## INCREMENTAL FILE REORGANIZATION SCHEMES

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## ABSTRACT

For many files, reorganization is essential during their lifetime in order to maintain an adequate performance level for users. File reorganization can be defined as the process of changing the physical structure of the file. In this paper we are mainly concerned with changes in the placement of records of a file on pages in secondary storage. We model the problem of file reorganization in terms of a hypergraph and show that this problem is NP-hard. We present two heuristics which can be classified as incremental reorganization schemes. Both algorithms incorporate a heuristic for the traveling salesman problem. The objective of our approach is the minimization of the number of pages swapped in and out of the main memory buffer area during the reorganization process. Synthetic experiments have been performed to compare our heuristics with alternative strategies.

## 1. INTRODUCTION

We can define file reorganization as the process of changing the physical structure of the file $[9,12]$. Reorganization may be performed for a variety of reasons such as to improve performance (e.g. reduce retrieval time) and to enhance storage utilization (e.g. compact space). Due to changes in user access patterns and unpredictable insertions and deletions, file reorganization becomes a necessary function.

File reorganization can be classified into three basic approaches [9]: off-line reorganization, incremental reorganization and concurrent reorganization. The first method prohibits user access to the entire file during

[^0]the reorganization period. The second method is an on-line strategy in which reorganization occurs incrementally. Under this strategy, the part of the file which is being reorganized is locked while user access is permitted to the remainder of the file. The third method is also an on-line approach but where reorganization is done continuously with file usage.

The traditional approach taken for file reorganization is off-line reorganization [9,13]. With this approach, the major effort addresses the problem of determining optimal reorganization points $[1,12,14]$. Work concerning concurrent reorganization is oriented towards performance modelling $[9,10]$. For incremental reorganization, the problem of determining optimal reorganization procedures has not been addressed and is the focus of this study.

In this paper, we consider file reorganization as being required due to a need to alter the placement of records of a file on pages of a secondary storage device. An example of this would be to place records which are frequently accessed together on the same page or pages in order to reduce retrieval time, e.g. record clustering $[5,15]$. A second example would be to move records from overflow pages to primary pages of the file, e.g. hash based files [9].

In section 2 we model the file reorganization problem in terms of a hypergraph and show that this problem is NP-hard. In section 3 we present our two heuristics for incremental file reorganization: STATIC_COST REORGANIZATION and DYNAMI $\bar{C}$ COST REORGANIZATION. We illustrate one scheme with an example in section 4 . In section 5 , we present the results of a number of experiments used to evaluate the performance of our reorganization schemes.

## 2. THE REORGANIZATION MODEL

Our reorganization approach is incremental with file usage, and thus requires locking only a small part of the file, while permitting access to the remainder of the file. We assume that the dominating cost is that incurred by page accesses from secondary
storage. We also assume that input and output to the secondary storage device is accomplished by using a single main memory buffer area. Thus our objective function is the minimization of the number of pages swapped in and out of the buffer during the reorganization process.

Our procedure requires two mappings as input: one PG, corresponding to the old (file) state and another NPG, corresponding to the new state. These mappings satisfy:

$$
\begin{align*}
& \text { PG: } \quad \mathrm{R} \rightarrow \mathrm{P} \\
& \text { NPG: } \mathrm{P}^{\prime} \rightarrow \mathrm{C}^{R^{\prime}} \tag{1}
\end{align*}
$$

where $R=$ set of record indentifiers
$P=$ set of old page numbers $P^{\prime}$, = set of new page numbers ( $P \subseteq P^{\prime}$ ) $2^{R^{\prime}}=$ set of subsets of $R$ of size s pagesize

To implement the mapping $P G$ we assume the existence of a PAGE-TABLE which associates with every record identifier the page number on which it resides. The use of the PAGE-TABLE introduces another level of indirection between any directory (index) and the data file, but has the advantage that changes to the data file do not affect the directory. Normally, in a tree structured directory [7], the pointers in the leaves represent the actual physical addresses, i.e., page numbers, of the corresponding records. Using the PAGE-TABLE concept, the directory is modified such that these pointers represent record identifiers. In addition, we shall need a LOCK table which contains a 1 bit entry for every page to indicate whether or not the page is currently being reorganized.

