A Corpus-Based Statistical Approach to Automatic Book Indexing

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Abstract
The paper reports on a new approach to automatic
generation of back-of-book indexes for Chinese
books. Parsing on the level of complete sentential
analysis is avoided because of the inefficiency and
unavailability of a Chinese Grammar with enough
coverage. Instead, fundamental analysis particular
to Chinese text called word segmentation is
performed to break up characters into a sequence
of lexical units equivalent to words in English.
The sequence of words then goes through part-of-
speech tagging and noun phrase analysis. All these
analyses are done using a corpus-based statistical
algorithm. Experimental results have shown
satisfactory results.

I. Introduction
Preparing back-of-book indexes is of vital importance to
the publishing industry but is a very labor intensive task.
Attempts have been made over the years to automate this
procedure for the apparent benefits of cost saving, shorter
preparation time, and possibility of producing more
complete and consistent indexes. Early work involves
using occurrence characteristics of contents words [Borko,
1970]. Later people came to realize that indexes are often
multi-word terms and their generation might involve more
elaborated syntactic analysis on phrasal or sentential level
[Salton, 1988; Dillon and McDonald, 1983]. However, a
full syntactical approach [Salton, 1988] to this task has real
problem with efficiency and coverage for unrestricted text.
No viable automatic solution is currently in use.

Indexing Chinese books involves another severe
obstacle, namely the word segmentation problem. Chinese
text consists of a sequence of characters which roughly
correspond to letters in English. However, there are no
spaces to mark the beginning and end of a word as in
English. Until recently, this problem has been considered
difficult to solve without elaborated syntactical and
semantic analyses [Chen, 1988].

Recent research advances may lead to the development
of viable book indexing methods for Chinese books. These
include the availability of efficient and high precision word
segmentation methods for Chinese text [Chang et al., 1991;
Sroat and Shih, 1990; Wang et al., 1990], the availability
of statistical analysis of a Chinese corpus [Liu et al., 1975]
and large-scale electronic Chinese dictionaries with part-
of-speech information [Chang et al., 1988; BDC, 1992],
the corpus-based statistical part-of-speech tagger [Church,
1988; DeRose, 1988; Beale, 1988], as well as phrasal and
clausal analyzers [Church 1988; Ejerhed 1990].

2. Problem description
As being pointed out in [Salton, 1988], back-of-book
indexes may consist of more than one word that are
derived from a noun phrase. Given the text of a book, an
indexing system, must perform some kind of phrasal and
statistical analysis in order to produce a list of candidate
indexes and their occurrence statistics in order to generate
indexes as shown in Figure 1 which is an excerpt from the
reconstruction of indexes of a book on transformational
grammar for Mandarin Chinese [Tang, 1977].

Before phrasal analysis can be performed, the text must
go through the more fundamental morphological and part-
of-speech analysis. The morphological analysis for
Chinese text is mainly a so-called word segmentation
process, which segments a sequence of Chinese character
into a sequence of words. See Figure 2 for illustration.

The noun phrase generation process described in this
paper is based on a corpus-based statistical analysis and
does not use an explicit syntactical representation.
Examples of noun phrases found are underlined as shown
in Figure 2.

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The constraint satisfaction problem
The constraint satisfaction problem involves the assignment of values to variables subject to a set of constraining relations. Examples of CSPs include map coloring, understanding line drawing, and scheduling [Detcher and Pear, 1988]. The CSP with binary constraints can be defined as follows: Given a set of n variables $X_1, X_2, ..., X_n$ and a set of binary constraints $K_{ij}$, find all possible $n$-tuples $(X_1, X_2, ..., X_n)$ such that each $n$-tuple is an instantiation of the $n$ variables satisfying

$$ K_{ij} (X_i, X_j) $$

for all $K_{ij}$.

