New indices for bibliographic data and their applications

by YAHIKO KAMBAYASHI, SHUZO YAJIMA, OSAMU KONISHI and TAKAKI HAYASHI
Kyoto University
Kyoto, Japan

INTRODUCTION

The KWIC Index is a widely-used tool for finding desired paper titles since it is simple yet very powerful. So in a bibliography of some specific area, the KWIC Index of Titles, Author Index and Subject Index are normally used. These indices are, however, not always sufficient for finding mutually-related papers. In this paper new indices for bibliographic data will be presented together with their applications.

The RS Index (Reference Structure Index) handles reference citation structure and is suitable for detecting influential papers, getting research trends and finding mutually-related research fields. A basic algorithm and improved algorithms have been developed, each of which requires memory only proportional to the number of papers to be handled (i.e. minimum). Functions of these algorithms are explained and example outputs are shown (see Figures 1, 2, 9 and 10).

The MULTI-KWIC has a capability of automatic detection of key phrases by finding maximum common subsequences contained in the paper titles. Using these key phrases, the following two kinds of indices are generated: (1) A MULTI-KWIC list (a linear list of titles ordered by one key phrase and one keyword, as in Figure 6), and (2) a year-distribution table (for each key phrase a table which shows identifications of papers classified by year is prepared, as in Figure 8).

These new indices are applied to 1600 papers in relational database and related areas which have been collected by the authors. The result shows their usefulness in bibliographic data-handling. A personal information system based on these indices has been also developed.

REFERENCE STRUCTURE INDEX

In order to treat a reference citation structure of bibliography, the following problems must be considered:

1. Large amount of input data is required, since for each paper the information on its references must be supplied.
2. Reference citation relationships among papers are usually represented by a directed graph. It is, however, very difficult to print out a directed graph.
3. Usually a large amount of memory space and large software are required to print out a directed graph.
4. It is necessary to print out a directed graph which is human-oriented (i.e., the information contained in the graph is understood easily by looking at the graph).

In our implementation of the RS Index, these problems are solved by the following methods:

1. Reference information is shortened by the use of the identification code (ID for short) representing the paper. The ID is constructed from the names of the authors and the publication date. It can be easily constructed and the maximum length is 10.
2. Usually we need to know a set of papers which have a direct or a transitive citation relationship with a given paper. In such a case, we can use a tree expansion of a directed graph. By this reason, the RS Index only treats tree outputs, which are easy to understand. This output tree is called an RS tree.
3. Even if we restrict the outputs to trees only, usually the required space for output buffer is more than $O(n)$, where $n$ is the number of papers contained in the output tree and $O(n)$ denotes that the value is proportional to $n$. We have developed a procedure which utilizes a push-down stack. $O(n)$ is the minimum storage space for memorizing the data, and the stack itself normally requires $O(\log n)$ space.
4. An RS tree is printed from left to right. When the RS tree reaches at the right end of the output paper, successive trees are printed after the main RS tree. So we can print the tree whose maximum level is arbitrary. Since the width of the tree is also arbitrary, essentially the tree of the arbitrary size can be printed (the size of the tree is actually restricted by that of push-down stack).
5. When the number of papers in the RS Index is large, the RS tree spreads widely. In such a case it may be difficult to get useful information from the RS tree. A procedure to produce compact RS trees without changing their structure is developed as well as a procedure with tree trimming and ordering facilities. These facilities are also realized by algorithms based on pushdown stacks, thus we don’t need separate procedures for these facilities.

From the collection of the Computer History Museum (www.computerhistory.org)
We have developed a PL/I program for the RS Index, which consists of approximately 800 steps.

Identification codes for papers must be simple as well as human oriented. We use a character string \( \Phi III \Delta \chi \)

of length ten as an ID.

\( \Phi \): (author field) It consists of first four characters of the first author’s name (\( \Phi \)) and first character of the second author’s name (\( \Phi \)). When the first author’s name is shorter than four and there is a second author, - (hyphen) is inserted. If only the first author is shown with \( \Phi et al. \), * is used.