Given the mappings from (1) we can obtain the mapping: $\Delta: P^{\prime} \rightarrow P$ which is defined as follows:

$$
\Delta_{p}{ }^{\prime}=\left\{P G(r) \mid r \in \operatorname{NPG}\left(p^{\prime}\right)\right\} \text { where } p^{\prime} \in P^{\prime}
$$

Thus $\Delta$ gives the set of pages (actually page numbers) which have to be available in a main memory buffer in order to construct a new page.
Our reorganization problem can now be modelled as a hypergraph [2], $\mathrm{H}=(\mathrm{V}, \mathrm{E})$ where the vertices correspond to the current pages, i.e., $\mathrm{V}=\mathrm{P}$, and the edges correspond to the new pages, i.e., $E=\left\{\Delta_{p} \mid p^{\prime} \quad \varepsilon P^{\prime}\right\}$. Figure 1 a illustrates a simple hypergraph $H$, with four edges, corresponding to the pages in the new state: $\Delta_{1}=\{1,2,3\}, \Delta_{2}=\{1,2,4,6\}, \Delta_{3}=\{5,6,7\}$ and $\Delta_{4}=\{3,7,8\}$.

Given a hypergraph $H$, we can obtain its representative graph which we denote as $H_{R}$. $H_{R}$ is the pair ( $V^{\prime}, E^{\prime}$ ) when $V^{\prime}=E$ and $E^{\prime}=\left\{\left(\Delta_{i}, \Delta_{j}\right) \mid \Delta_{i}, \Delta_{j} \varepsilon V^{\prime}\right.$ and $\left.\Delta_{i} \cap \Delta_{j} \neq \emptyset\right\}$. The representative graph $H_{R}$ of the hypgergraph $H$ in Fig. 1.a is pictured in Fig. 1.b.

(a)

(b)

FIGURE 1 HYPERGRAPH H AND ITS REPRESENTATIVE GRAPH

Since we assume that the major costs involved in the reorganization are due to page fetches, we shall associate with every edge $\left(\Delta_{i}, \Delta_{j}\right)$ in $H_{R}$ a cost, cost $\left(\Delta_{i}, \Delta_{j}\right)$, which reflects the number of page faults occurred in constructing $\Delta_{j}$, given that the pages relevant to $\Delta_{i}$ are currently in the buffer.

We can formally define the file reorganization problem as follows:

Given, a set of $m$ pages (i.e. the vertices of $H_{R}: \Delta_{1}, \Delta_{2}, \ldots, \Delta_{m}$ ) to be constructed for the new file state where the number of distinct pages in the old state that need to be accessed is
$n=\left|\bigcup_{i=1}^{m} \Delta_{i}\right| ; 1<B<n$ where $B$ is the buffer
capacity in pages; for all $i,\left|\Delta_{i}\right| \leqslant B$; and $a$ cost function $\operatorname{COST}\left(\Delta_{i}, \Delta_{j}\right)$ for each pair of new pages $\Delta_{i}, \Delta_{j} \in V^{\prime}$. Determine an ordering in which new pages should be constructed (i.e., a permutation $\langle\pi(1), \pi(2), \ldots, \pi(m)\rangle)$ such that m-1
$\sum_{i=1} \operatorname{cost}\left(\Delta_{\pi(i)}, \Delta_{\pi(i+1)}\right)$ is minimized.
$i=1$
Theorem: The file reorganization problem is NP-hard.

Proof: If we restrict for all $i,\left|\Delta_{i}\right|=B$, then we have eliminated the effect of any page replacement policy. Hence, the only pages that would be contained in the buffer would be those needed by the current $\Delta_{\pi}(i)$. As such, the cost
associated with an edge $\left(\Delta_{\pi}(i), \Delta_{\pi}(i+1)\right.$ ) is simply $\left|\Delta_{\mathrm{II}(i+1)}-\Delta_{\pi(i)}\right|$. With this restriction the problem is one of finding a tour or a Hamiltonian path of least cost for $H_{R}$, also known as the open traveling salesman problem $[4,6]$ which is a known NP-complete problem.

We should note that if the buffer capacity $B$ is equal to $n$ then every tour would yield a minimum cost of $n$ since no page would be swapped from the buffer and fetched back at a later time.

