Dresden Database Systems Group

4. Row-based Record Management

Architecture of Database Systems

Classification in 5-Tier-Architecture

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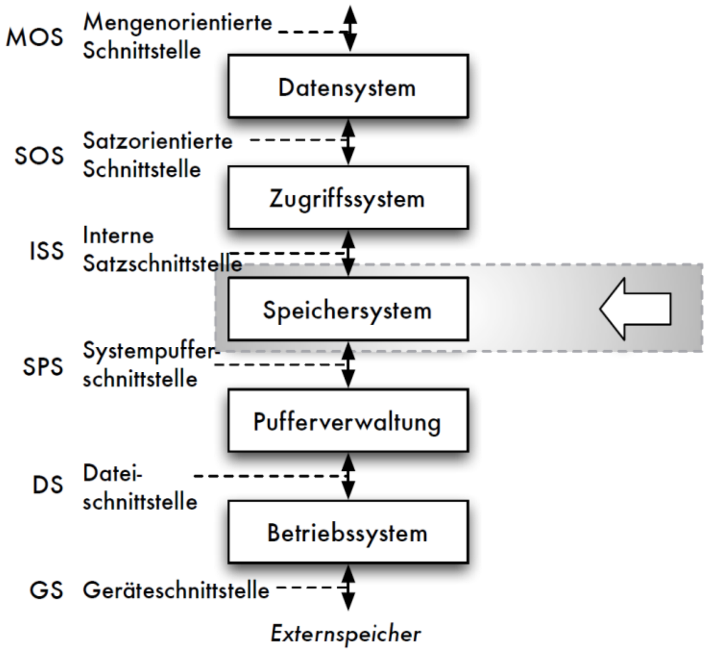
5-Tier-Architecture



Tasks

- **Storage system** requests pages through system buffer interface (Systempufferschnittstelle)
- Storage system interprets them as internal records
- Internal realisation of logical records via pointers, special index entries and further falsework
- Access system abstracts from the concrete implemention (further details in ADBS II)

Organisation of Sides (Review)

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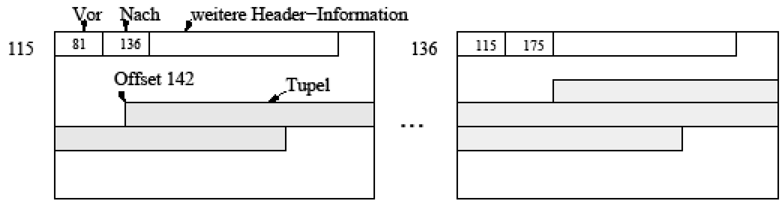
Concatenation

- Pages are linked together by double linked lists
- Recording of free pages: heap management (Freispeicherverwaltung)



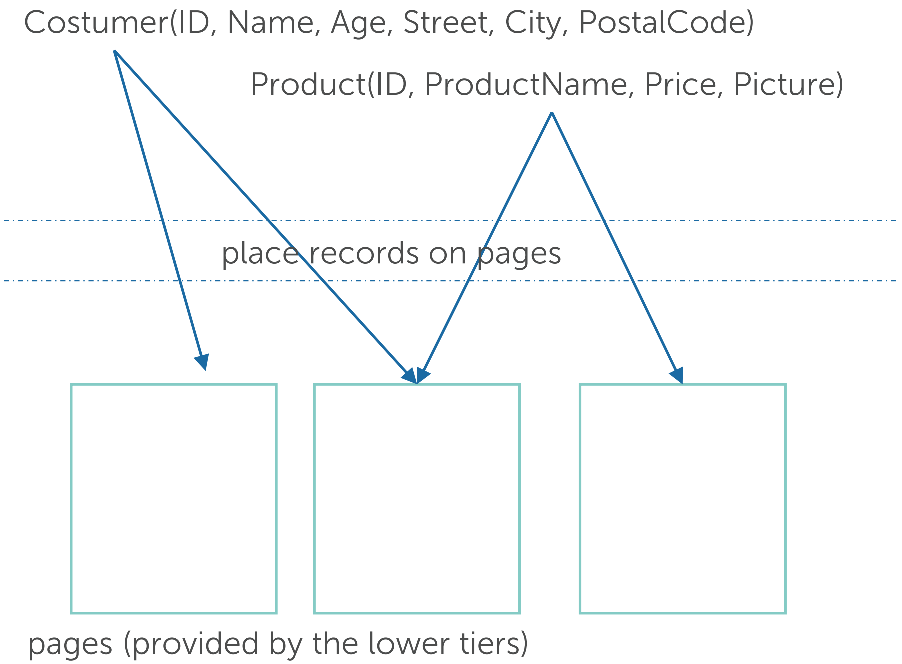
L_S = page size
L_{SK} = length of page header

