-article links. This indicates that we should not just abandon the idea of intra-article links: rather we should investigate how these links could be used in longer texts that are not intended to be skimmed.

## Chapter 7

# Deploying a system for a Web newspaper

While we have described the process of generating intra- and inter-article links, and have described a system used for performing a test of our linking methodology, we have still not discussed how such a system could be deployed over the World Wide Web. This chapter will detail the construction of the software infrastructure necessary to perform the tasks that we have described in the previous chapters. For the most part, the system, which we call HyperTect, is written in C++, although a few AWK scripts are used for simple tasks such as cleaning up the format of the news articles. Our goal in building this demonstration system has been to produce software that is capable of dealing with a reasonably large amount of text in a reasonable amount of time. By "reasonably large" we mean a year of a major newspaper such as the *Globe and Mail*. This seems like a useful measure, since this is far more text than is usually available on a newspaper Web site.

Although we are describing a system for use on the Web, it should be noted that most of the software described could easily be re-targeted to another hypertext system.

## 7.1 Preparing the database

The first step in the construction of our system is the extraction of the lexical chains from the articles and the generation of the weighted synset vectors. Figure 7.1 shows the connection between these processes.

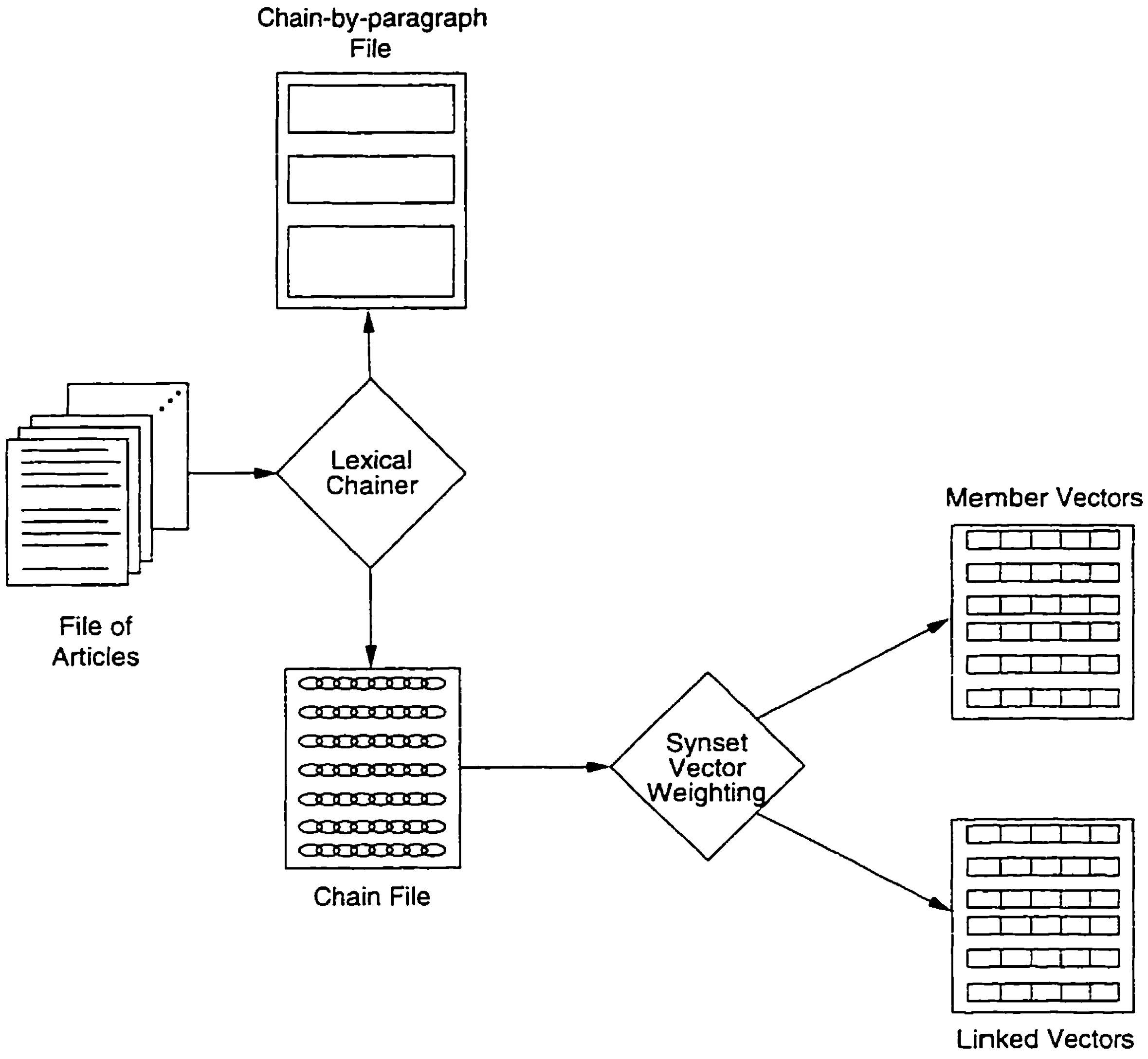


Figure 7.1: Preprocessing a file of articles.

### 7.1.1 Lexical chaining

We begin with a file containing a collection of articles. The first stage of processing is to lexically chain these articles. The lexical chainer produces two files from an input file of articles. The first is the *chain file*, which contains all of the lexical chains from the documents. The format of a single chain is shown in figure 7.2. The chain file contains not only the words contained in the chains but also the synsets of which the chained words are members and the synsets that are linked to these. The second file is the *chain-by-paragraph* file, which describes the paragraphs of the articles in terms of the chains that they contain.

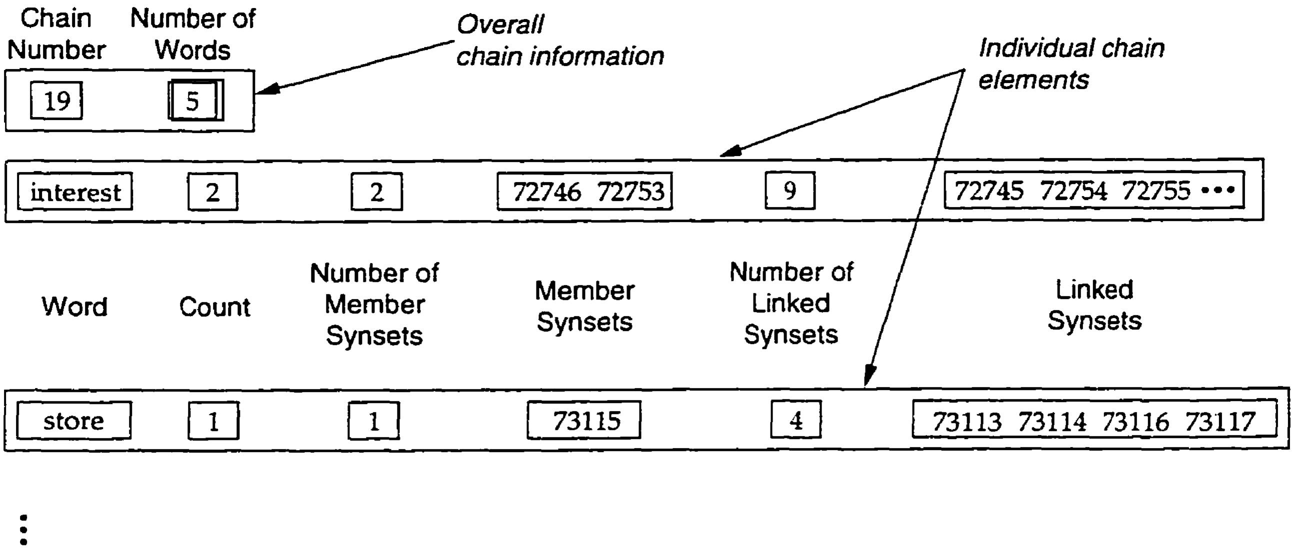


Figure 7.2: The format of a chain from the chain file.