At this time, we will define the cost function in more detail. Actually, we utilize two separate cost functions, each associated with a different reorganization scheme. The first cost function which is associated with the edges of $H_{R}$ is naive in the sense that it only considers the pages brought into the buffer by the most recently constructed page. This cost function is defined as

$$
\operatorname{cost}\left(\Delta_{i}, \Delta_{j}\right)=\left|\Delta_{j}-\Delta_{i}\right| /\left|\Delta_{j}\right|
$$

The cost is expressed such as to give preference to an edge ( $\Delta_{i}, \Delta_{j}$ ) where
$\left|\Delta_{i} \cap \Delta_{j}\right| /\left|\Delta_{j}\right|$ is closest to 1 . The second cost function is defined as follows:

$$
\operatorname{COST}\left(\Delta_{i} \Delta_{j}\right)=\left|\Delta_{j}-\operatorname{BUFFER}\right| /\left|\Delta_{j}\right|
$$

> where BUFFER = set of page numbers corresponding to
> pages currently in the buffer.

The latter cost function takes into account the entire contents of the buffer. Thus, the cost associated with an edge ( $\Delta_{i}, \Delta_{j}$ ) is the ratio of the number of pages needed to construct $\Delta_{j}$ which are not currently in the buffer to the total number of pages needed for $\Delta_{j}$.

## 3. HEURISTIC REORGANIZATION SCHEMES

Since the file reorganization problem is NP-hard we will focus our attention on efficient heuristics. One assumption which applies to both reorganization schemes is that the number of pages needed to construct any given new page will not exceed the buffer capacity. If this assumption does not hold we will not only have to determine an order in which to construct new pages but also an order for bringing the pages contained in $\Delta_{i}$ into the buffer. An outline of our first reorganization algorithm is shown below.

## Algorithm: STATIC COST REORGANIZATION

Input: ${ }^{H_{R}}=\left(V^{\prime}, E\right)$ with $\left|V^{\prime}\right|=m$ and file $F$
Output: A permutation of $V^{\prime}$, i.e., $\Delta_{\pi}(1)$, $\Delta_{\pi}(2), \ldots$ and reorganized file ${ }^{\prime}$,
Step 1: Determine a tour of $H_{R}$ based on the cost function
$\operatorname{Cost}\left(\Delta_{i}, \Delta_{j}\right)=\left|\Delta_{j}-\Delta_{i}\right| /\left|\Delta_{j}\right|$
Step 2: For $\ell+1$ to m do
2.1 Determine pages to be swapped from the buffer using a $K$-lookahead buffer paging policy UNLOCK pages swapped out;
2.2 Bring in pages needed by $\Delta_{\pi}(\ell)$ not currently in buffer LOCK pages brought in;
2.3 Rearrange records on buffer pages
until all records which make up the current page $\Delta_{\pi}(\ell)$, i.e. $\operatorname{NPG}\left(\Delta_{\pi}(\ell)\right)$ contained on a single page in the buffer; modify PAGE-TABLE;
2.4 Write page $\Delta_{\pi}(\ell)$ to disk; End.

We see that the STATIC COST REORGANIZATION algorithm employs a K-1ookahead buffer page replacement strategy. With K-lookahead buffering, we examine the next $K$ new pages to be constructed. If pages necessary to construct the next $K$ new pages are in the buffer then we want to retain those pages if possible by giving priority to the pages for $\Delta_{\pi}(\ell+1), \Delta_{\pi}(\ell+2), \cdots, \Delta_{\pi}(l+k)$ in this order. When $K=m-1$, we have the optimal strategy that selects for replacement that page which will not be referenced for the longest time in the future [8].

To determine a solution for the traveling salesman problem, the STATIC COST REORGANIZATION algorithm uses the Greedy heuristic [6]. Starting at a given vertex of $H_{R}$, the Greedy algorithm constructs the tour by choosing the next edge of minimum cost until all vertices are contained in the tour. Once the complete tour has been determined, the reorganization is performed by constructing one new page at a time for the given order.

Our second algorithm, DYNAMIC COST REORGANIZATION, alternates between finding the next edge in the tour and doing the reorganization for the vertex reached by this edge, i.e., constructing a new page. In order to determine the next edge in the tour we again employ a greedy approach which chooses that unvisited edge which has minimum cost.