Page Header

- Information about previous and and following page
- Optionally also number of the page itself
- Information about the type of record (Table Directory)
- Information about free space

Storage System-Requirement

Graphical Presentation



Key Aspects

- Representation of complete records on pages
- Organisation of structure formats for records
- Adressing of records
  - Allocation table
  - TID-concept
- Heap management (Freispeicherverwaltung)

Comparison to Key/Value-Store

Key/ Value Approach

- Get(Key) → (object, context)
  - Returns a list of data objects associated with key
  - More than one object only if there was a conflict
  - Returns a context
- Put(key, context, object)
  - Determine where replicas should be placed for associated key
  - Write the replicas to the disk
- Context
  - Encodes system metadata that the caller is not aware of
  - Includes versioning information

Differentiation

- Key – either an internal key (TID/RID) or an application key (in the worst case: composite key)
- Values – either known to the system or only known to the application

Assumption for now

- Key is “internal” / value structure is known to the system
- Value structure is preserved as a whole

Processing Unit ‘Record’

Definition “Record”

- Summary of data which belong to an object, a person, a circumstance etc. of an application and which describe the properties of the object
- Records are put together by fields
  (components of a struct in C).

Comment

- The structure of a record is irrelevant for the storage management on that level
  - every records has an arbitrary number of attributes → every record may have a variable length
- In this tier, a record is only a byte sequence which length is determined not any longer by the system but by the application!
- On this level of abstraction, a file is a (linear) sequence of records with a fixed or a variable length.

Tasks of the Record-Manager (Storage System)

- Physical storage / records organization on pages
- Operations: read, insert, update, delete

Mapping of Records on Sides

IMPORTANT

- **Until now:** page of fixed length as a processing unit
- **Now**: data record of variable length as a processing unit

DECOUPLING OF

- System given processing units (pages) (physical record)
- Data structure of an application (records) (logical record)

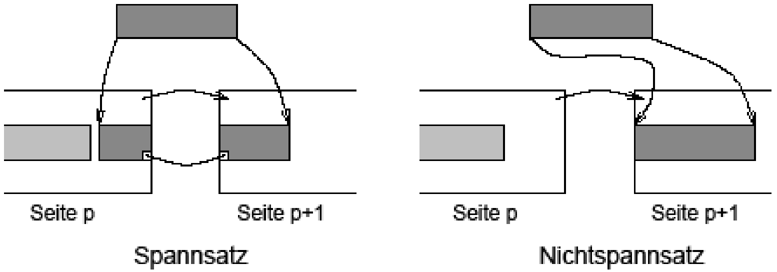
Mapping function:

Record
(logical record)

(physical record)
Page in Main Memory

REMEMBER: NO SPANNING RECORDS! (SPANNSATZ)

- The mapping of a single record may not cross the boundaries of a single page
- Large records are split into multiple smaller pieces at the logial level and connected via explicit record address



Record Formats

Format of Records

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Requirements for Processing Efficiency and Flexibility

- Every record is identified by a **record indentfier** (SKZ (= Satzkennzeichen) or OID (=Object Identifier))
- Storage as space-saving as possible (storage economy)
- Extensibility of record type should be possible any time during the operation (requirement of application)
- Simple calculation of an internal record address of the n-th field (when access to only a part of records)

Record Description

- Description of record and access path in catalogue
- Special methods of storage
  - Blank-/zero suppression
  - Character compression
  - Cryptographic encryption
  - Symbol for undefined values (NULL values)
- Organization
  - n record types per segment
  - m records of different types per page
  - Record length < page length

Format of Field

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Description of Attributes/Fields

- Name (often a difference between internal name of field and external name of type of attribute)
- Characteristic (fixed, variable, multiple)
- Length
- Type (alpha-numeric, numeric, packed, ...)
- Special methods for storage (zero suppression, character compression, cryptography etc.)
- If necessary symbol for a undefined value (if not globally defined as a segment or system constant)

The format description manages all operations on records.

Record Types

- Typically many records with the same structure/same arrays have a unique description in data dictionary for all
- **Record type**: set of records with the same structure gets a name (usually table name)
- Every records needs to be allocated to a record type when taken into storage
  (records without type are not allowed).

Record Types

Record Length of a Record Type

- Fixed, when all fields have a fixed length or when the maximal length is reserved for fields with flexible length
- Otherwise variable

Problem

- On which page is a record deposited and how can this record be found again, even if meanwhile several other records have been deleted and inserted?
- See record addressing!

Assumption

- Length of records is variable (general cases)
- Order of storage doesn't have to be the order of inserting
- Direct access to single records through their record address
- A record should be stored within a single page: $L_R \le L_S - L_{SK}$ (Standard)
- Several record types per page should be possible.