The chain file is used in the construction of inter-article links, while the chain-by-paragraph file is used to construct intra-article links. Currently, the chain file is quite large, approximately twice the size of the original input data. This is mostly due to the fact that we store all of the linked synsets in the chain file, in order to make the computation of the synset vectors more efficient, since it is then not necessary to look up all the linked synsets in WordNet. If this information were left out, the size of this file would drop dramatically.

### 7.1.2 Building weighted synset vectors

The weighted synset vectors are built using the information contained in the chain file. This is a two-pass process. In the first pass, the number of documents that a particular synset occurs in (i.e., the document frequency) is calculated for both the member and linked synsets. In the second pass, for each document the number of times that a particular synset appears in a set of member or linked synsets (i.e., the synset frequency) is calculated. When all of the term weights for the member and linked synsets have been calculated using the function shown in section 5.3.2, the member and linked weighted synset vectors are output to separate files.

While the member vector file is approximately one-third of the size of the original articles, the linked vector file is approximately 1.5 times this size. This difference is due to the fact that there is generally a much larger number of linked synsets than there are member synsets in a set of lexical chains. For example, in the database used for our evaluation, the average length of a member vector is 100.2 synsets, and the average length of a linked vector is 541.0. The sizes of both of these files could be reduced by compression techniques, but at a cost of speed. For the purposes of the evaluation described in the previous chapter, we have left them uncompressed.

### 7.1.3 Database updates

Updating the database of articles is slightly more difficult for a system such as the one that we have described than for a simpler system, such as one that uses inverted files. The difficulty arises from the fact that the weight for a synset in a particular document is based not only on the frequency of that synset in the document, but also on the frequency of that synset across all documents. Thus, adding a single document will change the weighting for all synsets in that document across all of the other documents.

Of course, adding a single document will not change the weights by a significant amount, but adding an entire day of a newspaper to an existing collection may. Thus, the best course seems to be to regenerate the weight vectors at each addition, especially if the amount of data kept online is relatively small.

### 7.1.4 Efficiency considerations

The chainer that we used to build the database for our evaluation is substantially faster than previous efforts. For our evaluation database of approximately 30,000 articles (about 85 MB), the time for chaining was approximately 6.6 hours on a Sun UltraSparc workstation with 256 MB of main memory. We should note, however, that the memory image of the program while running was only 20 MB in size, most of which is accounted for by a full copy of the WordNet graph and indices that are held in memory during chaining.

At this rate, a full year of the *Globe and Mail* (which we estimate to be approximately 75,000 articles) would take approximately 16.5 hours to chain. This is certainly a reasonable amount of time, amounting to about 3.5 minutes per issue of the paper. Also note that the work can be spread among as many machines as are available, since there is no dependence between articles at this stage.

More precisely, if we consider the description of the chaining algorithm given in section 2.2.1, we see that the majority of the work done during chaining is in building the strong and regular relations between synsets. In both cases, if $n$ is the number of chains, then we must calculate $O(n^2)$ relations between pairs of chains for each iteration so that we can decide which chains to merge. These iterations continue until no more chains can be merged. In the worst case, we could expect that there would be $n$ such iterations, since the number of initial chains is equal to the number of unique words in an article. This gives us a worst-case complexity for lexical chaining of $O(n^3)$.

In practice, however, we find that the complexity is approximately $O(n^2)$. Figure 7.3 shows a plot of the number of words chained ($w$) versus the time (in seconds) required for chaining ($t$) for approximately 25,000 articles. The plotted line corresponds to the best fitting (in the least squares sense) parabola for the data. We believe that this is a reasonable average-case estimate of the chainer's complexity.

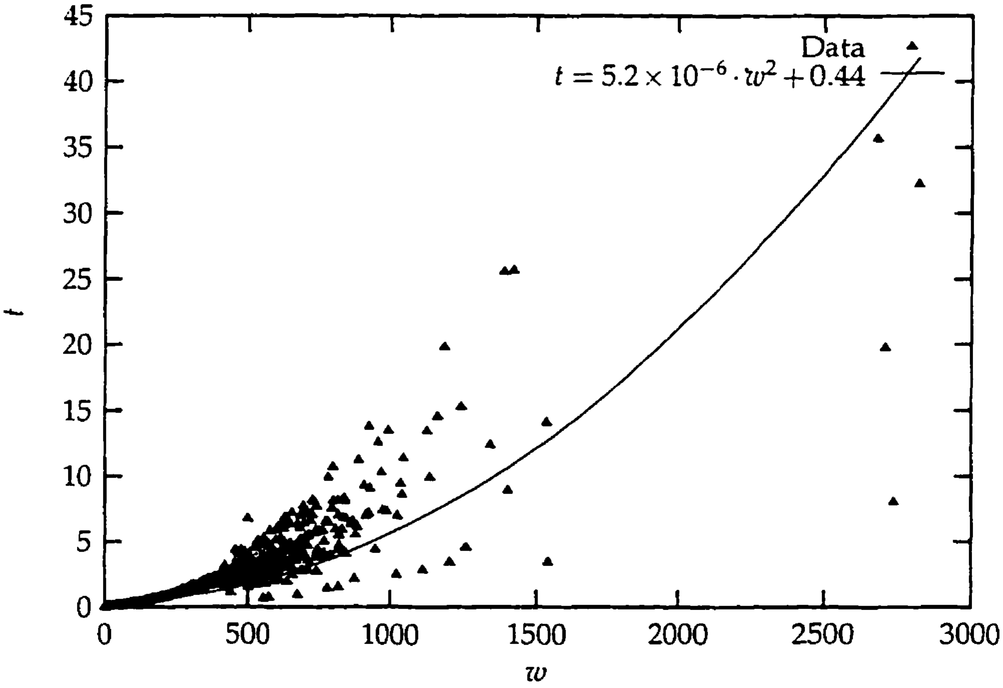


Figure 7.3: Graph of number of words chained versus Time to chain.

Notice that the constant for the parabola is quite small, indicating that an article must be relatively large before it begins to take a large amount of time to chain it. For our evaluation database, the average number of words chained per article is approximately 127.

The building of the weighted synset vectors is quite fast, requiring approximately 40 minutes to process the articles from our evaluation database. At this pace, the system would require about 1 hour and 40 minutes to process the chains from a full year of the *Globe and Mail.*

## 7.2 Serving articles over the Web

As we have mentioned, we would like to use the World Wide Web as our hypertext medium. Thus, we need a straightforward way to serve articles to a user's browser. Figure 7.4 shows the process by which this could take place.