Once a new vertex, say $\Delta_{j}$, has been reached in the greedy phase, we have to construct this new page in a single page of the buffer, say the first one for the sake of
simplicity. It could be that the first page of the buffer corresponds to physical page $\ell$, and consequently $\Delta_{j}$ will be stored in physical location $\ell$ since we are using only the storage space available originally. We shall also see that records can be moved around the other pages in the buffer in order to determine which pages are to be swapped if necessary. Hence our $H_{R}$ graph is a dynamic one, i.e., the numbers of the $\Delta_{i}$ 's for the successive vertices in the tour may change.

We proceed now to give an outline of our second reorganization algorithm:

Algorithm: DYNAMIC_COST_REORGANIZATION
$\begin{array}{ll}\text { Input: } & H_{R}=\left(V^{\top}, E^{\prime}\right) \text { with }\left|V^{\prime}\right|=m \text { and file } F \\ \text { Output: } & A \text { permutation of } V^{\prime}, i . e .,\end{array}$ $\left.\Delta_{\pi}(1), \Delta_{\pi}(2), \ldots, \Delta_{\mathbb{F}}, m\right)$ and
reorganized file
Notation: BUFFER $=$ the set of page numbers of the pages currently residing in the
buffer $\overline{B U F F E R}=$ the set of records contained in the pages currently residing in the buffer BUF $=$ the buffer capacity in pages

While tour of $H_{R}$ is not complete do
1.1 Determine next edge of tour based on cost function $\operatorname{COST}\left(\Delta_{i}, \Delta_{j}\right)=\left|\Delta_{j}-\operatorname{BUFFER}\right| /\left|\Delta_{j}\right|$ using a greedy heuristic; let $\Delta_{\pi(l)}$ be the new vertex reached by this edge.
1.2 Determine pages to be swapped from the buffer using fewest-records buffer paging policy;
UNLOCK pages swapped out;
1.3 Bring in pages needed by $\Delta_{\pi}(\ell)$ not currently in the buffer;
LOCK pages brought in;
1.4 Rearrange records on buffer pages until all records which make up the current page $\Delta_{\pi(\ell)}$, i.e. $\operatorname{NPG}\left(\Delta_{\pi(\ell)}\right)$, are contained on a single page in the buffer; modify PAGE_TABLE;
1.5 Write page $\Delta_{\pi}(\ell)$ to secondary storage;
1.6 (Consolidate)

Rearrange records for pages in the buffer such that records which belong to the same new page are grouped together as follows:
a) For each $k \in P^{\prime}$ such that ( $\Delta_{k}$ not in tour yet) and
(NPG(k) $\cap \overline{\text { BUFFER }} \neq \varnothing$ ) do

$$
S_{k}=\{r \mid r \in \operatorname{NPG}(k) \text { and } P(r) \in \operatorname{BUFFER}\} ;
$$

$S_{0}=\overline{\text { BUFFER }}-U S_{k}$
b) Order above sets (excluding $S_{0}$ ) by non-increasing size to obtain

$$
s_{\theta(1)}, s_{\theta(2)}, \ldots, s_{\theta(n)}
$$

c) Allocate sets in order $S_{\theta(1)}, \ldots, S_{\theta(n)}, S_{0}$ to buffer pages, $1,2, \ldots, B U F$ and modify PAGE TABLE.

The buffer paging policy employed by our reorganization procedure chooses the candidate pages for swapping to be the pages in the buffer which contain the fewest number of records needed by new pages. As a result of the consolidation procedure (Step 1.6) all that the fewest-records buffering algorithm has to do is to select the pages in reverse order of consolidation, i.e., page[BUF], page [BUF-1], ... where page[x] stands for the page in position $x$ in the buffer.

As shown in [5], the two dominant time costs in running the STATIC_COST and DYNAMIC COST reorganization algorithms are incurred by the greedy algorithm and the buffer paging strategy. The greedy algorithm requires time proportional to the square of the vertices visited, (i.e., the number of new pages to be constructed). The total worst case time complexity for the STATIC_COST reorganization is $\theta\left(m^{2}+m^{*}\right.$ BUF*Pagesize $)$ where $m=$ number of new pages to construct and BUF = buffer capacity in pages. The worst case time complexity for the DYNAMIC_COST reorganization is $\theta$ ( $\mathrm{m}^{2} *$ Pagesize + m*BUF*Pagesize $\log _{2}$ BUF*Pagesize).

## 4. EXAMPLE

For the sake of brevity, we will illustrate only the DYNAMIC_COST_REORGANIZATION scheme by way of the following example. The hypergraph and associated representative graph for this example is pictured in Figure 2.