Storage Structure for Records

Example

- Record type PERS with 6 fields
  (f_i = fixed, length i; v = variable length)

PERS(PNR: f_5;
Name: v;
Job: v,
Salary: f_6,
City: f_2,
DName: v
)

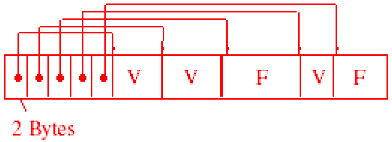
Option A)

- Concatenation of fields with fixed length

- Storage extensive
- Inflexible

Option B)

- Pointer in prefix

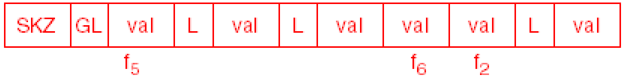


- Inflexible

Storage Structure for Records

Option C)

- Embedded length arrays

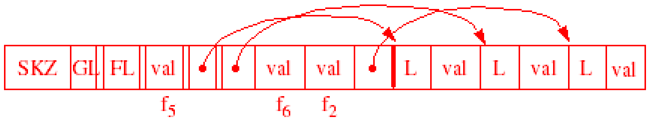


GL = Overall lenght

- Dynamic extension possible
- But: additional knowledge necessary:
  f_5 | v | v | f_6 | f_2 | v |
- Disadvantage:
  - Address of the n-th attribute cannot be calculated

Option D)

- Embedded length arrays with pointers
- Extension of C)



FL = lenght of fixed structure

- Address of the n-th attribute can be calculated

Variable Storages Structures

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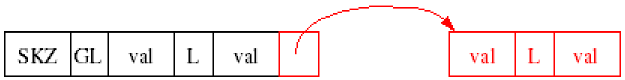
Problem

- Dynamic growth/variable length
  - Extension and contraction within a page
  - Overflow management
  - Garbage Collection

- Strictly connected storage of records
  - Possibly often rearrangement at a high change frequency
  - Advantage for indirect addressing schemata

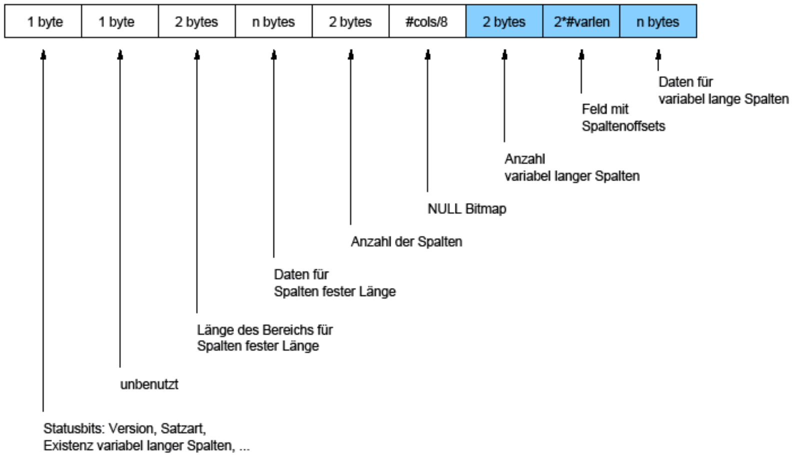
Split-up of a Record (Approach)



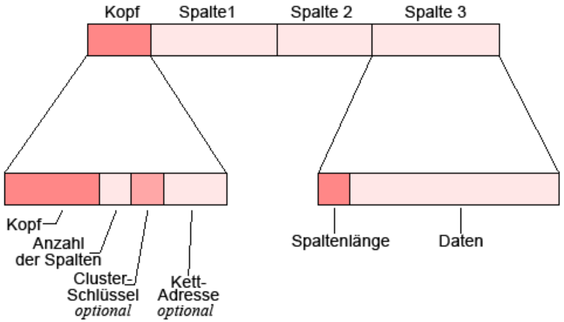
- Order according to frequency of reference
- Improvement of cluster formation
- Repeated overflow possible
- Unavoidable, when attributes TEXT or IMAGE are involved (except when saved as BLOB/CLOB)

Setup in Commercial Products

Microsoft SQL-Server



Oracle



Blocking Factor

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Typically Several Records Fit into a single page (Record Length 100 – 1000 Bytes)

- Blocking factor: number of records per page

Assumption: No Spanning Records, i.e. Every Record is Put Completely within a single page

  - Blocking factor computable of page size and record length
  - Mostly unused storage space at the end of a page

- Variable record length
  - Blocking factor changes from page to page

Record Addressing

Record Addressing

Problem

- Long-term storage of data records
- Avoiding dependency on technologies
- Support of migration.

