Record Management

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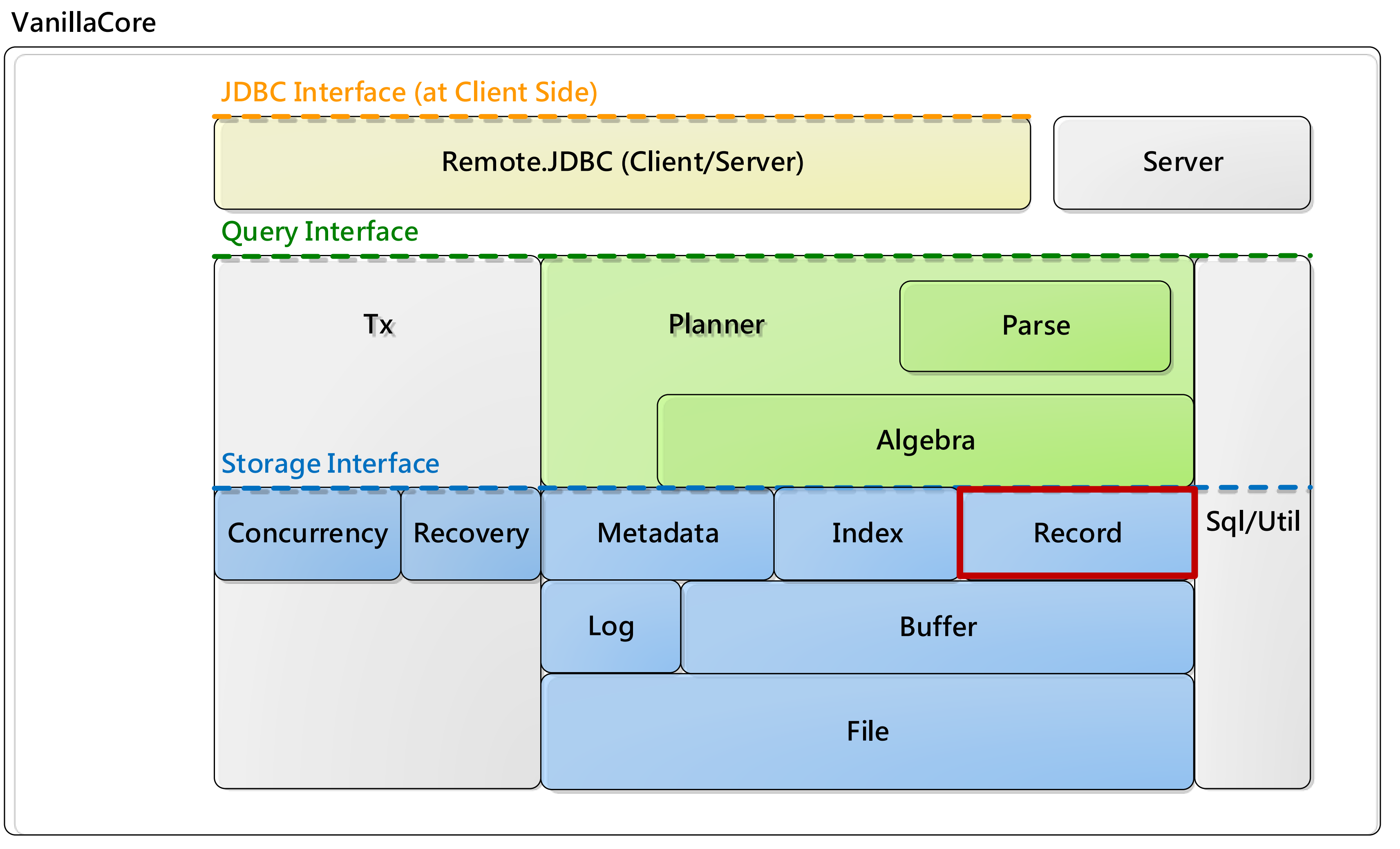
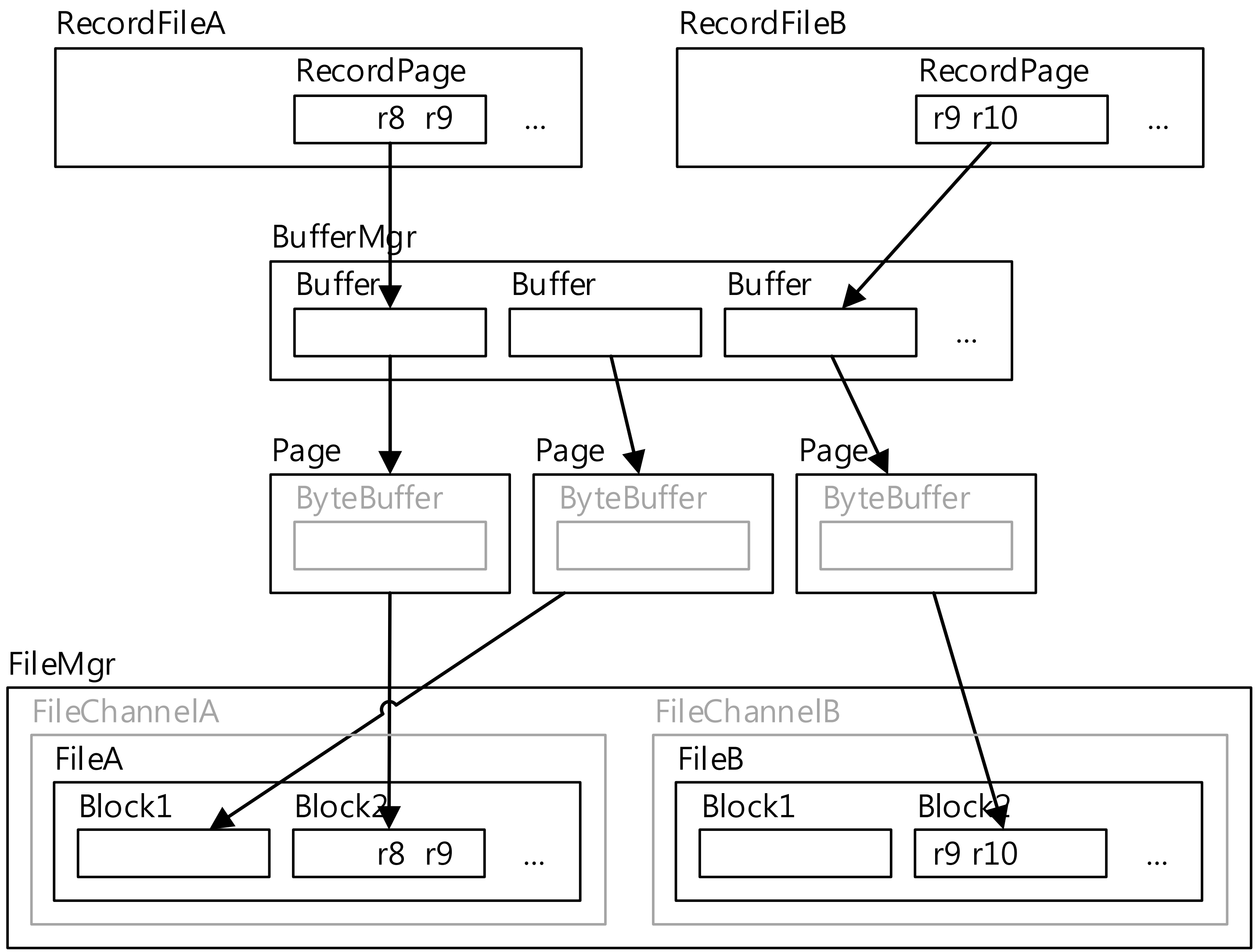
Outline