\( III \Delta \): (date field) Year (\( III \)) and month (\( \Delta \)) of the publication are shown. If not known, ? is used.

\( \chi \): (extension field) It is optionally used to distinguish the papers which have the same name and date fields. It is taken from the first letter of the title of the paper except articles. If two distinct papers have the same extension, the next unused character in the alphabetical order is assigned.

There are two kinds of RS Indices; one uses “A refers to B” and the other uses “A is referred to by B”. For simplicity, only the “A refers to B” relationship is considered in this paper to explain the algorithm.

**Basic algorithm for the RS index**

This algorithm needs only one-line output buffer and has a simple recursive formulation, which shows why a stack is needed.

Call display \( (P, 0) \), where \( P \) is the root paper and procedure display is defined as follows:

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procedure display (p: Paper, i: Integer);
begin L=list of papers referred to by p;
for x in L do;
    begin display (x,i+1);
    if x not last in L then newline;
    end;
    print p at level i;
end
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In an actual program, in order to add many additional facilities easily the iterative procedure is adopted using a push-down stack. The above algorithm is simple since it does not need to store the output position of each ID. The lines to indicate reference relationships among papers can be drawn by providing a bit for each level of the tree. In an actual program, if there exists a paper appearing more than once, after first appearance only “TO i**j” is printed if the paper is first printed at the \( j \)-th position of the \( i \)-th level. This algorithm needs constant output buffer, and the required size for the stack is \( O(n) \), which is in the worst case, where \( n \) is the number of nodes in the tree. If each paper has more than one reference (it is normally satisfied), the size is \( O(\log n) \).

In order to use the RS Index practically the following two problems must be solved.

1. If there exist two papers \( A \) and \( B \) such that \( A \) and \( B \) refer to (or transitively refer to) \( B \) and \( A \), respectively, then the basic algorithm fails.

2. When the number of references increases, it may be difficult to see the whole figure produced by the basic algorithm, because it spreads widely (see Reference 1 for the output of the basic algorithm). Figure 1 is an example of a program generated by an improved algorithm.

In order to handle Problem 2 some useful facilities are prepared such as ordering facilities and filtering facilities.

1. Elementary facilities
   a. Output of keywords, comments for each paper.
   b. Output of information about connection between papers. These are printed on edges.
   c. Designation of the width of the print-out by restricting maximum level of the RS tree.
   d. Process of pattern matching for IDs. In the case of specifying a paper, we may not know when the paper was published even though we know who wrote it. For this reason, if we specify “COD-D****,” for example, the RS trees can be produced whose root paper’s first author is Codd.

2. Ordering of references

We have adopted the following orderings from the practical viewpoint:

a. To arrange IDs in alphabetical order by author’s name.
   b. To arrange IDs in order of published date.
   c. To arrange IDs in order of labels of edges, which means the relationship or connection strength between a pair of papers.
   d. To arrange IDs in order of the path length from the root. In an RS tree, in order not to print out redundant subtrees, if there exists a paper appearing in the tree more than once, “TO i**j” is printed after the first appearance. This means that the maximum path from the root is not always expressed explicitly. We can position papers in the RS tree more clearly if the maximum path is output explicitly.

3. Tree-trimming facilities
   a. To eliminate IDs expressed such as “TO i**j.” This is available when looking over what papers are printed.
   b. To print out the papers which are cited more than \( N \) times, where \( N \) is a threshold value.
   c. To delete the transitively connected edges from the RS Index.
   d. To print out IDs whose authors and publishing date are specific.
   e. To eliminate IDs by the label of edges.
Figure 1 is an example which expresses the maximum path explicitly. Figure 2 shows the RS Index obtained by deleting transitively connected edges from Figure 1. More complicated examples are shown in Figures 9 and 10.

The algorithms of the aforementioned facilities are given in Reference 2.