Record Addresses

- Record addresses are generated when inserting records and can be used later to get access to the records

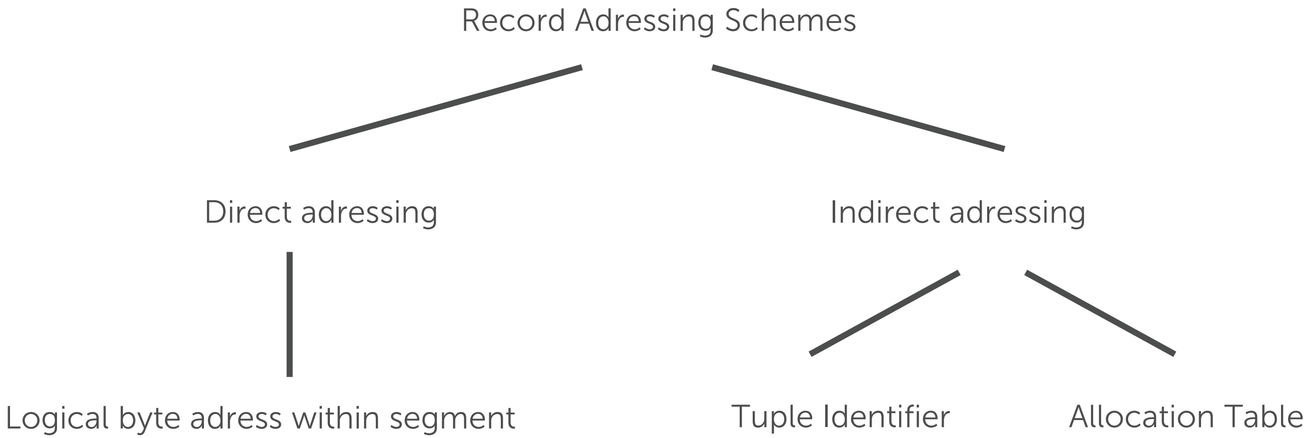
Goals of Addressing Technique

- Fast and preferably direct access to records
- Acceptably stable against slight displacements (displacements inside of a page without consequences)
- Rarely or no reorganisations

Common Form of a Record Address

- DBID, SID, TID and possibly qualification of relations (RID)
- Relation saved completely in a segment: TID DBID, SID in DB-catalogue
- Relation in several segments: SID, TID

Survey of Addressing Procedures



Direct Record Addressing

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Running Number of Record

- Instable!
  The running number and therefore the record address changes while inserte and delete operations

Blocking Number and Byte-Position Inside of a Block

- Instable!
  If a record inside of a block changes its length, usually all the other records have to be shifted.
- If a record itself gets to long for the block, it has to be placed to another block; then the block number changes as well.

Addressing in Segments

- Logically connected addressing space
- Direct addressing (logical byte-address)
  - -> Instable by displacements
  - -> Therefore indirect addressing

Allocation Table

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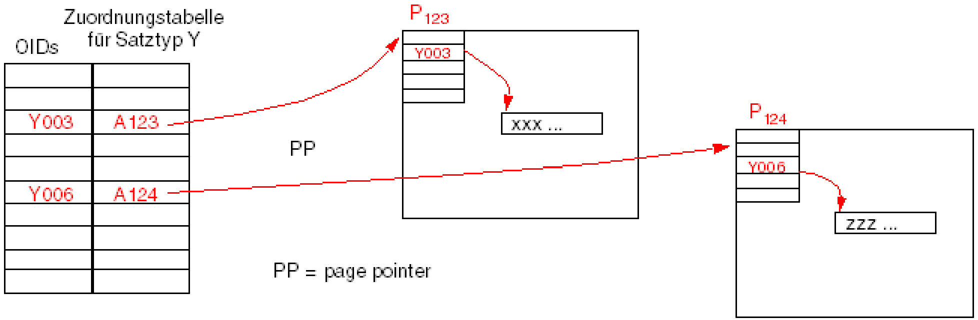
Record Addressing by Allocation Tables (Complete Indirection)

- Idea:
  administration of array in consecutive pages of the segment that specifies the page number of every index.
  - Inserting of a record
    generally allocation of new index (database key DBK) by the database system
  - Deleting of a record
    the data set entry of the corresponding index is marked invalid
  - Access to a record
    requires 3 record accesses: one for the array, one for the page with with the record itself
  - Relocation of a record to another page
    only the data set entry is changed; the index remains stable – the record is still findable by the index
  - Inside of a page
    the data set entry in the array has to be changed and written again on disk (additional E/A-operation)
  - The allocation table itself takes some storage

Allocation Table (2)



Comment: The DBK Is a „Non-speaking" Address (Telephone Number)

- The database key is built by a record type r and a sequence number f. r and f identify the record during its full lifetime within the DB.
- Table entry eferences to page P_k in segment S_i.