- Overview
- Design Considerations for Record Manager
- The VanillaCore Record Manager

Where?


VanillaCore
JDBC Interface (at Client Side)
Remote.JDBC (Client/Server)
Server
Query Interface
Tx
Planner
Parse
Algebra
Storage Interface
Concurrency
Recovery
Metadata
Index
Record
Sql/Util
Log
Buffer
File

Data Access Layers



Record Management

- Main interface: `RecordFile`
  - An iterator of records in a file
  - One instance per `TableScan`
    - Via `VanillaDb.catalogMgr().getTableInfo(tblName, tx).open()`
  - ***Thread local***

Responsibilities of `RecordFile`

- To decide how records are stored in a file
- To decide which block to pin
  - To save the cost of buffer access
- To work with the recovery and concurrency managers
  - To ensure tx ACID
  - Discussed later

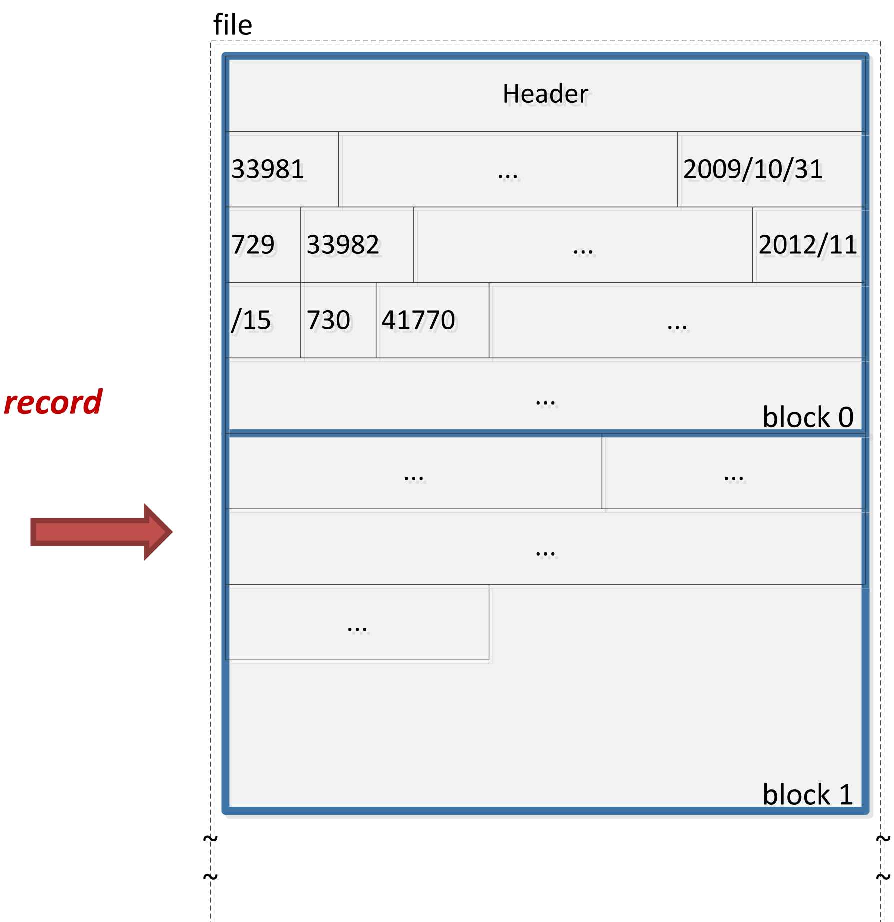
Logical Schema vs. Physical Schema

- Record manager converts (logical) schema to ***physical schema***

blog-posts

blog-id	url	created	author-id
33981	…	2009/10/31	729
33982	…	2012/11/15	730
41770	…	2012/10/20	736
45896	…	2012/10/31	729
50633	…	2013/01/15	25
55868	…	2013/8/21	199

record



Design Considerations for Physical Schema

- Should all records of a table be stored in the same file?
- Should a record be placed entirely within one block?
- Should all fields of a record to be stored next to each other?
- Should a field be represented as a fixed number of bytes?
- How to manage free space?

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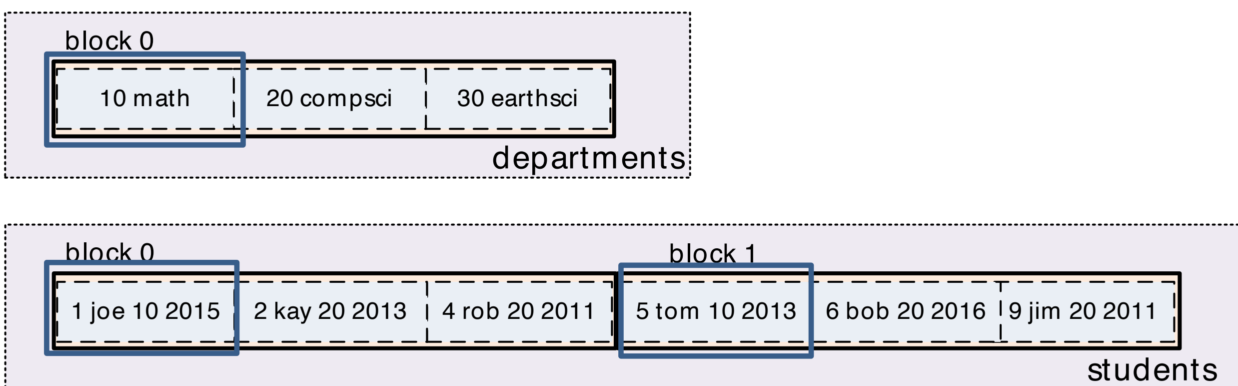
Should all records of a table be stored in the same file?

Homogeneous vs. Heterogeneous Files

- A file is ***homogeneous*** if all of its records come from the same table
  – Makes single-table queries easy to answer
- Allow ***heterogeneous*** files or not?

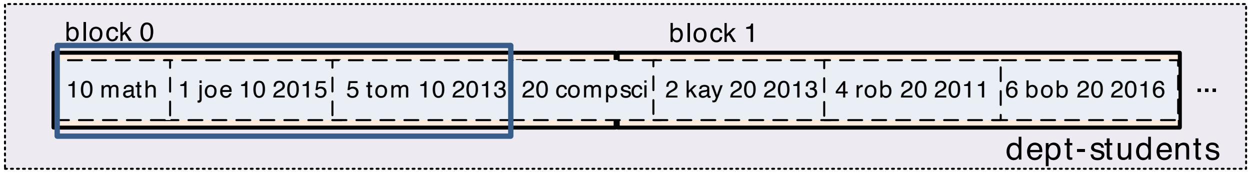
Tradeoff: Efficiency vs. Flexibility

- Query: SELECT s-name FROM students, departments WHERE d-id = major-id
- Homogeneous file
  - The disk drive has to seek back and forth between the blocks of two files