Segmentation as a Constraint Satisfaction Problem
The word segmentation problem can be cast as a CSP as follows: Suppose that we are given a sequence of Chinese characters $(C_1, C_2, ..., C_n)$ and are to segment the sequence into subsequences of characters that are either words in the dictionary or surname-names. We can think of a solution to this segmentation problem as an assignment of 'break/continue' (denoted by the symbols '>', '=' respectively) to each place $X_i$ between two adjacent characters $C_i$ and $C_{i+1}$:

$$ C_1 \mid C_2 \mid C_3 \mid ... \mid C_n $$

$$ X_0 \mid X_1 \mid X_2 \mid ... \mid X_{n-1} \mid X_n $$

subject to the constraint that the characters between two closest breaks correspond to either a Chinese word in the dictionary or surname-names. (For convenience, we add two more places; one at the beginning, the other at the end.) So the set of constraints can be constructed as follows:
For each sequence of characters \( C_i, \ldots, C_j \) (\( j \geq i \)) which are a Chinese word in the dictionary or a surname-name, if \( j = i \), then put \((>,>)\) in \( K_{i-1,i} \). If \( j > i \), then put \((>,=)\) in \( K_{i-1,i} \), \((=,=)\) in \( K_{i,i+1} \), ..., and \((=,>)\) in \( K_{j-1,j} \).

For example, consider again the following:

The corresponding CSP is

\[
K_{0,1} = \{(>,>)\}, \\
K_{1,2} = \{(>,=)\}, \\
K_{2,3} = \{(=,=),(=,>)\}, \\
K_{3,4} = \{(>,,>\}, \\
K_{4,5} = \{(>,>)\}, \\
K_{5,6} = \{(>,>)\}, \\
K_{6,7} = \{(>,),(>,=)\}, \\
K_{7,8} = \{(>,=)\}, \\
K_{8,9} = \{(>,=),(>,=)\}, \\
K_{9,10} = \{(>,),(>,=),(>,=)\}, \\
K_{10,11} = \{(>,=),(>,=),(>,=)\}, \\
K_{11,12} = \{(>,>)\}, \\
K_{12,13} = \{(>,>),(>,=)\}, \\
K_{13,14} = \{(>,=)\},
\]

since

把 劉 體 仲 的 確 實 行 動 作 分 析

are either words in the dictionary or probable surname-names (hypothesized words).

Typically, there will be more than one solution to this CSP. So the most probable one with highest product of probability of hypothesized words is chosen to be the solution. Ordinary words are listed in the dictionary along with this kind of probability estimated from a general corpus [Liu et al., 1975]. As for proper names such as Chinese surname-names not listed in the dictionary, their probability are approximated by using another corpus containing more than 18,000 names as described in the following subsection.

The Problem with Proper Names in Chinese Text

Proper nouns account for only about 2% of average Chinese text. However, according to a recent study on word segmentation [Chang et al., 1991a], they account for at least 50% of errors made by a typical segmentation system. Moreover, proper names are sometimes indexes. Therefore their correct segmentation is crucial to automatic generation of back-of-book indexes.

The difficulties involved in handling proper names are due to the following: (1) No apparent punctuation marking is given like capitalization in English. (2) Most of characters in proper names have different usage. So this problem has been held impossible to solve in the segmentation process. And it was suggested that proper names are best left untouched in the segmentation process and rely on syntactical and semantic analysis to solve the problem when nothing can be made out of the characters representing them [Chen, 1988]. Using the corpus-based statistical approach, we have shown that it is possible to identify most Chinese surname-names (姓名) without using explicit syntactical or semantic representation.

Most surnames are single character and some rare ones are of two characters (single-surnames and double-surnames). Names can be either one or two characters (single-names and double-names). Some characters are more often used for names than others. Currently, there are more double-names than single-name in Taiwan.