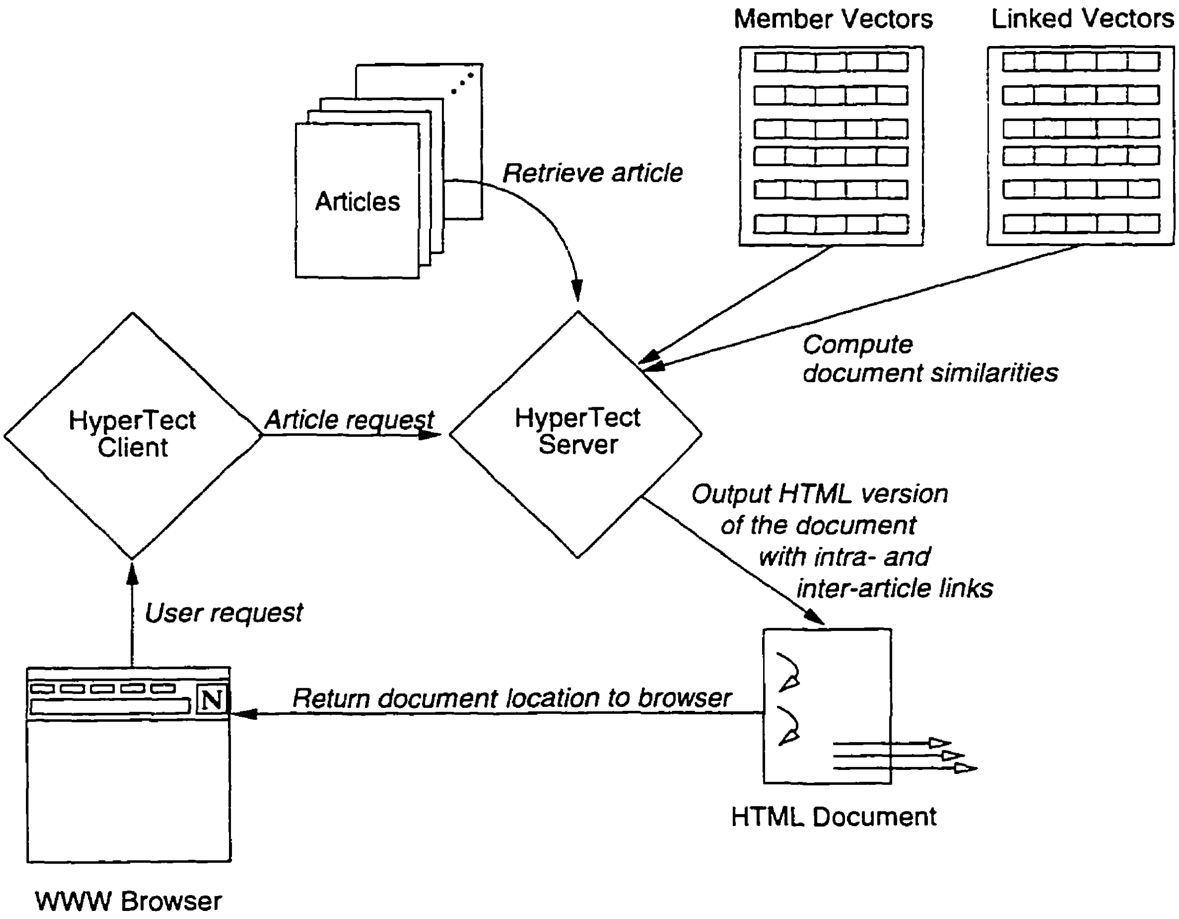


Figure 7.4: HyperTect client-server model.

### 7.2.1 The HyperTect client

We begin by supposing that a user has come to a newspaper's Web site and has clicked on a link that will take her to the text of an article. We can view this click as a request for a particular article. Associated with this request will be the article number from the database, the set of parameters for building intra-article links, and the threshold to use when calculating inter-article links. The parameter set and threshold used to generate the hypertext could be different for each user, if the Web site supports user authentication.

The article request is handled by a simple CGI script running on a Web server. We call this script the HyperTect client. The HyperTect client passes this document request to a HyperTect server via a TCP/IP connection, so that the server may be running on any computer on the Internet. We make this distinction between the client and server because the process of building inter-article links is quite compute and I/O intensive and so is probably best handled by a dedicated server, rather than a Web server prone to load fluctuations.

### 7.2.2 The HyperTect server

The HyperTect server performs several actions when it receives a document request from the client:

1. The requested article, along with its chain-by-paragraph description and its weighted synset vectors are retrieved from their various places.

2. The parameter set passed in the article request is used to generate a set of intra-article links. The main body of the article is written to an HTML file using the procedure described in section 4.2.6.

3. The weight vectors for the requested article are read in and compared against the rest of the vectors in the file. The first stage of the comparison is to compute the member-member similarity. If this similarity exceeds the threshold set by the user, then the member-linked similarities are calculated. The document is then added to the list of documents to return to the user. This document list is ranked by the sum of the three similarities

and written to the end of the HTML file. The headlines of the related articles are used as anchor text.

4. The location of the HTML file is returned to the HyperTect client, who returns it to the browser, using the HTTP `Location` directive.

### 7.2.3 Efficiency issues

Generating a set of intra-article links for a single article, given a set of parameters, takes approximately 0.03 seconds. This is certainly fast enough for our target environment of the Web, since this amount of time will be completely overshadowed by network lag.

The computation of inter-article links is also reasonably fast. For our evaluation database of 30,000 articles, using a threshold of 0.15, testing a single article's vectors against all others takes on the order of 1.2 CPU seconds on a Sun UltraSparc workstation. This implies that the system is capable of making approximately 25,000 vector similarity computations per second. At this rate, comparing a single document against a full year of a paper would take approximately 2.5 CPU seconds. This performance is comparable to the SMART system.

We believe that this is a reasonable amount of time for such a search to take, and indeed, when using the system, the wait time does not seem overly long. The server is very "lightweight", with resident set size of only 1 MB when running document comparisons, so that for our current database, the amount of real time required for performing document comparisons is almost the same as the amount of CPU time required.

We decided that, for efficiency reasons, the server should output an HTML file and return its location, rather than simply send HTML to the browser. While our search times are reasonable, we felt that it would be unwise to overload the server with requests that are simply due to the user hitting the "Back" button on their browser.

Chapter 8

# Contributions and suggestions for future work

We believe that there are several valuable contributions in the work that we have done. In addition, we will provide some indications of future work that may be derived from the thesis.

## 8.1 Contributions

### 8.1.1 Inter-linker consistency

Our first contribution is the replication of Ellis et al.'s (1994a) study on inter-linker consistency. While their results were quite conclusive, the conditions under which their task was performed left open questions as to how humans would fare on shorter, better structured texts. Our use of newspaper articles addresses these issues and shows that the conclusions that they reached are equally valid for short, well structured texts.

Of course, it may be possible that if a large number of human linkers were employed to build hypertext links within articles then we could "average out" the links to a stable, consistent set. Unfortunately, it seems that this is too much to hope for in current online newspaper efforts where the online edition is prepared by a small number of people. In addition, the costs in time and money to perform such a task are prohibitive. Thus, we conclude that if we need to provide hypertext links in online newspapers, then these links will need to be generated automatically.

### 8.1.2 Linking methodology

Most efforts at hypertext generation have focused on generating a hypertext from a single large document. Often these efforts focused on building purely structural links to sections and subsections along with links to subject indices and some keyword search facility. Few have attempted to build semantic links, and fewer still have attempted to build such links in large unrestricted collections of documents. Aside from this consideration, most of these systems are based on the traditional IR notions of document similarity, that similar documents will tend to use the *same* words. These systems are plagued by the problems of synonymy and polysemy. Although attempts have been made to cope with these difficulties, these attempts are often made when trying to retrieve documents, rather than when representing them for retrieval.