Tradeoff: Efficiency vs. Flexibility

- Query: SELECT s-name FROM students, departments WHERE d-id = major-id
- Nonhomogeneous file
  - Stores the students and departments records in the same file
    - Records are ***clustered*** on department id
  - Requires fewer block accesses to answer this join query



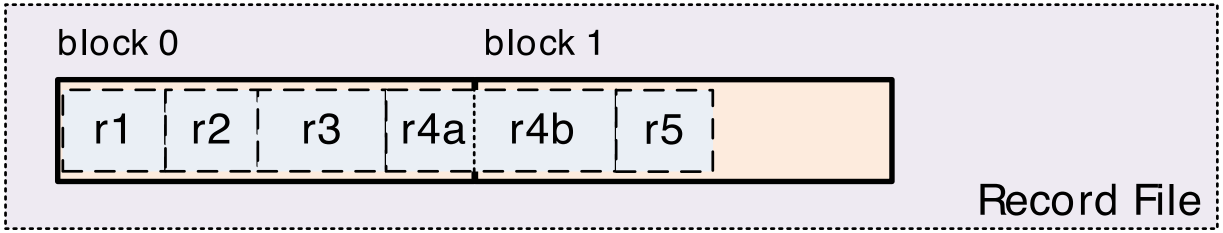
Homogeneous vs. Nonhomogeneous Files

- Nonhomogeneous file
  - Pros
    - Clustering improves the efficiency of queries that join the clustered tables
  - Cons
    - Single-table queries become less efficient
    - Join queries on non-clustered field will also be less efficient
    - Suits only for schemas with hierarchy

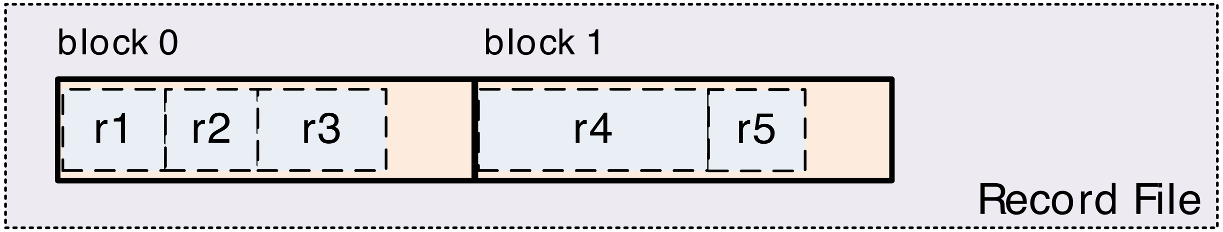
Should each record be placed entirely within one block?

Spanned vs. Unspanned Records

- A ***spanned record*** is a record whose values span two or more blocks



spanned



unspanned

Spanned vs. Unspanned Records

- Spanned record
  - Pros
    - No disk space is wasted
    - Record size is not limited by block size
  - Cons
    - Reading one record may require multiple blocks access and reconstruction

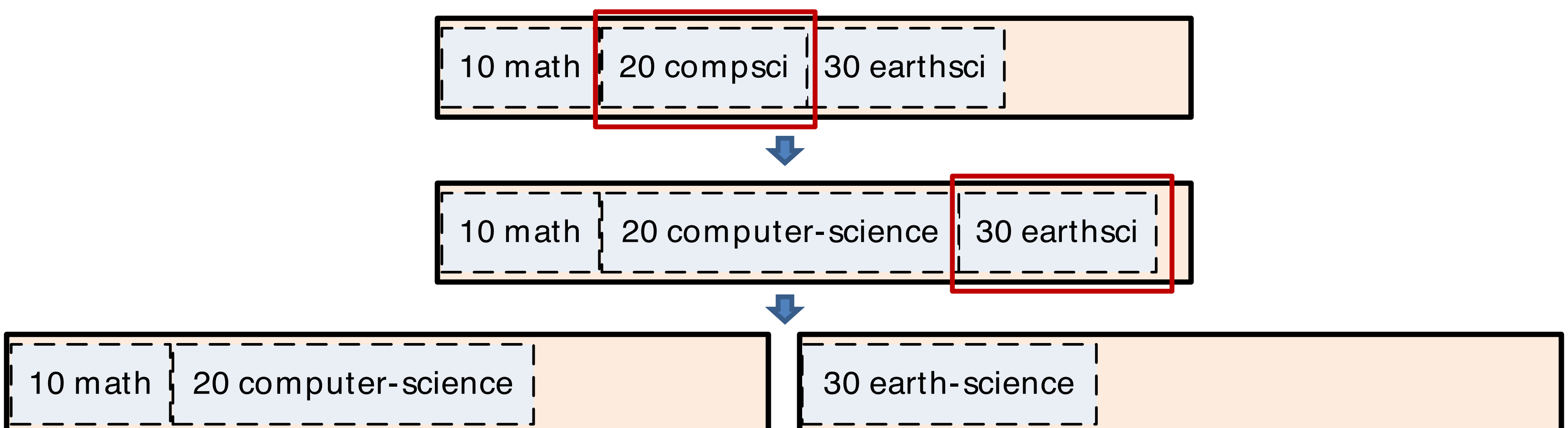
Is each field in a record represented as a fixed number of bytes?