MULTI-KWIC INDEX

The MULTI-KWIC Index offers the following facilities:

1. KWIC list with an improved ordering—Paper titles are ordered by a keyword and words before and after the keyword.
2. Key phrase extraction—Key phrases are extracted by finding maximum common subsequences contained in the given set of paper titles.
3. MULTI-KWIC list—Titles with one common key phrase and one common keyword are adjacently printed in a MULTI-KWIC list.
4. Year-distribution table—For each extracted key phrase, a table is prepared in which IDs are grouped by their publication years.

For the purpose of simplifying the algorithm, the MULTI-KWIC Index uses no dictionary. The program is written in PL/I and the total number of steps is about 1000. A utility for sorting is combined with the program.

Figure 3 shows a KWIC list produced by our program in which paper titles are ordered by a keyword and words before and after the keyword. There are two known versions of the KWIC. A primitive version produces a KWIC list by considering only a keyword. Figure 4 shows an example of such a KWIC list. In this example two titles with the common phrase "RELATIONAL DATA BASE MANAGEMENT SYSTEM" are not adjacently printed since words other than the keyword are not used to determine the order.
of the titles. In another version a KWIC list is produced by considering the keyword and words after the keyword. The total length of the subsentence (the keyword and the words after the keyword) is fixed and thus a sorting facility can be used to produce the output. This version, however, still has the following problems:

1. Since titles are not ordered by the words before the keyword, there are still cases when two titles with a common key phrase are not printed adjacently.

2. Because of the inflections of words, similar key phrases may be printed separately.

In our version of KWIC the following methods are used to solve these problems:

1. For each word only the first six characters are used for the ordering information.
2. Words before the keyword are considered as well as the keyword itself and words after the keyword.

Figure 2—The RS Index obtained by deleting transitively connected edges from Figure 1.

Figure 3—An improved KWIC list.

Figure 4—Conventional KWIC list.
Approach 1 is employed since a dictionary is not required. By our experience in using 750 titles there are only three cases when different key phrases are regarded as the same ones. For the purpose of handling this kind of error, an editing facility is prepared in the program. In order to handle the problem of ordering by words before and after the keyword the following approach is used:

1. First, a primitive version of a KWIC list is prepared.
2. Let \( f_6(W) \) be the operation of extracting first six characters from \( w \) (when the length of \( w \) is less than six, blank characters are added and the length is adjusted to six; \( w \) can be a null string—a string of length 0) and let \( W \) be the keyword in the list prepared in Step 1. For each sub-sentence \( w_1 w_2 w_3 \) of the title, calculate \( f_6(W), f_6(w_1), f_6(w_2), f_6(w_3) \) and \( f_6(w_4) \). Here \( w_1, w_2, w_3 \) are words after the keyword and \( w_4 \) is word before the keyword.
3. Sort the titles by \( f_6(W) f_6(w_1) f_6(w_2) f_6(w_3) f_6(w_4) \), where \( \circ \) denotes the concatenation of the words.

The output of the above procedure gives an improved KWIC list. For further improvement the consecutive retrieval property is used. The consecutive retrieval property is introduced by Ghosh for organizing an efficient file. (For further information see the list of papers prepared by Lipski, currently of the Coordinate Science Laboratory, University of Illinois). For example, consider the titles containing key phrases \( AB, CA, CAB \) where \( A \) is the keyword. The ordering shown in Figure 5(a) is appropriate. By this method the list shown in Figure 5(b) is rearranged and the list in Figure 5(c) is obtained.

Using this result key phrases consisting of less than seven words can be extracted from a set of titles. The program has a facility to extract key phrases contained in \( M(\geq N) \) for a given threshold value \( N(\geq 2) \). By this method key phrases of the form of "\( W_1 \) of \( W_2 \)" or "\( W_1 \) and \( W_2 \)" can be extracted. Extraction of such key phrases is not possible by the commonly used extraction method whereby phrases are selected from words between conjunctions and prepositions.