Allan (1995) was among the first to attempt unrestricted hypertext generation, using the vector space methodology of the SMART information retrieval system. While this is important work, it is hampered by the necessity of term repetition for links to be built. As we showed in chapter 5, this requirement can affect the quality of the results obtained. To avoid this problem, it is necessary to consider the fact that articles that are about the same or related topics will tend to use words that are related by synonymy and other relations such as IS-A and INCLUDES.

Our representation of the contents of a document as a pair of weighted synset vectors accounts for these problems as a side-effect of the representation. Because of this, we are able to consider document similarity in a new light, namely that similar documents will tend to use *similar* words. By using a synset-based representation, we abstract the documents from the *word* level to the *concept* level. The member synset vector that represents a document allows us to capture relations between documents due to synonymy as well as term repetition. The linked synset vector allows us to capture other relations. As a useful side effect, by building vectors of synsets, we need not concern ourselves with the problem of word sense ambiguity, since a synset represents a single sense of a word.

Despite building a more complicated representation for the documents, we were able to demonstrate that document linking could be done in real-time, and that pre-processing documents for use in the system could be done in a reasonable amount of time. Within a document, the lexical chains give us a much richer representation of the content, and to some extent, the structure of a document, so building links between the paragraphs becomes a much simpler task. To our knowledge, we are the first to apply lexical chaining techniques to such a task, and the first to attempt building hypertext links within smaller documents.

### 8.1.3 Evaluation

Our evaluation showed that we cannot reject the null hypothesis that there are no differences in the two linking methodologies. Even so, the probability of a chance result such as those that we achieved is less than 0.1. In addition, we showed that for a particular partition of the subjects, the only significant differences were the number of HT links followed and the number of answers found. We believe that there are several implementation factors that, when remedied, will produce a significant result for our system.

We were somewhat surprised by the lackluster showing of the intra-article links in our evaluation. The best that we can say about them is that, in general, they probably had no effect on how well the subjects did in their question-answering tasks. It may be the case that the anchors for the intra-article links simply did not provide enough information about where a link was leading. Another factor may have been the set of parameters that we selected to generate the intra-article links during the evaluation. This set was one that we had used to test the system and we felt that the links generated were "good enough".

The fact remains, however, that the Low Web group in our evaluation followed significantly more intra-article links that the High Web group and the model shown in section 6.2.6 demonstrates that these links probably had some benefit for these subjects. Thus, such links should be provided so that the novice users can have them, but an experienced user should be able to turn them off, or modify how they are generated.

### 8.1.4 Large-scale lexical chaining

One of the less obvious contributions of our work is that we have shown that the technique of lexical chaining can be used on a much larger scale than had previously been attempted. This is especially gıatifying in light of the fact that the extra work required to do lexical chaining (as opposed to keyword extraction) seemed to be repaid when our concept level representation of texts performed better than the traditional representation during the evaluation.

The database that we built for our evaluation showed that at least one of the claims made for lexical chaining is valid. In the evaluation database selected from the TREC corpus, before chaining the average number of senses associated with each word was 3.4. After chaining, the number of senses dropped to 1.2, showing that the lexical chainer is performing lexical disambiguation, albeit imperfectly.

This thesis also shows that techniques drawn from the field of Computational Linguistics — techniques that are relatively complicated compared to traditional IR document processing — can be used to successfully perform IR tasks in a wide domain on a large number of documents.

## 8.2 Suggestions for future work

### 8.2.1 Further evaluation

We believe that the somewhat inconclusive results of our evaluation indicate that it is necessary to replicate our evaluation in order to gain more evidence.

The evaluation that we conducted was somewhat contrived, in the sense that by testing only the differences between linking methodologies, we have not exactly answered the question of whether our methodology produces good links *in general*. That is, we must consider whether we can claim that our methodology is useful if it has not been fully used. We are willing to defend our method on the basis that if we added the links that the methods agreed upon, then our method would perform at least as well as, and possibly better than, the competing methodology operating on its own. Even so, this is exactly the sort of question that is amenable to evaluation and so we must conduct experiments to test this hypothesis.

Furthermore, we need to test our methodology on a wider range of tasks, such as a broader question-answering task, where the subjects must integrate information from several articles into their answers.

### 8.2.2 Lexical chaining

As we mentioned in section 6.4.1, there were several problems with the implementation of the lexical chainer that may have lead to less-than-optimal performance during our evaluation. Clearly, these problems need to be fixed in the next version of the lexical chaining software.

The first thing we need to add to improve the lexical chaining is proper-noun recognition. Even a simple version of this, such as collecting words that begin with upper-case characters, would improve the capabilities of the chainer. More importantly, we can add proper names to WordNet as a sort of pseudo-synset. These pseudo-synsets would consist of all of the variations that we can find on a person or entity's name. For example, the proper noun *Steve Martin* and the form of address *Mr. Martin* could be referring to the same individual, and should therefore be together in a synset. This would also work for company names and their abbreviations, such as *International Business Machines* and *IBM*. Although we would expect there to be many "Mr. Martin"s, the disambiguation properties of the lexical chainer will select the right one, at least in a newspaper domain. After each set of articles have been processed, the new pseudo-synsets could be written to a file to be used in successive runs. Of course, these synsets will not be linked into the WordNet hierarchy, but they will allow us to build synset-based representations using words not in WordNet.

Another problem with using WordNet is that it was intended as a very general lexical resource, and therefore lacks the kinds of domain-specific lexical items that we would like to be able to recognize, even in a general domain such as newspapers. In the short term, we can do this simply by representing unknown terms as a single new concept. In essence, the representation of a document would be based on weighted synset vectors and weighted term vectors. It may, however, be possible to go a step further than this.

One of the useful features of Latent Semantic Indexing is that it is possible to calculate term-term similarities. We could use these similarities to determine how a new, unknown term could be included in existing lexical chains. In the extreme, we may be able to build lexical chains using only these term-term similarities. On a more reasonable level, we want to investigate how LSI could be used to infer relationships between people and the positions that they hold (e.g., recognizing that Jean Chrétien is the Prime Minister of Canada). This would be very useful in a newspaper domain.

We need to work on the lexical chainer's disambiguation ability, since our linking methodology depends on well-disambiguated text. Others have been building lexical chainers (see, for example, Barzilay and Elhadad, 1997) that take much more care in attempting to disambiguate words. The downside of this is that doing so may increase the amount of time necessary to chain an article.

The final area of improvement for the chainer is its efficiency. The algorithm that we are currently using is $O(n^3)$ in the worst case, although it only begins to slow down when processing large articles. There are some obvious changes that can be made in the current implementation to remedy these problems, at the expense of making the chainer code more complex.

It may be possible, however, to avoid the complexity problem altogether. WordNet is a relatively stable resource, and so we can consider determining all of the possible lexical chains that each WordNet synset could appear in. Since how the chains are built does not depend on the text, we could then compute the lexical chains in a document as some subset of the possible chains in WordNet. There is no doubt that computing this set of chains would require a lot of time and space, but it only needs to be done once and the benefit is that computing the lexical chains in a document could then be done in constant time.