Fixed-Length vs. Variable-Length Fields

- Field types supported by SQL
  - int, varchar(n), text, etc.
- Most of types are naturally fixed-length
  - All numeric and data/time types
- A ***fixed-length field representation*** uses the same number of bytes to hold each value of the field
  - Integer can be stored as 4-bytes binary value
- How about those fields with variable-length types?
  - varchar(n),clob(n), etc.

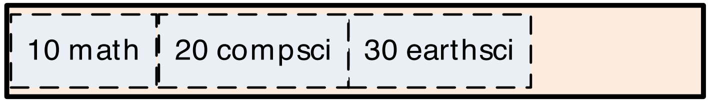
Fixed-Length vs. Variable-Length Fields

- Consider a field "d-name" defined as type varchar(20) using the variable-length representation
- Modifying this field may require rearrange other records

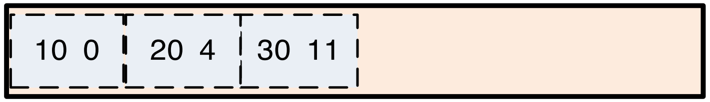


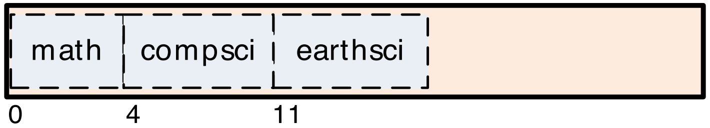
Storing Variable-Length Fields

- Three different ways to store a varchar(n)
  - Variable-length representation



  - Indexed representation, which stores the string value in a separate location





  - Fixed-length representation, which allocates same amount of space for this field in each records

Pros & Cons

- Variable-length representation
  - Space-efficient
  - Costly record rearrangement is possible
- Indexed representation
  - Space-efficient (although with overhead of index)
  - Extra index access for each record read/write
  - Suits for text, clob(n)
- Fixed-length representation
  - Easy implementation of random access
  - Wastes space

Should all fields of a record to be stored next to each other?

Column-Store vs. Row-Store

- Row-oriented store
  - Row-by-row sequentially on disk
  - `(s-id,s-name,major-id,grad-year)`

1 joe 10 2015	2 kay 20 2013	4 rob 20 2011	5 tom 10 2013	6 bob 20 2016	9 jim 20 2011

- How about storing the values of a single column contiguously on disk?
  - Sorted by `s-id`

1 2 4 5 6 9	joe kay rob tom bob jim	10 20 20 10 20 20	2015 2013 2011 2013 2016 2011

Pros & Cons

- Row-oriented store
  - Accessing a single row is more efficiently
  - Write-optimized
  - For OLTP workloads
- Column-oriented store
  - Efficient column read
  - Efficient column calculation (e.g., group by and aggregation)
  - Better comparison
  - For OLAP workloads

Design Considerations for Record Manager

- How to choose a proper record file structure?
- Several factors that should be taken into account
  - Workload
  - Supported SQL types
  - Schema

Implementing a File of Records

- A simple implementation for OLTP workloads:
  - Homogeneous files
  - Unspanned records
  - Fixed-length records
  - Row-oriented store
- Treats each file as a sequence of blocks and treats each block as an array of records
  - We call such a block a ***record page***

Record Page

- Divides a block into ***slots***, where each slot is large enough to hold a record plus one additional integer
  - This integer is a flag that denotes the slot usage
  - 0 means "empty" and 1 means "in use"