Problem: Where is the Allocation Table Saved?

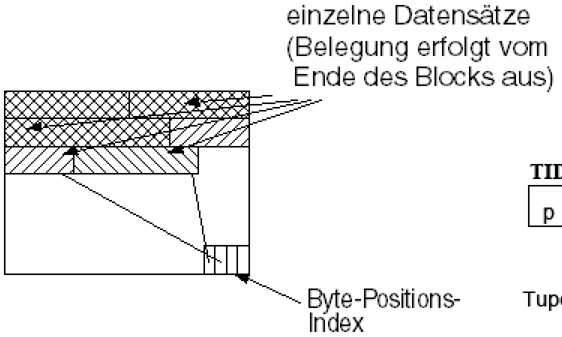
- At the beginning – how to expand?
- At the end – how to expand the data array?
- In an own segment?

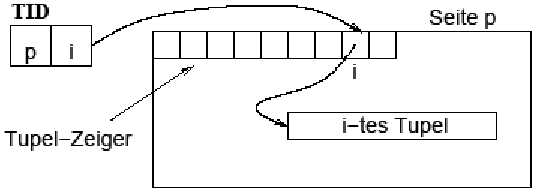
TID-Concept

Record Addressing through Indirection Inside of a page

- Array with byte-positions of records in this page
- Address is a pair consisting of a page number and an index on that array ("TID = Tuple IDentifier")

- Only one (!) page access is needed for the access to a record
- Structure of a page:





TID-Concept (2)

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Deleting a Record

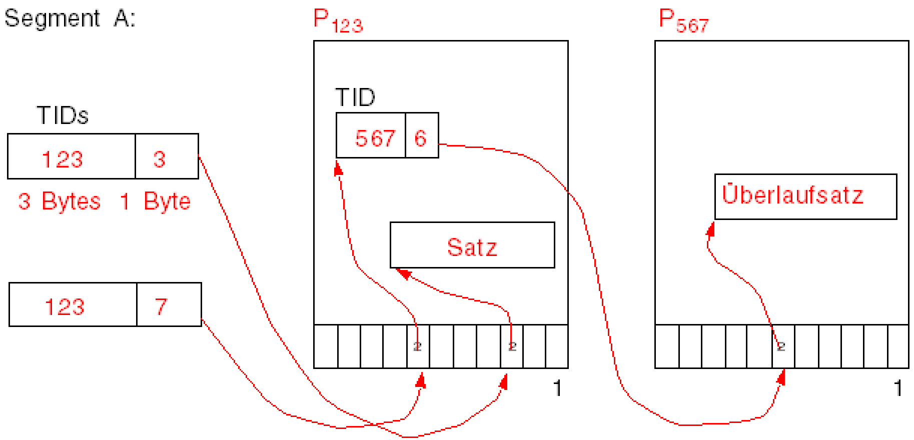
- The corresponding entry of a page array is marked invalid
- All the other records on the same pages can be moved to maximize the free space only the start address change in the page array.
- All page addresses remain stable

Update-Operation of a record

- Can change the length of a data set!
- Data set gets smaller or bigger (without overflow):
  - Every record is moved inside of a page and the byte positions are adjusted accordingly
- Data record gets bigger and there is not enough free space in the block for the storage of the now bigger data record (overflow):
  - Displacement of record to another page!

Overflow Handling TID-Concept

RELOCATION OF A RECORD



Overflow Handling TID-Concept (2)

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PROCEDURE

- The new record address referring to the new page remains at the old page at the place of the original record (home address is stable)
  - In that (rare) case, two pages must be read
  - If the record is moved another time, the record address in the first page changes, so there is maximum one indirection

TRICK

- The length of the overflow chain is always smaller or equal 1, i.e. a overflow record must not continuing to overflow, but has to be replaced from its home address.

PROS

- No allocation table
- A record can be moved inside of a page and across pages without changes of the TID

Free Space Administration

Free Space Administration

Situation

- Example: where is enough space to save a new record?

Free Place Administration (FPA)

- In a table F_i to the segment S_i is the information for every page s_k, how many bytes are still free in there
- $F_i(k) = n$ <-> on page s_k of the segment S_i are bytes free.

Problem

- How big is the FPA-table?
- Where (on which pages of a segment) is the PFA-table saved?

