ON STORAGE STRUCTURES AND THEIR TRANSFORMATIONS

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Abstract

A number of operations which are of importance when dealing with data reorganization and data translation are introduced. We employ a model based on straightforward mathematical tools to describe these operations more formally and to provide an insight to their meaning and application. We recognize that high level primitive operations are necessary to ensure the correctness of storage structure representations.
Introduction

Choosing the best storage structure and access strategy for the implementation of a given logical data structure is an extremely difficult problem. The current trend in data base management system design is to relieve the casual user from the need to this by providing different levels of interface with the system [6]. The actual burden of implementation and encoding detail is placed upon the Data Base Administrator(s), who is also responsible for the reorganization, maintenance and back-up of the data base. The main reason behind this is the desire to achieve a high-level of data independence [10], so that users' programs are "invariant" under physical storage transformations.

Reorganization of a given data base occurs basically due to two reasons: desire to improve the performance of the system, usually estimated in terms of search time and storage cost [7], or the adaptation to a new software/hardware environment [3].

This paper addresses aspects of the reorganization problem, namely the primitive operations involved in the transformation from one storage structure to another. No attempt is made to provide a complete set of such operations, but rather we point out some of the complexities inherent in the problem and the implications for the development of data description and manipulation languages.
Part 1 - Review of the Storage Structure Model

Before we can speak about the operations for dealing with reorganization of data in physical storage, we need a frame of reference. We briefly outline the model presented in greater detail in [5].

We have characterized the mappings of data to physical storage in terms or standard algebraic tools, namely relations. Two types of relations can be used recursively to convey the meanings of the connectivities for arbitrary structures.

A. Pointer Relations

These are defined by the binary relations $P(S,T)$ on the set of data elements (fields or groups of fields) as follows:

$$P(S,T) \text{ means } S \rightarrow T \text{ (read "S points to T"})$$

i.e., there is a pointer from $S$ to $T$. Proceeding recursively:

$$P_2 = P$$

$$P_n(S_1,S_2,\ldots,S_n) = P_{n-1}(S_1,S_2,\ldots,S_{n-1}) \& P_2(S_{n-1},S_n) \quad n > 2$$

e.g., $P_3(S_1,S_2,S_3) = P_2(S_1,S_2) \& P_2(S_2,S_3)$ implies there is a pointer from $S_1$ to $S_2$ and a pointer from $S_2$ to $S_3$.

It is also useful to have another type of pointer relation $\tilde{P}$, to indicate pairs of data elements symmetrically connected:

$$\tilde{P}(S,T) \text{ means } S \rightarrow T \text{ and } T \rightarrow S$$

i.e., there is a pointer from $S$ to $T$ and a pointer from $T$ to $S$ and we similarly generalize:
\[ \tilde{\mathcal{P}}_n(S_1, S_2, \ldots, S_n) = \tilde{\mathcal{P}}_{n-1}(S_1, S_2, \ldots, S_{n-1}) \cup \tilde{\mathcal{P}}_2(S_{n-1}, S_n) \]

\( \tilde{\mathcal{P}}_n(S_1, S_2, \ldots, S_n) \) has the obvious meaning: there is a pointer from \( S_1 \) to \( S_2 \), from \( S_2 \) to \( S_3 \), from \( S_{n-1} \) to \( S_n \), and vice-versa.

**B. Contiguous Relations**

These describe data items which are stored contiguously on the physical device. \( C(S_1, S_2) \) means \( S_1 \) is stored contiguously to \( S_2 \); and similarly:

\[ C_2 = C \]

\[ C_n(S_1, S_2, \ldots, S_n) = C_{n-1}(S_1, \ldots, S_{n-1}) \cup C_2(S_{n-1}, S_n) \quad n > 2 \]

The description can be further refined to distinguish between \( C_n \) sequential and random access tuples:

(i) the first denoted by \( C_n(S_1, S_2, \ldots, S_n) \) specifies that in order to access a given item \( S_j \) you have to retrieve first \( S_1, S_2, \ldots, S_{j-1} \)

(ii) while the latter, denoted by \( \tilde{C}_n(S_1, S_2, \ldots, S_n) \) implies that every item \( S_j \) can be accessed at random.