### 8.2.3 Typing links

One of the advantages of Allan's work (1995) is that the links between portions of two texts can be given a type that reflects what sort of link is about to be followed (e.g., *revision* or *contrast*). Although Allan could not show that users would have assigned these link types themselves, this is still very interesting work. We currently have no method for producing such typed links, but it may be the case that the relations between synsets could be used to build these links, once we have used our synset weight vectors to determine whether two articles are related.

For example, consider two articles $A_1$ and $A_2$. If the member-member similarity of these two articles exceeds the threshold, then we will consider placing a link between them. By looking at the member-linked similarities we can get some idea of how the synsets in $A_1$ are related to the synsets in $A_2$. If the member vector of $A_1$ and the linked vector of $A_2$ show sufficient similarity, then we know that terms in $A_1$ are one link away from those in $A_2$, perhaps indicating that the content of $A_1$ is a generalization or specialization of the content of $A_2$.

More generally, once we have made our determination about linking two articles, we could resort to a full comparison of the chains in the two documents, similar to the comparison that we showed in section 5.2, our starting point for building inter-article links. If we can make the lexical chainer more efficient, we should be able to make this comparison for a relatively small number of documents in real time. If the result in section 6.3.2 is valid, then it would seem that it would be most useful to type the links on the "first page" of the links shown to the user.

### 8.2.4 Efficiency

Although the system that we have proposed and built is sufficient to deal with a year of a newspaper, we would need to make some changes in order to cope with larger amounts of text (i.e., in the gigabyte range). Clearly, having access to faster workstations will provide some relief in this area, but there are other optimizations that can be made.

Foi example, in the SMART vector space system, the vectors representing documents can be clustered so that a first pass can be made, determining which document clusters are most similar to a query document. More detailed computations can be made once a subset of the document collection has been selected in this way. A similar technique could be used for our weighted synset vectors.

### 8.2.5 A wider range of texts

As we proceeded with the research on inter-article linking, we became more and more convinced that this methodology should work reasonably well, given any well-written text. The preliminary test of our linking methodology that we discussed in section 5.4 and the database that we used for our evaluation (see section 6.1.2) provide us with some support for this conviction. Some of the articles from the Ziff corpus are long magazine articles (some more than 70 paragraphs in length). Their length did not seem to stop them from being included in clusters or linked to other articles.

It seems that there are some reasonable intra-article links generated in these longer magazine-style articles, although the number of links generated per paragraph appears to be much larger. The number of links drops when normalization is used on the chain density vectors for the paragraphs. This seems to be natural, given the longer paragraphs in such articles.

For example, appendix A shows the hypertext that resulted from applying the methodology described in chapter 4 to an article from *Maclean's* magazine (Chidley, 1997) about the amalgamation of the Greater Toronto Area into a "megacity". This article is much larger than the virtual parenting article that we presented earlier. There are approximately twice the number of paragraphs, and the paragraphs are substantially longer. Because the article is much larger, it will cover more topics, and it's structure will be more complicated than the one shown in table 4.2.

The hypertext links shown in appendix A were generated using the Mean Euclidean distance metric, no weighting function, and normalization of the chain density vectors to a unit length. A z-score of 1.0 was used and all links are shown.

As you can see, the method generates some very useful links. For example, paragraph 5, describing the expected savings from amalgamating is linked to paragraph 17, which describes how the costs of amalgamation soared when Halifax and Dartmouth, Nova Scotia merged. Of course, this is only a single example, meant to demonstrate the process on a longer text. We would suggest that an evaluation like the one that we carried out be attempted using longer, more diverse sources of texts. We believe that in these instances, the use of intra-article links will have more effect on determining how successful the subjects will be.

### 8.2.6 Applying lexical-chaining techniques to traditional IR

In a more speculative vein, we are considering ways that lexical chaining could be incorporated into more traditional IR systems. Such systems show a remarkable advantage when given only a few words as a query. Lexical chaining is not effective on such small pieces of text, since there is not enough context to build good chains and disambiguate the words.

It may be possible, however, to build a set of lexical chains for a single user over a period of time, incorporating each query into a representation of a particular user's interests. These lexical chains could then be used to modify the retrieval behaviour of the IR system by selecting articles that use only a particular sense of a word, as opposed to all senses.

Such a set of lexical chains may also be useful in our own hypertext generation system, where they could be used to modify the process of producing both intra- and inter-article links.

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# Index

# Appendix A

# The Toronto amalgamation article in hypertext format

This appendix contains the text of the Toronto amalgamation article discussed in chapter 8[1]. The hypertext links between the paragraphs were built using the Mean Euclidean distance metric, no weighting function, normalization to a unit length, and a $z$-score threshold of 1.0. All generated links are shown. The format of the links is as follows:

| Anchor | Paragraph Number / Page |
|---|---|
| ▶ Oppusition to the bill, scheduled for final reading in the provincial... | ¶ 4 / next page |

## A proposed merger draws cries of outrage from rich and poor, right and left

by
Joe Chidley

1. It is an unwritten code of conduct for big-city life: avoid speaking to strangers on the public transit system–and if talking to a friend, keep it down, please. So ingrained is that protocol that when a group of Toronto teenagers started talking loudly on the Gerrard streetcar one late-February afternoon, the discomfort among other passengers was almost palpable. It was only heightened when one of the kids, a long-haired girl in a green bomber jacket, actually addressed an older stranger. "How are you going to vote on megacity? You gotta vote No, man," she remarked, unbidden. Before he could respond, another teen piped in: "I dunno. It's gonna happen anyway–Scarborough's going to get sucked up by Toronto. Scarborough's so small." The stranger, getting a word in edgewise, pointed out that Scarborough and Toronto are, in fact, about the same size. "Really?" said the second teen, her nose-ring twitching with curiosity. "I dunno, around my subway station, Kennedy–" "That station sucks," interjected Teen No. 1. "Yeah," continued Teen No. 2. "Anyway, around there, it's pretty small."

| | |
|---|---|
| ▶ Opposition to the bill, scheduled for final reading in the provincial... | ¶ 4 / next page |
| ▶ Still, few who have seriously studied the problems facing Toronto say... | ¶ 9 / page 135 |
| ▶ Unfortunately, there is no consensus on the best way to address those... | ¶ 10 / page 135 |
| ▶ It was a hardball tactic that, to many critics, seemed both... | ¶ 15 / page 136 |
| ▶ During provincial hearings on the megacity bill that culminated last... | ¶ 16 / page 136 |
| ▶ Like many others, City of Toronto Mayor Hall predicts dire... | ¶ 21 / page 137 |

2. For once, strangers are talking to one another in Toronto. And what's got them talking–even the teenagers–is municipal politics, something Torontonians usually find so unenthralling that only about a third of them

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vote in civic elections. But in Toronto–that somewhat arrogant metropolis the rest of the country loves to hate–these are unusual times. The city is in the grip of Mega-Madness, and a rivetting drama is being played out on the civic stage. To the provincial Conservatives and their supporters, it is a tale of solid municipal policy and sound fiscal management. But to many Torontonians, who fear that the province's reforms will destroy their city, it has taken on the proportions of a horror movie–Megacity: The Tory Monster that Ate Toronto.

▶ Still, few who have seriously studied the problems facing Toronto say... ¶ 9 / next page
▶ Like many others, City of Toronto Mayor Hall predicts dire... ¶ 21 / page 137

3. The plot goes something like this. Last December, the provincial government introduced Bill 103, which as of next year will unify the area's six municipalities, along with the regional government of Metropolitan Toronto, into a single city of about 2.3 million people–Toronto the Good becomes Toronto the Huge. It might seem a relatively innocuous bit of legislative tinkering, but with the proposed amalgamation, the provincial government stepped boldly –some say blindly–into a political minefield.