By this method sometimes improper key phrases are extracted. Editing facility for eliminating such key phrases is also prepared. Since key phrases contained in many titles are not useful for characterizing the paper, key phrases contained in \( M(N_1 \geq M \geq N_2) \) titles can be used for paper characterization, where \( N_1 \) and \( N_2 \) are user-determined threshold values. There will be, however, papers without any characterizing key phrases and thus thesauri may be required for full automatic classification of papers.

The extracted key phrases are used to generate a MULTI-KWIC list. In the list titles with one common key phrase and one common keyword are adjacent printed. A MULTI-KWIC list is shown in Figure 6.
Double-KWIC list\(^2\) is also known as a list with two keys. The major differences are (1) a MULTI-KWIC list has a capability of automatic key phrase extraction and (2) the output format of MULTI-KWIC is similar to conventional KWIC so both outputs can be combined.

An example of the MULTI-KWIC list is shown in Figure 6, where the titles containing “access” and “data” are listed. The procedure used for the MULTI-KWIC list is explained in Figure 7. Assume that we have a set of titles having key phrases and keywords shown in Figure 7(a) (here, the first line shows that the identification number is 1 and the title contains one key phrase ABC and two keywords E and F). The priority of sorting is determined as (1) the keyword part of the key phrase, (2) the keyword and (3), the remaining part of the key phrase. The result is shown in Figure 7(b).

Figure 8 shows a year-distribution table which will be prepared for each extracted key phrase (here, ‘relations’ and ‘conceptual schema’). If a paper contains two key phrases \(W_1\) and \(W_2\), where \(W_2\) is a proper substring of \(W_1\), then the paper is classified to key phrase \(W_1\) category. By this table activity transition of some specific area will be observed.

APPLICATIONS

Figures 9 and 10 show RS Indices taken from the result of application to papers of relational database and related areas, which are collected by the authors (it is an extension of Codd’s bibliography\(^9\)). Figure 9 shows the RS tree for the referred-to-by relationship whose root is Abrial’s paper which discusses data semantics. This RS tree presents many papers concerned with some kinds of data models and conceptual schema. For example, there are the DIAM II model by Senko (SENK7601, SENK7501), conceptual schema by Tsichritzis (TSIC7507, TSIC7606), DBMS architecture of the next generation by Nijssen (NIJS7601), criterion of conceptual schema by Kent shown in KENT7609, entity-relationship model by Chen (CHEN7603), and so on. Figure 10 is a descendant tree whose root is the paper of Armstrong. This paper is concerned with axiomatization for functional dependency in relational databases. Some of the descendants of this paper are one of Bernstein, which discusses a synthetic design of relational databases, and one of Fadous, which introduces the algorithm for finding candidate keys efficiently. The papers written by Zaniolo, Fagin and Beeri are also printed, which discuss multi-valued dependency or generalizations of functional dependency.

Another application of indices introduced in this paper is a personal information system. The system has been developed under the LABOLINK network\(^7\) using the model M-190 computer of Fujitsu at the Data Processing Center, Kyoto University. Papers are accessed by a combination of keywords, authors and years. The system has the following specific features:

1. For selecting appropriate keywords, a key phrase KWIC table is shown (see Figure 11). It is a KWIC list of key phrases which are automatically detected by the MULTI-KWIC.
2. For each specified key phrase a year-distribution table (Figure 8) can be displayed.
3. For each paper an RS Index for the paper can be generated.

The system is examined by JICST (Japan Information Center of Science and Technology) bibliographic data tapes as well as the papers of relational database areas collected by us (about 1,600 papers) and the effectiveness of the system is proved. These facilities are to be merged with the relational-model-based research information system currently under development.\(^*\)
New Indices for Bibliographic Data and Their Applications

Figure 9—The RS Index for ABRI7404.
Figure 10—The RS Index for ARMS7408.

Figure 11—Key phrase KWIC table.
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REFERENCES

6. Lipski, W., Jr., "Consecutive 1’s Property and Related Topics: Recent Results," *Technical Report*, Institute of Computer Science, Polish Academy of Science, Warsaw Poland (Dr. Lipski is currently with the Coordinated Science Laboratory, University of Illinois.), October 1977.