To complete our descriptive mechanism we also need a means of representing the actual assignment of data to particular physical devices. For this purpose we introduce an address space function: \( AS : D \rightarrow I \), where \( AS(d) \) identifies a given device, or device extent, \( i \), on which the data element \( d \) is stored. For example, if a given data element resides on a disk, then \( AS(d) = 1 \) represents an encoding of its actual positioning in terms of device, cylinder, track or block.
To illustrate the concepts described above, suppose that we deal with hierarchical records, each containing information about a given vendor, the orders received and the items supplied for each order. (Figure 1). These records may be mapped to physical storage using ring structures as illustrated in Figure 2.

In our formalism this corresponds to:

\[ P_{n+2}(V,0_1,0_2,0_3,\ldots,0_n,V) \& \{ P_{k+2}(0_1,I_{11},I_{12},I_{13},\ldots,I_{1k_1},0_1) | i = 1,\ldots,n \} \]

In addition, the implementor has decided to store the root segments (vendor) and the order segments on device extent 1, and the leaf segments (items) on device extent 2:

\[ AS(V) = 1, \{ AS(0_1) = 1 | i = 1,\ldots,n \}, \{ AS(I_{1j}) = 2 | j = 1,\ldots,k_1 \} \]
Part 2 - High Level Primitive Operations

Our goal is to define more formally the meaningful operations for transforming one storage representation into another. Their use is either in reducing the storage cost or in improving the access time for certain transactions performed on the database. Some of the operations mentioned here are encountered in other papers dealing with the subject [6,9], while the others have been used in an ad hoc fashion by many implementors.

A. Fusion and Fission

The conversion from a linked list allocation strategy to a sequential contiguous allocation strategy is called fusion (Figure 3). The inverse operation is called fission.

In our formalism, we define the FUSION operation as follows:

\[
\begin{align*}
&\tilde{P}_n(D_1,\ldots,D_n) \\
&\text{FUSION} \quad \downarrow \\
&\tilde{C}_n(D_1,\ldots,D_n)
\end{align*}
\]

where we have adopted the abbreviation: \(\tilde{P}_n = P_n\) or \(\tilde{P}_n\) and \(\tilde{C}_n = C_n\) or \(\tilde{C}_n\).

This transformation is performed when dealing with records which have a fixed number of fields or segments. However, we have not yet conveyed the complete meaning of the accessing mechanism for the \(D_1\) elements in the new contiguous relation. This must be done if the system is to keep track of all search paths. We can see easily that if the physical device in question is a tape, only a sequential \(C_n\) can be created. Thus it is necessary to do some "device
type checking" to eliminate inconsistent representations (here is where the address space function appears on the scene).

B. Extract and Embed

The next transformation, extract, allows us to convert a list structure into a pointer array, as illustrated in Figure 4. After extracting the pointers from the list elements, the first element (sometimes referred to as header or owner) contains pointers to each member or detail element.

Note that the extract operation saves no space, but simplifies processing for the cases in which no complete traversal of the original list is required. Formally we write:

\[
\mathcal{F}_{n+1}(D_0, D_1, D_2, \ldots, D_n) \\
\xrightarrow{\text{EXTRACT}} \\
\{\mathcal{F}_2(D_0, D_1) | 1 \leq i \leq n\}
\]

The inverse of this operation is embedding. As harmless as it seems this transformation involves an unseen complexity. One of the desirable features of a "concrete" storage structure is to preserve all the properties of the more abstract data structure [2]. However, when dealing with the encoding of an information space in storage, a number of superimposed levels of representation are present. The user has one "view" of the logical information, and the implementor imposes on this his own access paths and encoding scheme. When the structure of the user's view is preserved at the encoding level, we can say that the mapping is a type-isomorphism to use a term coined by Childs [1], and it is not difficult to see
that the actual requirements of the data-manipulation programs are simplified in this case. For example, going back to Figure 4, if the user visualizes his/her records as composed of a segment \( (D_0) \) containing some fixed information about a given employee, and a number of segments \( (D_1) \) containing information about different jobs held in a company, the pointer array implementation reflects exactly this situation, namely that the \( D_1 \)'s are disjoint [5]. However the embedded structure does not preserve this property, and extra processing is required.