The formation of hypothesized surname-names is triggered by the recognition of a surname. In the example above, 劉 (Liu) is one of some 300 surnames. Subsequently, we will take one character and two characters after the surname as probable last names, in this case 體 (Xian) and 體仲 (Xian-Zhong). A general corpus, \( G \) and a surname-name corpus \( N \) are used to evaluate the probability of a surname-name. For instance, the probability of a most common kind of 3-character name (single-surname/double-name) such as 劉體仲 is:

\[
P( 劉體仲 ) = P(\text{single-surname/double-names in } G) \times P(\text{being a surname in } N) \times P(\text{being 1st character in names in } N) \times P(\text{being 2nd character in names in } N)
\]

Names of other combinations can be handled similarly.

The Algorithm

To sum up, the whole process of word segmentation with surname-name identification is as follows:

1. Scan from left to right across the sentence
2. Check to see if the prefix of what is being scanned is a hypothesize word, by
   2.1. dictionary lookup of an ordinary word and its probability
   2.2. checking for the existence of a surname
      2.2.1. forming possible combinations of the surname-name
      2.2.2. evaluating the probability of each combination
   3. Post the constraints of the CSP and probability for each hypothesized word
4. Solve the CSP
5. Find the most probable solution to CSP through dynamic programming

3.2. Part-of-speech Tagging

As far as we know, there has been only scarce research done on part-of-speech tagging for Chinese [Chang et al., 1988; Chen, 1991; Bai and Xia, 1991; BDC, 1992]. As for English, there are at least three independently developed
tags [Church 1988; DeRose 1988; Beale 1988]. We started out using an electronic dictionary [Chen; 1991; Chang et al., 1988] with a very elaborated part-of-speech system based on Chao's work [Chao, 1968]. Because it is difficult to get sufficient manually tagged data for a large tag set, we have since switched to another electronic dictionary with some 90,000 entries and a much smaller tag set. The dictionary is actually a bilingual one (Chinese-English) developed by Behavior Design Corporation [BDC, 1992]. The list of part-of-speeches is shown in Figure 3. The algorithm is essentially the same as [DeRose, 1988]. The BDC Chinese-English Dictionary is used to obtain the list of possible part-of-speeches for each segmented word. Currently, the collocation probabilities of part-of-speech are estimated from a manually tagged text of about 4,000 words.

3.3. Finding Noun Phrases

Instead of using a full-blown parser to find noun phrases, we first mark the noun phrases in the same text of about 4,000 words and compute the statistical characteristics of categoric patterns of noun phrase and then use the statistics in a stochastic algorithm for finding noun phrases in a manner similar to [Church 1988; Ejerhed 1990].

Extracting keywords from a noun phrase is somewhat heuristic unlike the rigorous approach of using the syntactical structure within the noun phrase in [Salton, 1988].

4. The Experimental Results

The algorithm described in Section 3 is currently under development and the programs are written in C and ProFox, and run on an IBM PC compatible machine. The segmentation, tagging, and NP identification parts are completed, while the statistical analysis of the occurrence of NPs is being implemented now. The statistics used in the system consists of four parts:

(S1) Appearance counts of 40,032 distinct words from a corpus of 1,000,000 words of Chinese text [Liu et al., 1975].
(S2) The BDC Chinese-English Dictionary [BDC, 1992].
(S3) A general corpus of 300,000 words. Some 4,000 words of text from this corpus is tagged and marked with NP.
(S4) A name corpus of some 18,000 surname-names.

The performance of the completed parts of the system is as follows: The hit rate of word segmentation is about 97% on the average. For the surname-names alone, we get 90% average hit rate which eliminate about 40% of errors produced by our previous segmentation system. About 98% of part-of-speeches are tagged correctly. And about 95% of the noun phrases are found successfully.

5. Concluding Remarks

The preliminary results that we have obtained seem very promising. The approach presented here does not rely on a fully developed Chinese grammar for syntactical analysis on the sentential level. Thus the efficiency in system development and generation of indexes is reasonable and cost of building and maintaining such a system is acceptable. Currently, we are working on (1) handling translated names, (2) improving the hit rate of tagging and NP identification by using a larger and more correctly tagged and marked training corpus, and (3) completion of the statistical analysis of occurrence of noun phrases.

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