▶ But the real trouble for the Tories is that few Torontonians think... ¶ 7 / this page
▶ Unfortunately, there is no consensus on the best way to address those... ¶ 10 / next page
▶ It was a hardball tactic that, to many critics, seemed both... ¶ 15 / page 136
▶ Like many others, City of Toronto Mayor Hall predicts dire... ¶ 21 / page 137

4. Opposition to the bill, scheduled for final reading in the provincial legislature next month, was immediate. And the cries of outrage–remarkably loud for such a politically staid city–have come from rich and poor, left and right. The protests could be heard at any of the 20 or so community meetings at which amalgamation has been discussed every week for the past three months, or seen on the myriad "Vote No to megacity" signs outside homes and businesses. Last week, in referendums sponsored by the six municipalities–all of whose mayors oppose the megacity–the opposition culminated in a rejection of amalgamation by Toronto residents. Three-quarters of participating voters (turnout was, again, about one-third) said No to the megacity. Provincial officials, who charged that the referendum questions were biased and that the voters' lists were unreliable, had repeatedly vowed to ignore the results. But last week's No vote still sent them scrambling for damage control, even as they vowed that amalgamation will continue.

▶ Unfortunately, there is no consensus on the best way to address those... ¶ 10 / next page
▶ In the wake of last week's referendum results, the Conservatives had... ¶ 20 / page 137
▶ Like many others, City of Toronto Mayor Hall predicts dire... ¶ 21 / page 137

5. The provincial plan for Toronto is, in fact, a radical piece of legislation, and its effects will transcend the borders of the new city. The unified Toronto will be a virtual city-state, outpacing the populations of six provinces and rivalling that of Alberta (population 2.7 million). The new Toronto will be bigger than any American city except New York, Los Angeles and Chicago. Ostensibly, the new city will also be leaner and more efficient than the old one: the government projects cost savings of $865 million by the year 2000, thanks to less waste, fewer politicians–and the elimination of as many as 4,500 civil service jobs. An amalgamated Toronto will "have a strong, unified voice to sell itself internationally" in the global marketplace, boasts Municipal Affairs Minister Al Leach. "We have the potential to take a great city and make it even greater."

▶ One miscalculation was the process. These days, amalgamation is all... ¶ 13 / page 136
▶ Other critics, like federal NDP Leader Alexa McDonough, questioned the... ¶ 17 / page 136

6. Many Torontonians, however, clearly do not buy Leach's argument. They fear that amalgamation, by reducing the number of councillors to 44 from the current 106, will dilute their political voices and make local government less responsive. Others are concerned that property taxes will rise–not only because of amalgamation, but also because of separate provincial plans to reform the tax system and to off-load the cost of social services onto the municipalities. Still others simply do not like the way the Tories have gone about implementing change–and use loaded words like "tyranny" and "dictatorship" to prove their point.

7. But the real trouble for the Tories is that few Torontonians think about the city in terms of the "global marketplace." Sure, they are smugly satisfied when, as Forbes magazine did last November, Toronto is rated as

the best place in the world to balance work and family. But they remain tied not so much to the idea of city as to the idea of neighborhood: communities like Cabbagetown or Baby Point or the Beaches; street designations like the Kingsway or the Danforth; even–as with the teenager from Scarborough–the subway stop near their homes. To them, amalgamation seems a threat to their sense of community, to the places they call home. "If it wasn't so destructive, it would be funny," says City of Toronto Mayor Barbara Hall. "It makes no sense, they've not thought it through, and yet it has the potential to seriously damage a community that is the envy of the world."

▶ Still, few who have seriously studied the problems facing Toronto say... ¶ 9 / this page

▶ Unfortunately, there is no consensus on the best way to address those... ¶ 10 / this page

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8. That worry is echoed by North York Mayor Mel Lastman, a passionate civic booster who gets visibly upset when he talks about the megacity. At a recent anti-amalgamation rally–one of many at which he and the other mayors have spoken out–he waved around the province's map of the new municipal boundaries. "You won't find North York anywhere on the map! North York is gone!" Lastman half-yelled, his face turning red. "They're carving us up like a turkey and it isn't even Thanksgiving!"

9. Still, few who have seriously studied the problems facing Toronto say that the status quo is acceptable. In the current division of powers, the Municipality of Metropolitan Toronto provides about 70 per cent of services, including police, ambulances, sewage, water and public transit, across the entire area. But the rest of the municipal structure is a complex network of individual city bylaws governing roads, health, garbage collection and planning. And there is redundancy: the Toronto area has six different fire departments, each with its own fire chief and training facilities. Further confusion results from the fact that some services are provided both by the Metro government and by the individual cities. Some roads are owned by Metro, others by the local municipality. "People don't know what's going on, people get confused and angry and afraid, because it's complicated," says Patricia Petersen, director of the urban studies program at the University of Toronto and a supporter of amalgamation. "The current system is not conducive to developing any reasonable discussion on issues that really matter to us."

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10. Unfortunately, there is no consensus on the best way to address those problems. Last winter, a provincial task force, led by local United Way president Anne Golden, suggested that the Metro level of government be dissolved and that the other municipal-ities, reduced in number to four, become part of a wider government–the Greater Toronto Area, or GTA, encompassing Toronto and its outlying areas. Then, the Who Does What Advisory Panel, chaired by former Toronto mayor and federal Tory cabinet minister David Crombie, endorsed a strong urban core for the GTA and some degree of consolidation in the metropolitan area–but not specifically amalgamation. Another scheme, developed last year by Toronto-area mayors, opted for the abolition of regional governments, including Metro, with municipalities co-ordinating services among themselves.

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11. The Conservatives had, as part of their cost-cutting platform, promised in the last election to get rid of at least one level of Toronto government. And according to Municipal Affairs Minister Leach, they at first considered dissolving Metro–but decided last fall that it would be too complicated. "How do you dissolve down the services that are provided by Metro?" he asks. "The longer we looked at it, the more obvious it was that with the majority of major services already at the upper tier, the right option was a single city."

12. And then the trouble really started for the Tories in Toronto.

13. One miscalculation was the process. These days, amalgamation is all the rage in Ontario, where about 350 municipalities are now negotiating mergers. In Kingston, for instance, city and county municipalities have been working towards amalgamation for the past two years. And in Hamilton, a constituent assembly has developed an amalgamation plan that would replace existing municipalities with one Hamilton-Wentworth authority. Although those schemes have not been uniformly popular (Hamilton-area residents voted against amalgamation in a February referendum), they at least involved extensive local input.

14. But not in Toronto. The Tories sent Bill 103 straight to first reading–without releasing a position paper, as would have been usual for such a major reform. And in the legislation itself, the government gave much of the control over existing municipalities to an appointed interim board of trustees, whose decisions would be final. Those trustees would be followed by another appointed body–a transition team to assist in the implementation of the megacity–with many of the same powers.