Storage Costs for Heap Management

- With
  - L_S = page length
  - L_{SK} = length page header for the describing information on a page
  - L_F = length of the entry (usually 2 byte)
- Result
  - $k = (L_S - L_{SK}) / L_F$ = number of entries per page
  - s = number of pages in the segment
  - $n = s / k$ = taken pages in the segment

Free Space Administration

Storage Location

- Equally spaced allocation of the table pages according to (i*k +1) with i = 0, 1, 2, ..., n – 1 i.e. a table page stands before the k pages for what it saves free storage information.
  - Pro: segment can easily be expanded
  - Con: search for free space „jumps" through the segment
- Therefore the first n pages are usually reserved for the FPA-table when the page is addressed directly
  - con: expanding of the segment
- When the pages are addressed indirectly, the free storage information is kept within the page table

Seite	1	2	3	. . .	s
Block	i	j	k	. . .	r
Freier Platz	F(1)	F(2)	F(3)	. . .	F(s)

Management of Large Objects

Large Unstructured Records

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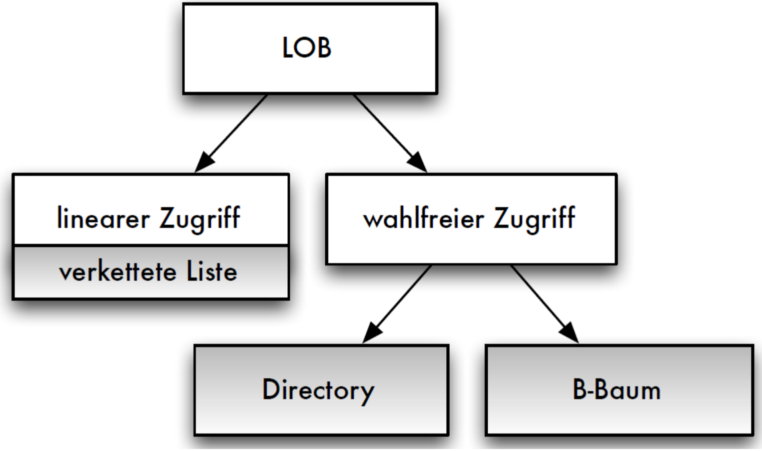
Data Types for very Large, unstructured information

- Binary Large Objects (BLOBs): byte-order as images, audio and video sequences
- Character Large Objects (CLOBs): orders of ASCII-symbol (unstructured ASCII-text)

Observation

- Long arrays don't exceed pages
- NON-BLOB-fields are stored at the original page



BLOB-Storage

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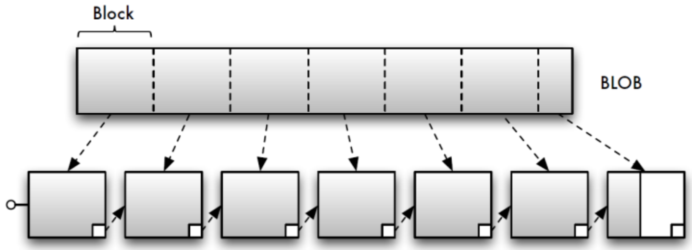
Variation 1

- As attribute value pointer: pointer shows to the beginning of a page or block list that takes BLOB



- Advantage for inserting, deleting and converting
- Disadvantage for random access into the BLOB

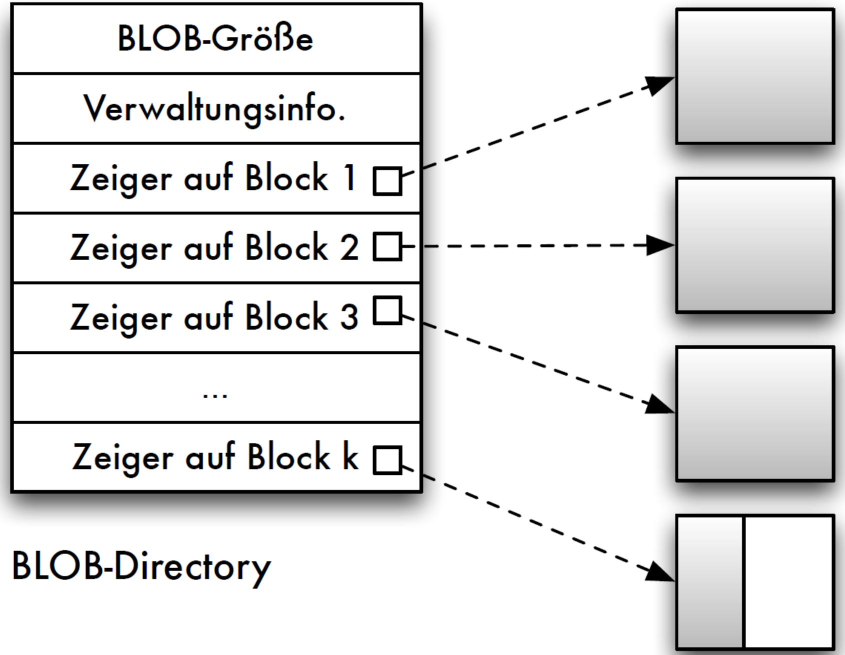
BLOB-Storage

VARIATION 2

- As attribute value BLOB-Directory:
  - BLOB-size
  - Further administration information
  - Several pointers that point to the single pages