EXAMPLE: REORGANIZATION PROBLEM

| 1 | 1 |  |  |  |
| ---: | :--- | :--- | :--- | :--- |
| 2 | 1 | PG | 19 | 5 |
| 3 | 1 |  | 20 | 5 |
| 4 | 1 |  | 21 | 6 |
| 5 | 2 |  | 22 | 6 |
| 6 | 2 |  | 23 | 6 |
| 7 | 2 |  | 24 | 6 |
| 8 | 2 |  | 25 | 7 |
| 9 | 3 |  | 26 | 7 |
| 10 | 3 |  | 27 | 7 |
| 11 | 3 |  | 29 | 8 |
| 12 | 3 |  | 30 | 8 |
| 13 | 4 |  | 31 | 8 |
| 14 | 4 |  | 32 | 8 |
| 15 | 4 |  | 33 | 9 |
| 16 | 4 |  | 34 | 9 |
| 17 | 5 |  | 35 | 9 |
| 18 | 5 |  | 36 | 9 |


|  | NPG |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| 1 | 1 | 2 | 5 | 10 |
| 2 | 3 | 13 | 17 | 21 |
| 3 | 9 | 14 | 15 | 25 |
| 4 | 18 | 19 | 26 | 29 |
| 5 | 22 | 23 | 30 | 33 |

FIGURE 2: Hypgergraph and representative graph for example


Hypergraph H


Since the buffer is initially empty, the cost of choosing any of the vertices as a starting point of the tour is the same. We choose the vertex $\Delta_{j}$ where $\left|\Delta_{j}\right|$ is the smallest as is done with the static cost reorganization scheme. In this example, where more than one vertex satisfies this criterion, we choose the one whose subscript is smallest. We choose $\Delta_{1}$ to start with and bring pages 1, 2 and 3 into the buffer. The buffer contents before (on left) and after (on right) record rearranging is shown below. At this point we write page 1 back to secondary storage.


The number of page accesses is four (i.e. three for reading and one for writing). Next, we rearrange records on pages 2 and 3 using the consolidation procedure, Step 1.6. The result is the following:


$$
\begin{aligned}
& S_{2}=\{3\} \quad S_{3}=\{9\} \\
& S_{0}=\{7,8,6,4,11,12\}
\end{aligned}
$$

To determine the next edge of the tour we apply the Greedy algorithm to the cost function:

$$
\begin{array}{ll}
\operatorname{cosT}\left(\Delta_{1}, \Delta_{2}\right)=3 / 4 & \operatorname{cosT}\left(\Delta_{1}, \Delta_{3}\right)=2 / 3 \\
\operatorname{cosT}\left(\Delta_{1}, \Delta_{4}\right)=3 / 3 & \operatorname{cosT}\left(\Delta_{1}, \Delta_{5}\right)=3 / 3
\end{array}
$$

The edge of least cost is ( $\Delta_{1}, \Delta_{3}$ ) so we bring in pages 4 and 7 . The buffer contents before and after rearranging records and after consolidation appears below.


BUFFER

| 3 |  |
| :--- | :--- |
| 4 |  |
| 7 | $\left\|\begin{array}{rrrr}13 & 3 & 26 & 16 \\ 6 & 4 & 11 & 12 \\ 8 & 7 & 27 & 28\end{array}\right\|$ |
| $\substack{\text { after } \\ \text { consolidation }}$ |  |

This new page, $\Delta_{3}$, requires three page accesses. Now we determine the next edge of the tour.

$$
\begin{aligned}
& \operatorname{cost}\left(\Delta_{3}, \Delta_{2}\right)=2 / 3 \\
& \operatorname{cost}\left(\Delta_{3}, \Delta_{4}\right)=2 / 3 \\
& \operatorname{cost}\left(\Delta_{3}, \Delta_{5}\right)=3 / 3
\end{aligned}
$$

We choose $\left(\Delta_{3}, \Delta_{2}\right)$ for the next edge and bring pages 5 and 6 into the buffer which necessitates writing page 7 back to secondary storage. Again, we show the buffer before and after rearranging records for the new page and after consolidation.