15. It was a hardball tactic that, to many critics, seemed both dictatorial and undemocratic. And it is what particularly sticks in the craw of John Sewell, the former Toronto mayor and local newspaper columnist who has galvanized anti-amalgamation forces as a leader of Citizens for Local Democracy. "I live in a democracy, and I want control over people who make decisions for me," said Sewell, whose group's weekly meetings have regularly attracted more than 1,000 concerned Torontonians for the past three months. "The Tories are saying, 'You can't have it any more, we've got a better idea'—which is putting autocrats in charge." (The trustees question created a political embarrassment for the government last month when an Ontario Court judge ruled that their appointment by executive order, before Bill 103 had passed, had no standing in law.)

➤ Like many others, City of Toronto Mayor Hall predicts dire... ¶ 21 / next page

16. During provincial hearings on the megacity bill that culminated last week, speaker after speaker voiced their concern over the Tory reforms. Among the most articulate was Jane Jacobs, the American-born architect and author of the influential The Death and Life of Great American Cities. "Anyone who supposes harmony will prevail and efficiency reign after whole-hog amalgamation," said Jacobs, a Toronto resident for the past 30 years, "has taken leave of common sense."

17. Other critics, like federal NDP Leader Alexa McDonough, questioned the government's claim that amalgamation will save money. McDonough pointed out that in her home town of Halifax, which joined in 1996 with Dartmouth and two other municipalities, transition costs have soared to $22 million–more than double what the Nova Scotia government projected. Still others claimed that amalgamation in Toronto will also drive up long-term costs. A megacity, they argued, would eliminate competition among municipalities, add the expense of providing equal services to a wider area, and result in higher labor costs thanks to larger, more powerful unions.

18. The Conservatives' timing, meanwhile, also fuelled public opposition. A month after introducing Bill 103, the province announced a sweeping package of other municipal reforms over a seven-day period dubbed Mega-Week. Those included adopting a new property tax formula, called actual value assessment. Tax reform has long been a contentious issue in Toronto, and some downtown homeowners will probably see their property taxes rise substantially under the new scheme. At the same time, the province unveiled plans to remove $5.4 billion in education bills from municipal property taxes–but then download $6.4 billion in service costs to the municipalities, with the difference made up by a $1-billion reserve fund. The most controversial change was that municipalities would share the costs of welfare equally with the province, where before they paid only 20 per cent. The City of Toronto estimated that, together with other social-service costs, the welfare shift would cost property taxpayers $202 million annually. Even the Board of Trade of Metropolitan Toronto and Crombie, a Conservative, found the downloading hard to swallow. "It is an egregious error," said Crombie, who supports amalgamation. "It's just as though they went to a baseball game and tried to score a hockey goal."

➤ In the wake of last week's referendum results, the Conservatives had... ¶ 20 / next page

19. In the minds of many Torontonians, amalgamation, property tax reform and downloading all added up to nothing less than a Conservative conspiracy to ruin the city. "They're driven by two people who resent the big city–[Finance Minister] Ernie Eves and Mike Harris," declared Sewell. "They're both small-town guys, they're out of their depth in the city, they resent it, and they're going to go out and get it." Leach, a lifelong

Torontonian, acknowledges that had the government not been under a self-imposed time constraint to enact municipal reform by the end of 1997, "I would have kept the issues separate–dealt with amalgamation, and done that separately without some of the other things."

20. In the wake of last week's referendum results, the Conservatives had to address the scale–and volume–of opposition to their municipal reform package. First, they delayed the deadline for amendments to Bill 103 until the end of March–an indication that substantial changes are in the works. Those could include curtailing the powers of the trustees and transition team, and possibly guaranteeing that property taxes will not rise as a result of amalgamation. More important, Harris has broadly hinted that the government will rethink its downloading scheme. One option, which Crombie and other Tory supporters have been pressuring the province to adopt: leaving some capital costs of education, like busing and building maintenance, with the municipalities, while maintaining the traditional 80-20 provincial-municipal split on welfare funding. But Leach and Harris have also made it clear–referendum or not–that the megacity will go ahead more or less as planned.

21. Like many others, City of Toronto Mayor Hall predicts dire consequences for downtown neighborhoods like Cabbagetown, where she has lived for the past 30 years: a flight of the middle class, declining infrastructure, more poor people on the streets. Yet, sitting over a cappuccino in a small, trendy caf recently–as patrons regularly come up to say "Hi"–Hall foresees something positive arising from the megacity debate. "Whatever happens, big change will come from it," she says. "People have seen their communities at risk, and have put time and energy into organizing and talking about things. I don't believe that will disappear–people will stay involved, and find ways to take responsibility in civic life." If that prediction turns out to be true, there might be hope for the megacity after all.

# Appendix B

# Instructions to subjects

## The Task

You will be given three questions that you will need to answer by searching a database of newspaper articles. You will be doing the searches using an information retrieval system designed here at the University of Toronto.

When you begin, you will be looking at the text of a "query" that will give you a list of starting points for your search. As you navigate around the database of articles, you can write your answers in the space provided on the question sheet. Please try to write as neatly as you can.

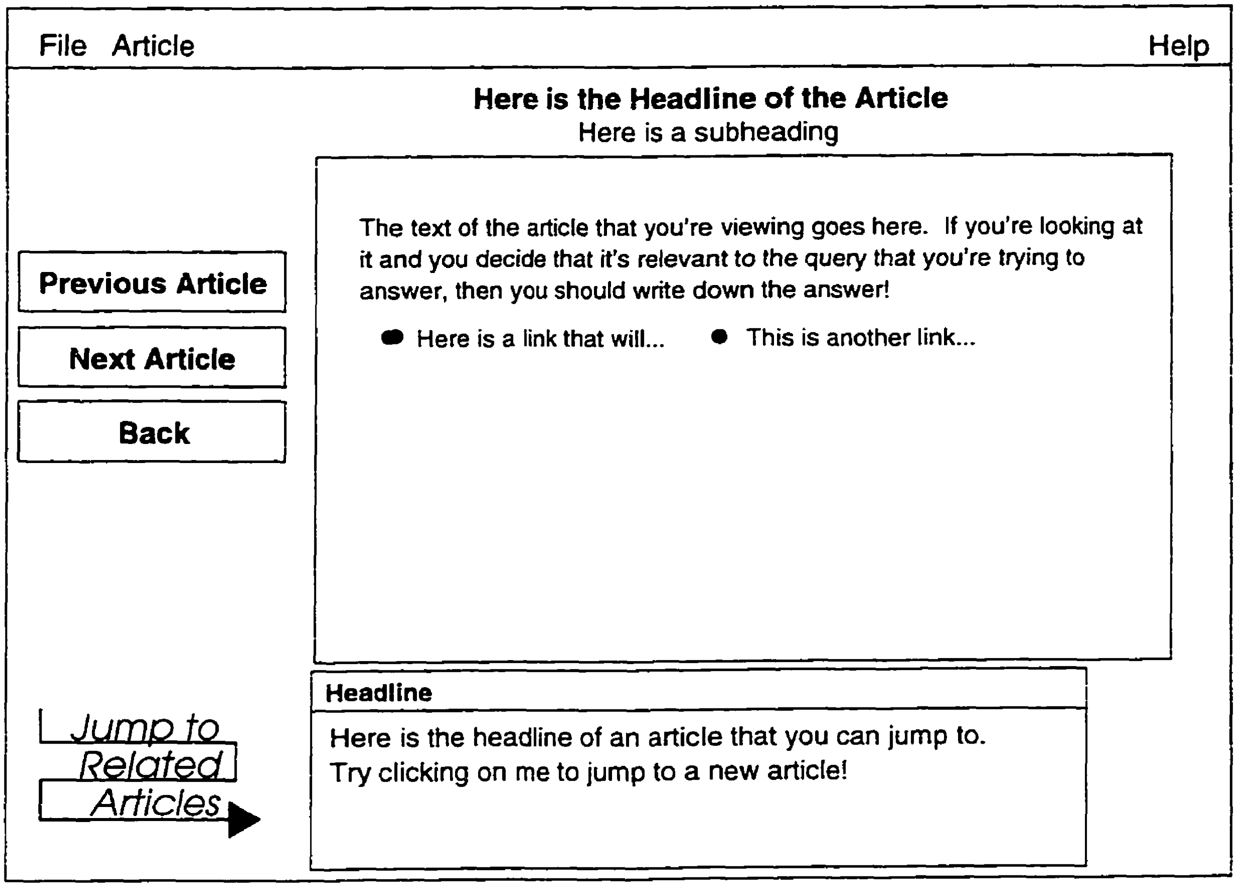
You should try to find as many answers as you can in the time provided, but if you need help or you're not quite sure what the question means, please ask the person running the experiment for assistance!