- Advantage: fast access to subarea of the BLOB
- Disadvantage: fixed, restricted maximum size of the BLOBs
  (Gigabyte-BLOB: 8-Byte-addressing; page size 1KB→ 8MB for a BLOB-Directory)

- More efficient: B-tree for storage of BLOBs



Management of External Data

Management of External Data

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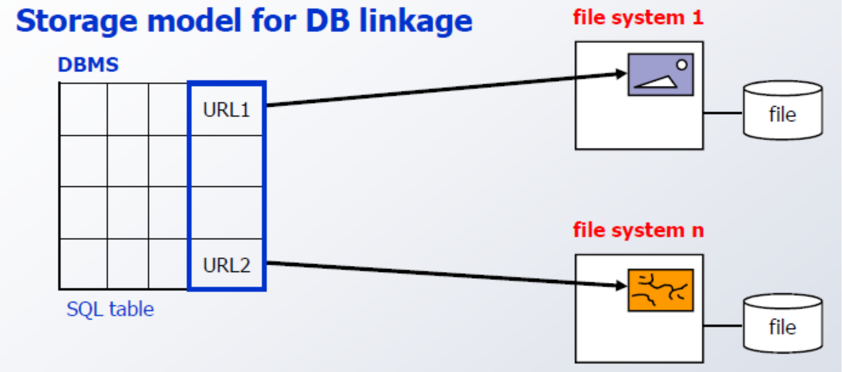
Motivation

- More and more data is (still) saved in files
- Many applications are working in a file-based fashion, native file access has to be supported
  - CAD solutions, Multimedia objects (movies) HTML and XML files

Drawbacks

- File systems do not support classical DB features
  - Referential integrity
  - Fine-grained access control
  - Consistent backup and recovery
  - Transactional consistency/isolation/…
  - Sophisticated support for an efficient search
- DBMS are tuned to work on well-structured (and potentially) large datasets

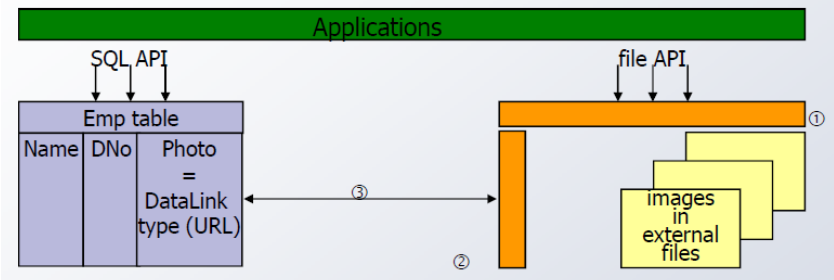


Goal

- Combination of file systems and DBMSs as best-of-breed approach

DB Links

Application Support



DataLinks File System Filter (DLFF)

- Enforces referential integrity when files are renamed or deleted
- Enforced db-centric access control when a file is opened
- File API remains unchanged in the read/write parth for external files
- DLFF does not repage in the read/write parth for external files

DataLinks FileManager (DLFM)

- Executes Link/Unlink operations under transaction protection
- Guarantees referential integrity
- Supports coordinated backup/recovery

DBMS manages/coordinates operations on external files

- Files referenced by URLSs or via DLFM API

DB Links - Options

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LINK CONTROL

- NO LINK CONTROL: URL-format of data link; no further control
- FILE LINK CONTROL: existing file must be referenced; type of control determined by further operations

INTEGRITY (INTEGRITY CONTROL OPTION)

- INTEGRITY ALL: referenced files can only be deleted or renamed by SQL
- INTEGRITY SELECTIVE: referenced files can be deleted or renamed by file-manager-operations as long as there is not data linker
- INTEGRITY NONE: referenced files can only be deleted or renamed by file-manager-operations -> not compatible with FILE LINK CONTROL

READ PERMISSION (READ PERMISSION OPTION)

- READ PERMISSION FS: read permission for referenced files is determined by the file-manager
- READ PERMISSION DB: read permission for referenced files is determined by SQL

WRITE PERMISSION (WRITE PERMISSION OPTION)