$\left|\begin{array}{cccc}\text { BUFFER } \\ \hdashline 17 & 21 & 13 & 3 \\ 18 & 22 & 23 & 24 \\ 19 & 20 & 26 & 16 \\ 6 & 4 & 11 & 12\end{array}\right|$

BUFFER

3 4 | $\left\|\begin{array}{rrrr}18 & 19 & 26 & 24 \\ 22 & 23 & 20 & 16 \\ 6 & 4 & 11 & 12\end{array}\right\|$ |
| :---: |
| $\substack{\text { after } \\ \text { consolidation }}$ |

Constructing $\Delta_{2}$ generates four page accesses. We then determine the next edge of the tour using our cost function.

$$
\begin{aligned}
& \operatorname{cost}\left(\Delta_{2}, \Delta_{4}\right)=1 / 2 \\
& \operatorname{cost}\left(\Delta_{2}, \Delta_{5}\right)=2 / 3
\end{aligned}
$$

We construct $\Lambda_{4}$ next by bringing page 8 into the buffer. The buffer snapshot follows.

BUFFER
8
6
4 $\left|\begin{array}{cccc}29 & 30 & 31 & 32 \\ 18 & 19 & 26 & 24 \\ 22 & 23 & 20 & 16 \\ 6 & 4 & 11 & 12\end{array}\right|$

BUFFER

after rearranging

BUFFER
$4{ }^{4}\left|\begin{array}{cccc}22 & 23 & 30 & 16 \\ 24 & 20 & 31 & 32 \\ 6 & 4 & 11 & 12\end{array}\right|$

Building new page $\Delta_{4}$ required 2 page accesses. The last new page to be constructed is $\Delta_{5}$. This requires bringing page 9 into the buffer. The buffer snapshots appear next.


The last new page needed two page accesses (i.e. one for reading and one for writing) and an additional three page accesses to write the remaining pages from the buffer to secondary storage. This yields a total of 18 page accesses using the DYNAMIC_COST_REORGANIZATION algorithm.

## 5. EXPERIMENTAL RESULTS

This section presents the results of a number of synthetic experiments. The objective of the experiments is to compare the STATIC COST and DYNAMIC COST reorganization schemes with various alternative strategies. For the other strategies we will use two different ordering schemes as well as two different page replacement policies. We also modify the buffer size to see what effect the buffer capacity has on the various reorganization strategies.

For these experiments, we randomly generate records for 25 pages where the page size is 10 records. The record identifiers are in the range from 1 to 1000 and the buffer size is initially 10 pages. These 25 pages represent the new pages that must be constructed. The original state of the file (100 pages) is represented by the following formula:
set of record identifiers on page
10
$p=\bigcup_{i=1}\{10 *(P-1)+i\}$.
In the first set of experiments, shown in Table 1, we are interested in the effect the ordering scheme has on the STATIC_COST and DYNAMIC COST reorganization schemes. We have two versions of each scheme differing only in the order in which new pages are constructed. The version denoted as LINEAR simply constructs the new pages in numerically increasing order (i.e., $\Delta_{1}, \Delta_{2}, \Delta_{3}, \ldots$ ) and the ORDERED version constructs pages in the order determined by the greedy heuristic. The two rightmost columns of the table represents reorganization strategies that use a LINEAR ordering and either an LRU (least recently used) [8] or ARBITRARY (random) page replacement policy.

Table 2 shows the average number of page accesses and the percentage of page accesses less than the LINEAR ordering scheme using the ARBITRARY page replacement policy. From Table 2, we see that the versions of the STATIC COST and DYNAMIC_COST schemes utilizing their ordering heuristic are superior to the associated schemes using a linear ordering. However, the DYNAMIC COST scheme with a linear ordering produces a greater savings than either STATIC COST version. This demonstrates the importance of the buffer management scheme for the DYNAMIC_COST strategy. Another observation is that the LRU page replacement policy which is used in operating systems does not fair much better than the arbitrary page replacement policy. This has also been shown in other studies concerning database systems [3,11].

In the second set of experiments, Table 3, we want to observe, for the STATIC COST scheme, whether a complete lookahead (i.e. 24-lookahead) yields an increased savings over the 1 -lookahead. In addition, we want to see what improvement can be gained by using the greedy heuristic as in the DYNAMIC COST algorithm to determine the ordering with the LRU and arbitrary page replacement strategies. Table 4 summarizes the results of these experiments. As we see, using the $24-100 k a h e a d$ gives us essentially no improvement. This is as anticipated for these experiments. Since the 10 records for a new page are randomly generated, we would expect the 10 records to reside on close to ten different pages. Hence, with the 24-lookahead scheme as well as with the 1-lookahead scheme it would be possible to keep only a few if any pages in the buffer beyond those needed for the current new page. By using the greedy algorithm for determining the order we see that the LRU and arbitrary schemes are just as good as the STATIC COST method. Although, the DYNAMIC cost ordered scheme is the best showing approximately a $41 \%$ savings.