Note that not all articles will contain an answer, and some may contain more than one answer!

## The System

The system that you will be using to perform your searches has a very straightforward graphical interface. When running, the system looks like the screen shown in figure B.1. On this screen you can read the text of an article and decide whether it is relevant to the question that you have been asked to answer.

You will notice that after some of the paragraphs, there are two columns of blue coloured text. These are *links* to other paragraphs *in the same article*. The blue text of the link is the first few words of the paragraph that you will jump to when you click on the link.



**Here is the Headline of the Article**
Here is a subheading

The text of the article that you're viewing goes here. If you're looking at it and you decide that it's relevant to the query that you're trying to answer, then you should write down the answer!

● Here is a link that will... ● This is another link...

Here is the headline of an article that you can jump to.
Try clicking on me to jump to a new article!

Figure B.1: The System

If you click on one of these links and then decide you want to return to the paragraph where you started, simply click on the button labeled **Back.**

You can scroll through the text of the article using the scroll bars or by using the Page Up and Page Down keys.

At the bottom of the screen is a list of the headlines of articles that are related to the article that you are currently viewing. When you move the mouse over one of the headlines, it is highlighted, and when you click on one of them, you jump to that article.

If you jump to another article and decide that you would like to return to the article that you jumped from, simply click on the **Previous Article** button to move back to the last article that you were looking at. If you've moved backwards, and you want to move forwards, simply click on the **Next Article** button.

### How to tell where you've been

As you search for articles that are relevant to your question, you should be aware that the lists of related articles at the bottom of each article are colour coded to help you remember what articles you've already seen.

Articles that you have seen are magenta coloured when shown in a list of links. Also, when you follow a link within an article that you are browsing, any links to that paragraph are then magenta coloured.

# Appendix C

# Post-task questionnaire

Name: ______________________________

Education: ______________________________

Occupation: ______________________________

If student, field of study: ______________________________

1. I understood the questions I was supposed to answer.

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| Strongly<br>disagree | Disagree | Neutral | Agree | Strongly<br>agree |

2. I am confident that all the answers that I found were correct.

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| Strongly<br>disagree | Disagree | Neutral | Agree | Strongly<br>agree |

3. Were the links *within* the articles useful?

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| Not at all | Not really | Somewhat | Useful | Very useful |

4. Did the links *between* articles connect articles that were related?

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| Never | Almost never | Sometimes | Usually | Always |

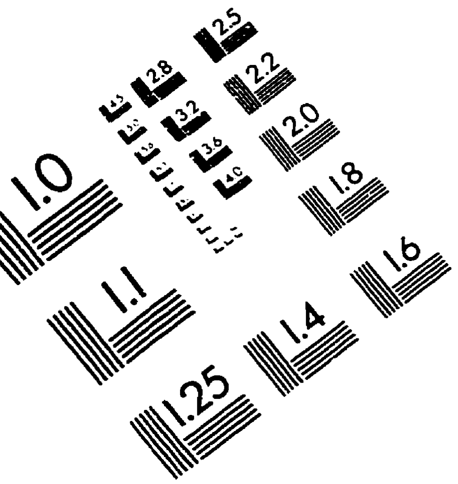
5. How often do you browse the World Wide Web?

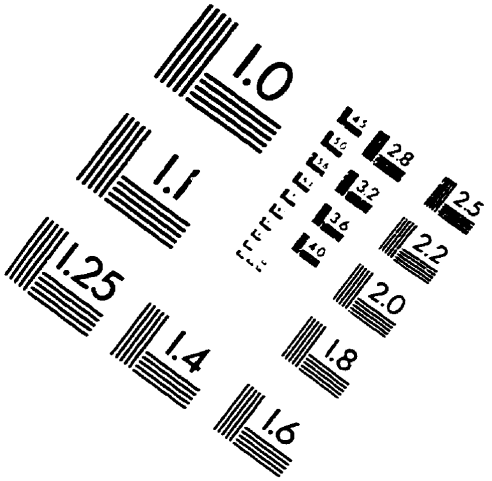
| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| Never | Once or twice a month | Once or twice a week | Three or four times a week | Every day |

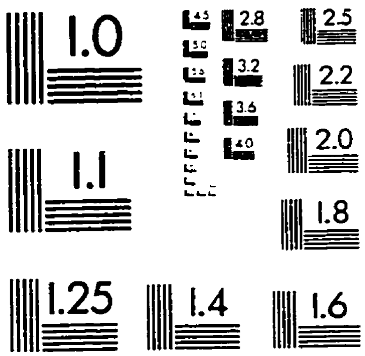
6. Did you like the system?

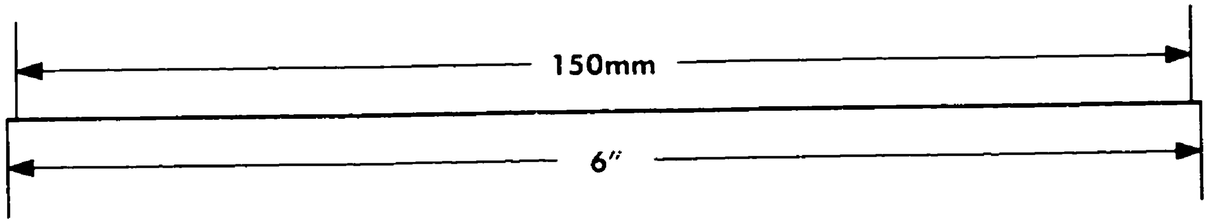
Yes _____ No _____

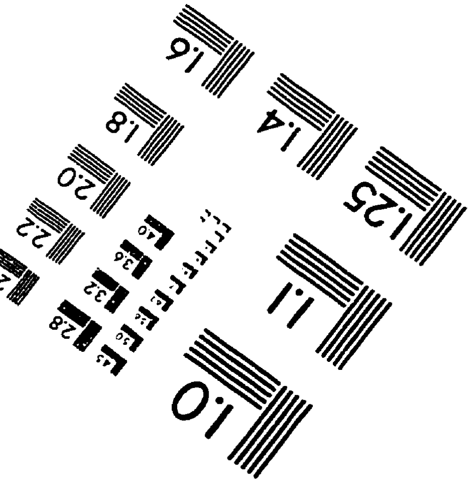
# IMAGE EVALUATION TEST TARGET (QA-3)











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