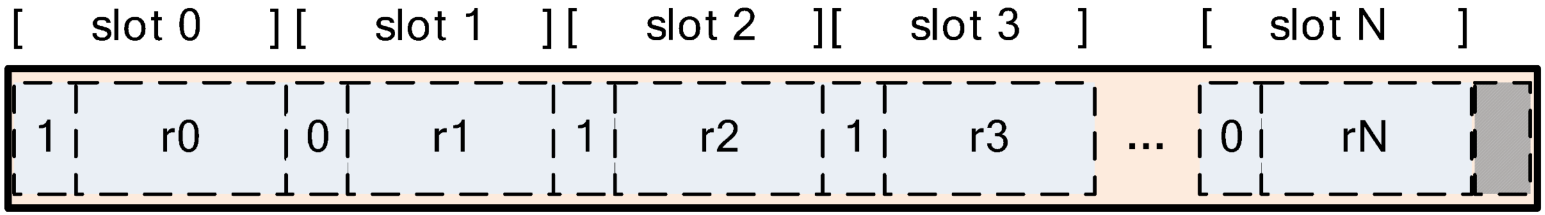


Table Information

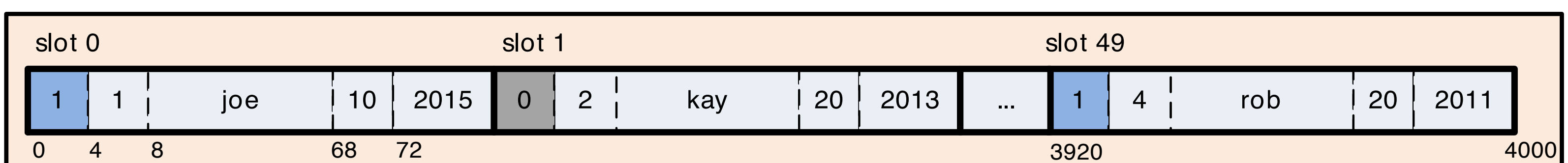
- The table information stores
  - The record length
  - The name, type, length, and offset of each field of a record
- The table information allows the record manager to determine where values are located within the block

Table Information

- Table information of `students` table
  - Record length: 76 bytes
  - Fields information:

```
students(s-id:int,
         s-name:varchar(20),
         major-id:int,
         grad-year:long)
```

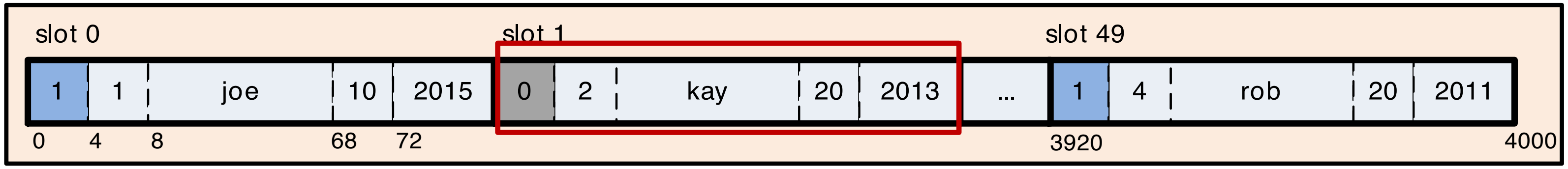
Field Name	Type	Max Size (in byte)	Offset
`s-id`	`int`	4	0
`s-name`	`varchar(20)`	60	4
`major-id`	`int`	4	64
`grad-year`	`long`	8	68



The position s-id field of record in slot n is $n * (76 + 4) + 4$

Accessing The Record Page

- To insert a new record
  - The record manager finds a slot with empty flag
  - Updates the flag as in use
  - Returns the slot number
  - If all flag values are “1”, then the block is full



Accessing The Record Page

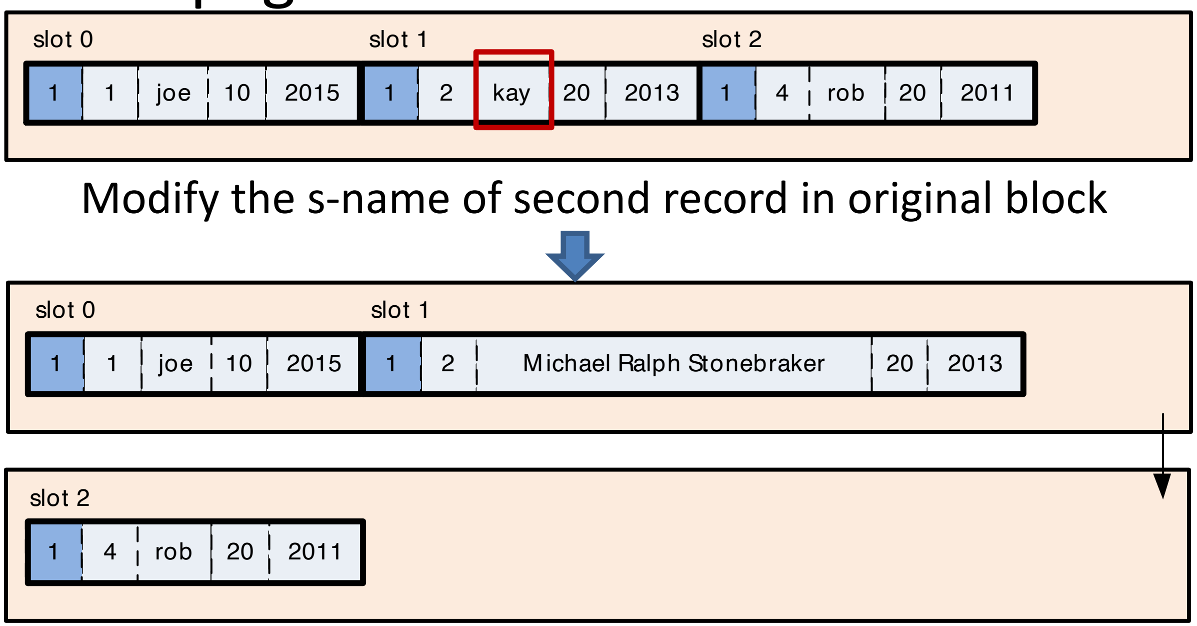
- To delete the value of the record in slot k
  - The record manager simply sets the flat at that slot to 0 as empty
- To modify a field value of the record in slot k
  - The record manager determines the location of that field, and writes the value to that location
- Each record in a page has an ID. When the records are fixed-length, the ID can be its slot number