Tables 5 and 6 show the results of the third set of experiments. For these experiments the buffer capacity is increased by $50 \%$. Once again, the DYNAMIC_COST ordered scheme provides the largest savings, about $45 \%$. However, since the buffer capacity is extended, the 24 -lookahead STATIC COST scheme now shows a marked improvement over the 1-lookahead scheme and the dynamic ordered LRU and arbitrary schemes. Again, the improvement of the 24-lookahead scheme is due to the fact that we can keep more pages in the buffer (i.e., pages which will be referenced in the future).

Tables 7 and 8 show the results of the fourth set of experiments. For these experiments the buffer capacity is increased $100 \%$ over the initial buffer size. The DYNAMIC COST ordered scheme is still the best approach with approximately a $47 \%$ savings. Again the 24-lookahead scheme is showing an improvement due to the increased buffer size. The performance of the other schemes remains about the same.

| STATIC |  | DYNAMIC |  | LINEAR |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| LINEAR | ORDERED | LINEAR | ORDERED | LRU | ARB |
| 426 | 364 | 296 | 226 | 436 | 438 |
| 420 | 376 | 304 | 270 | 426 | 424 |
| 434 | 372 | 286 | 260 | 434 | 434 |
| 388 | 352 | 280 | 230 | 398 | 398 |
| 436 | 360 | 288 | 242 | 446 | 448 |
| 426 | 374 | 268 | 242 | 434 | 432 |
| 418 | 366 | 296 | 240 | 424 | 424 |
| 418 | 368 | 282 | 242 | 424 | 424 |
| 426 | 382 | 290 | 270 | 434 | 434 |
| 424 | 358 | 320 | 238 | 434 | 436 |

TABLE 1. Comparison of Reorganization Schemes with Buffer Size = 10 (In Page Accesses)

|  | AVERAGE PAGE ACCESSES | \% LESS THAN LINEAR-ARB |
| :---: | :---: | :---: |
| STATIC-LINEAR | 421.6 | 1.77 |
| STATIC-ORDERED | 367.2 | 14.45 |
| DYNAMIC-LINEAR | 291.0 | 32.20 |
| DYNAMIC-ORDERED | 246.0 | 42.68 |
| LINEAR-LRU | 429.0 | 0.04 |
| LINEAR-ARB | 429.2 | 0.00 |

TABLE 2. SUMMARIZED DATA FROM TABLE 1

| STATIC-ORDERED |  | DYNAMIC ORDERED | LINEAR |  | DYNAMIC-ORDER |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1-LOOK | 24-L00K |  | LRU | ARB | LRU | ARB |
| 360 | 360 | 246 | 444 | 446 | 358 | 356 |
| 350 | 350 | 264 | 422 | 416 | 348 | 356 |
| 354 | 352 | 234 | 438 | 438 | 362 | 358 |
| 356 | 356 | 264 | 440 | 440 | 358 | 358 |
| 370 | 366 | 244 | 438 | 440 | 360 | 360 |
| 350 | 350 | 254 | 436 | 436 | 358 | 360 |
| 378 | 378 | 254 | 432 | 432 | 370 | 372 |
| 378 | 376 | 282 | 438 | 438 | 360 | 360 |
| 380 | 378 | 272 | 436 | 436 | 384 | 384 |
| 370 | 368 | 252 | 440 | 442 | 364 | 364 |

TABLE 3. COMPARISON OF REORGANIZATION SCHEMES WITH BUFFER SIZE $=10$ (In Page Access)

|  | average page ACCESSES | \% LESS THAN <br> LINEAR-ARB |
| :---: | :---: | :---: |
| 1 - LOOK | 364.6 | 16.45 |
| 24-LOOK | 363.4 | 16.73 |
| DYNAMIC-ORDERED | 256.6 | 41.20 |
| LINEAR-LRU | 436.4 | 0.00 |
| LINEAR-ARB | 436.4 | 0.00 |
| DYNAMIC-LRU | 352.2 | 19.29 |
| DYNAMIC-ARB | 362.8 | 16.87 |