C. Split and Combine

When records have some long, infrequently accessed fields, it may be more efficient to separate these fields out, store them separately, and access them only when needed. For example, in a collection of art object descriptions, the infrequently accessed biographical information on the artist can be maintained separately, thereby reducing the average transfer time for the records. Figure 5a shows this type of "splitting" and the inverse operation, "combining". We define the SPLIT1 operation as:

\[
P_n(C_2(D_{11}, D_{12}), \ldots, C_2(D_{n1}, D_{n2}))
\]

\[
\text{SPLIT1 } \downarrow
\]

\[
P_n(D_{11}, \ldots, D_{n1}) \& \{P_2(D_{11}, D_{12}) | 1 \leq i \leq n\}
\]

and after the operation:

\[
\{AS(D_{11}) = I_1 | 1 \leq i \leq n\}
\]

\[
\{AS(D_{12}) = I_2 | 1 \leq i \leq n\}
\]

where \( I_1 \) and \( I_2 \) are indexes of separate address spaces.
A second type of splitting is shown in Figure 5b and can be described as:

\[
\begin{align*}
C_n(C_2(D_{11}, D_{12}), \ldots, C_2(D_{n1}, D_{n2})) \\
\text{SPLIT2} \quad \downarrow \\
P_2(C_n(D_{11}, \ldots, D_{n1}), C_n(D_{12}, \ldots, D_{n2}))
\end{align*}
\]

and after the operation:

\[
\{\text{AS}(D_{11}) = I1 | 1 \leq i \leq n\} \\
\{\text{AS}(D_{12}) = I2 | 1 \leq i \leq n\}
\]

where \( I1 \) and \( I2 \) are the indexes of separate address spaces.

Of course, the data elements, the \( D \)'s, may have a complex substructure of their own.

D. Factor and Distribute

The factoring operation, first defined in connection with the DIAM model [6], has the purpose of minimizing storage utilization by eliminating redundancy. Going back to the hierarchical records defined in Figure 1, let us consider the case when all the segments contain the same value, \( D_{\text{field}} \), in one of the fields. Obviously, that value can be "factored" out and stored in the header. Similarly, if any \( k \)-level segments contain a common value, it can be factored to the common ancestor, a \( k-1 \) level segment. We illustrate this factoring operation in Figure 6 and define it as:

\[
\begin{align*}
P_{k+1}(R_0, R_1, \ldots, R_k) \\
\text{FACTOR}(\text{field}) \quad \downarrow \\
P_{k+1}'(R_0', R_1', \ldots, R_n')
\end{align*}
\]
where

\[ R_0 = C_n(D_1, \ldots, D_n) \]

\[ R_i = C_m(E_1, \ldots, E_m), \quad 1 \leq i \leq k \]

\[ 1 \leq \hat{m} \leq k \]

and in the target structure

\[ R'_0 = C'_{n+1}(D'_1, \ldots, D'_{n+1}) \]

\[ R'_i = C'_{m-1}(E'_1, \ldots, E'_{m-1}) \]
Part 3 - Conclusions

No attempt has been made to provide a complete set of operations meaningful to the problem of data reorganization. While the actual transformations from one storage scheme to another could be performed with only a small set of low level primitive transformations [9], no guarantees could be given to ensure the preservation of the more abstract properties of the data. An analogy could be drawn to assembly language operations which give us a great deal of freedom, but do not allow type checking or a protective mechanism. The need for more powerful programming languages for data base systems has been stressed only recently [4]. Data manipulation languages which support reorganization operations should have the capability to handle different levels of abstraction, especially if the system has to keep track of all the search paths and eventually has to automatically generate code for the new storage schemes.

The goal of this paper is to suggest the kind of operations that would be meaningful for data translation at an intermediate implementor-oriented level. As such, the operations are below the level proposed in [8] which uses a high level construct, the form, as a basis for the operations. Our operations are a step above the low level generalized data translator-oriented operations proposed in [11].

We hope to pursue more precise definitions of these operations and will investigate the possibility of establishing a "complete" set of translation operations. Other research directions include the study of the "correctness" of the translation and efficient implementation of the operations.
References


Figure 1 - Logical view of VENDOR/ORDER/ITEMS RECORDS
Figure 2 - Physical implementation of VENDOR/ORDER/ITEMS RECORDS
Figure 3

Figure 4
Figure 5a

Figure 5b
Figure 6