Implementing Variable-Length Fields

- What changes to make when we want to support variable-length fields?
  - The field offsets in a record are no longer fixed
  - The records of same table can have different lengths
    - The record position cannot be calculated by multiplying its slot number by slot size
    - Modifying a field value can cause a record's length to change

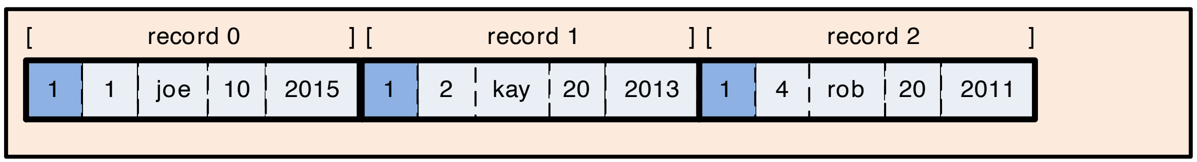
Implementing Variable-Length Fields

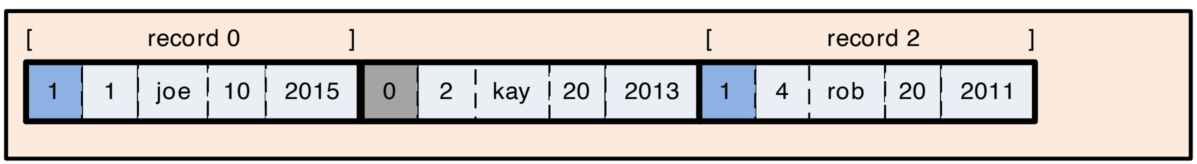
- If the record's length changes
  - We need to shift the records after modified record
  - The shifted records may spill out of the block
    - Move to ***overflow block***
- The original block and overflow block form a single large record page



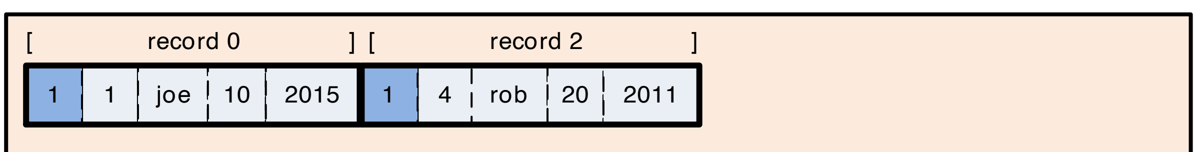
Implementing Variable-Length Fields

- How to delete a record?
  - Only set the flag to empty
    - Record size is variable, this empty space may not be re-use





  - Reclaim the empty space
    - Dissociate the record's ID from slot

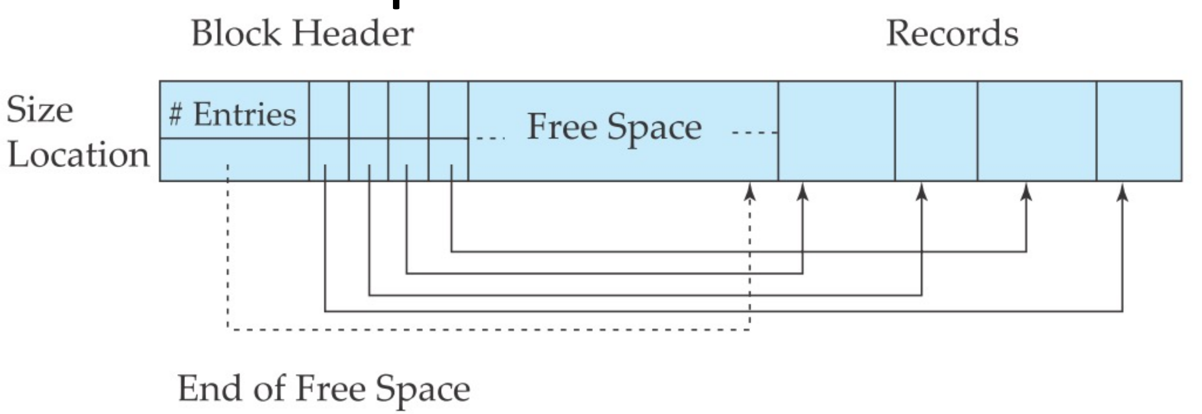


Implementing Variable-Length Fields

- The record manager cannot random access a record in a page, because it has no position information
  - We need a different ***page layout***