TABLE 4. SUMMARIZED DATA FROM TABLE 3

| STATIC-ORDERED |  | DYNAMIC ORDERED | LINEAR |  | DYNAMIC-ORDER |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1-LOOK | 24-LOOK |  | LRU | ARB | LRU | ARB |
| 326 | 282 | 238 | 426 | 408 | 332 | 334 |
| 324 | 280 | 226 | 384 | 388 | 316 | 334 |
| 312 | 284 | 208 | 410 | 414 | 330 | 330 |
| 332 | 290 | 220 | 410 | 408 | 348 | 354 |
| 350 | 302 | 232 | 412 | 410 | 332 | 344 |
| 318 | 284 | 228 | 414 | 412 | 326 | 350 |
| 348 | 312 | 216 | 412 | 412 | 350 | 356 |
| 336 | 294 | 226 | 414 | 418 | 334 | 354 |
| 344 | 308 | 218 | 406 | 416 | 342 | 358 |
| 332 | 298 | 226 | 434 | 418 | 342 | 340 |

TABLE 5. COMPARISON OF REORGANIZATION SCHEMES WITH BUFFER SIZE $=15$ (In Page Accesses)

|  | AVERAGE PAGE ACCESSES | \% LESS THAN <br> LINEAR-ARB |
| :---: | :---: | :---: |
| 1-LOOK | 332.2 | 19.05 |
| 24-LOOK | 293.4 | 28.51 |
| DYNAMIC-ORDERED | 223.8 | 45.47 |
| LINEAR-LRU | 412.2 | -0.44 |
| LINEAR-ARB | 410.4 | 0.00 |
| DYNAMIC-LRU | 335.2 | 18.32 |
| DYNAMIC-ARB | 345.4 | 15.84 |

TABLE 6. SUMMARIZED DATA FROM TABLE 5

| STATIC-ORDERED |  | DYNAMIC ORDERED | LINEAR |  | DYNAMIC-ORDER |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1-LOOK | 24-L00K |  | LRU | ARB | LRU | ARB |
| 304 | 250 | 208 | 382 | 370 | 316 | 320 |
| 308 | 244 | 198 | 356 | 362 | 292 | 306 |
| 298 | 256 | 200 | 378 | 390 | 312 | 318 |
| 320 | 262 | 204 | 380 | 382 | 306 | 332 |
| 332 | 266 | 202 | 382 | 394 | 314 | 324 |
| 306 | 252 | 200 | 392 | 396 | 306 | 324 |
| 336 | 280 | 198 | 388 | 380 | 330 | 332 |
| 320 | 264 | 202 | 382 | 384 | 304 | 320 |
| 336 | 282 | 202 | 384 | 382 | 330 | 342 |
| 318 | 262 | 200 | 412 | 396 | 298 | 320 |

STEP
7. COMPARISON OF REORGANIZATION SCHEMES WITH BUFFER SIZE $=20$ (In Page Accesses)

|  | AVERAGE <br> PAGE ACCESS | $\%$ <br> LINEAR-ARB |
| :--- | :---: | :---: |
| 1-LOOK | 317.8 | 17.15 |
| DYNAMIC-ORDERED | 261.8 | 31.75 |
| LINEAR-LRU | 201.4 | 47.50 |
| LINEAR-ARB | 383.7 | -0.03 |
| DYNAMIC-LRU | 383.6 | 0.00 |
| DYNAMIC-ARB | 310.8 | 18.98 |

TABLE 8. SUMMARIZED DATA FROM TABLE 7
6. CONCLUSION

The file reorganization problem has been modelled in terms of a hypergraph and was shown to be NP-hard. Two heuristics have been introduced which include specific buffer paging strategies. Experiments were performed to compare a number of alternative strategies
featuring different orderings and page replacement schemes. The DYNAMIC_COST reorganization algorithm is clearly the superior approach in the experiments. The STATIC COST algorithm with complete lookahead is good if the buffer capacity is large. The linear LRU and linear arbitrary schemes produce essentially the same results which are poor. The dynamic LRU and dynamic arbitrary schemes produce approximately the same savings and in the case where the buffer capacity is small they are as good as the STATIC_COST algorithm.

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