- WRITE PERMISSION FS: write permission for referenced files is determined by the file-manager
- WRITE PERMISSION BLOCKED: no writing access to referenced files, unless there is an implementation independent mechanism
- WRITE PERMISSION ADMIN [NOT] REQUIRING TOKEN FOR UPDATE: write permission for referenced files is determined by SQL

RECOVERY (RECOVERY OPTION)

- RECOVERY YES: with data base servers coordinated recovery (data linker-mechanism)
- RECOVERY NO: no recovery for referenced files

UNLINKING (UNLINK OPTION)

- ON UNLINK RESTORE: existing permission before setting up the link are restored by the file-manager when unlinking
- ON UNLINK DELETE: Deleting when unlinked
- ON UNLINK NONE: not consequences to the permissions when unlinked

SQL-Functions for DataLinks

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New SQL-Functions

- Constructor: DLVALUE, …
- (components of) URLs: DLURLCOMPLETE,

Examples

```
INSERT INTO Movies (Title, Minutes, Movie)
       VALUES('My Life', 126,
               DLVALUE('http://my.server.de/movies/mylife.avi'))
```

```
SELECT Title, DLURLCOMPLETE(Movie)
  FROM Movies
 WHERE Title LIKE '%Life%'
```

```
UPDATE Movies
  SET Movie =DLVALUE('http://my.newserver.de/mylife.avi')
  WHERE Title = 'My Life'
```

```
SELECT Title, DLURLCOMPLETEWRITE(Movie) INTO :t, :url ...
```

```
UPDATE Movies
  SET Movie = DLNEWCOPY(:url, 1)
  WHERE Title = :t
```

DBLinks Architecture

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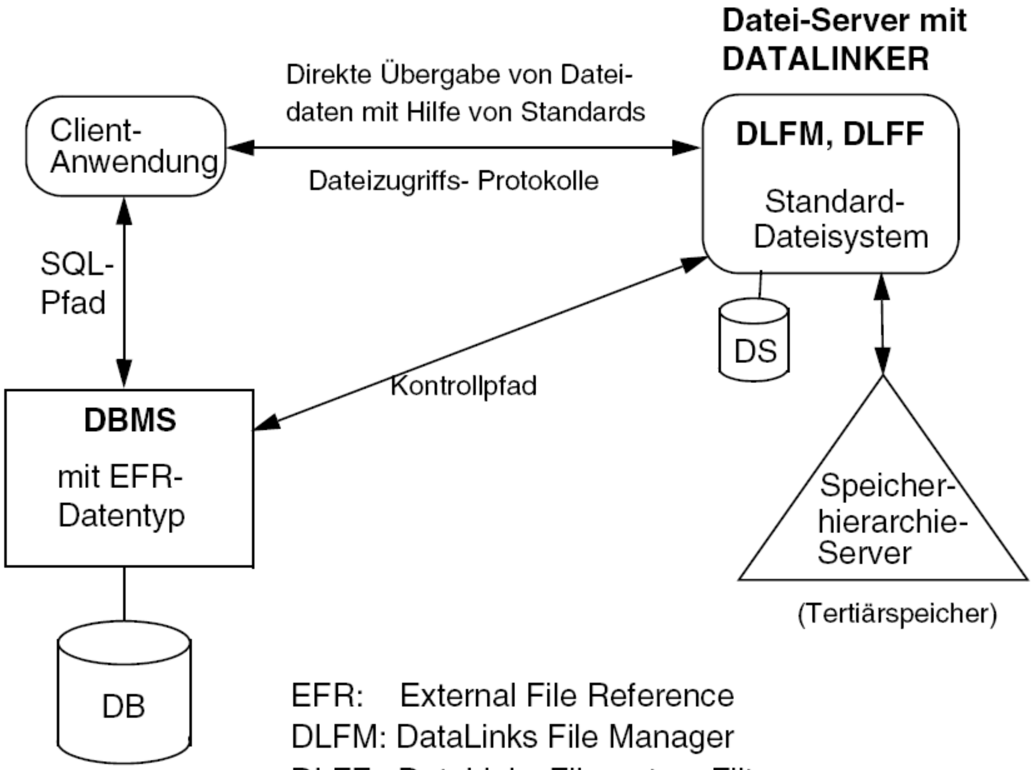

EFR: External File Reference
DLFM: DataLinks File Manager
DLFF: DataLinks Filesystem Filter

Summary

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Representing Records

- Storage of variably long arrays
- Dynamic options of expansion
- Calculation of array addresses

Goals for the external storage based Addressing

- Combination of speed of direct access with the flexibility of an indirection
- Record displacements o a page without consequences

Alternatives

- TID-concept
- Allocation table

Storage of Big Data Sets (BLOBS)

Administration of External Data