Implementing Variable-Length Fields

- There is a header at the beginning of each record page containing following information
  - Number of records
  - The end of free space in that page
  - IDs and pointers to each record and size of each record
- The records are placed at the other end of page



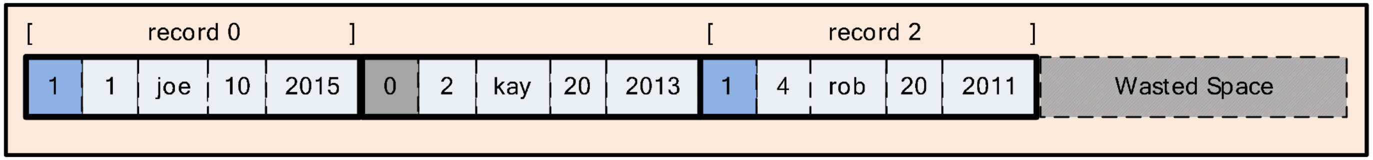
From Database System Concepts 6/e, Silberschatz, Korth. Sudarshan.

Implementing Variable-Length Fields

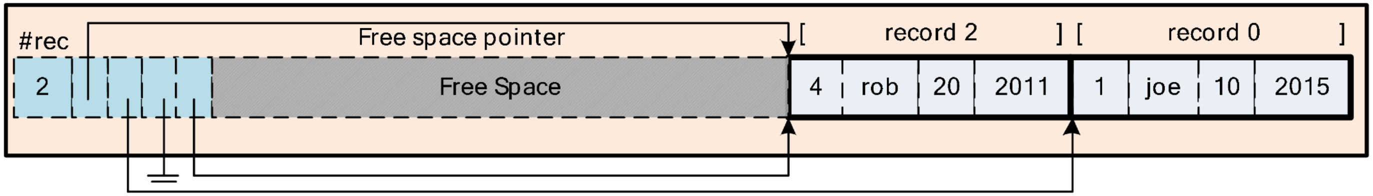
- When a modification on a record requires more spaces, the record manager will find a continuous free space within that page
- Rearranging the record page when record's length changes can eliminate the fragmentation
  - VACUUM command

Managing the Free Space Within a Record File

- Each record page in a file has different amount of free spaces
  - The fixed-length field implementation

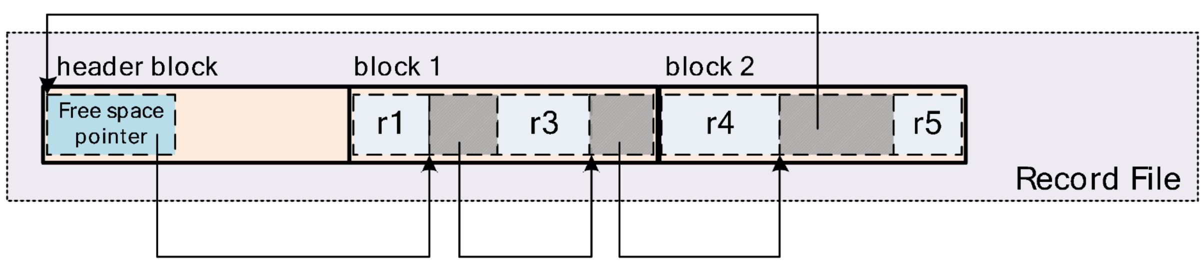


  - The variable-length field implementation with id table



M1: Chaining

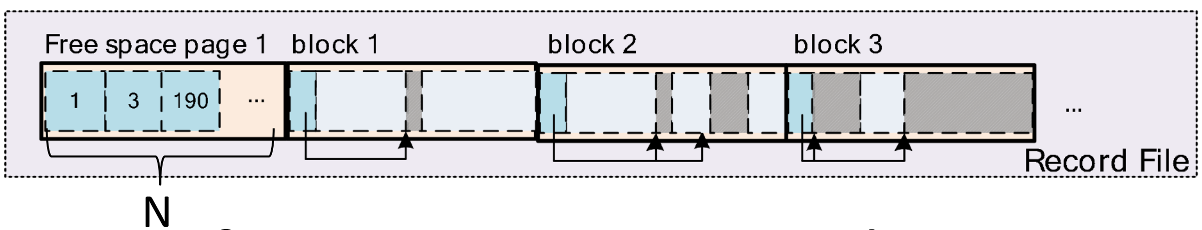
- When the client wants to insert a new record, the record manager needs to find continuous unused bytes for it
- How to manage the free space within a file?
- Chaining the free spaces



- For variable-length records, it may access many blocks to find out a large enough free space

M2: Meta-Pages

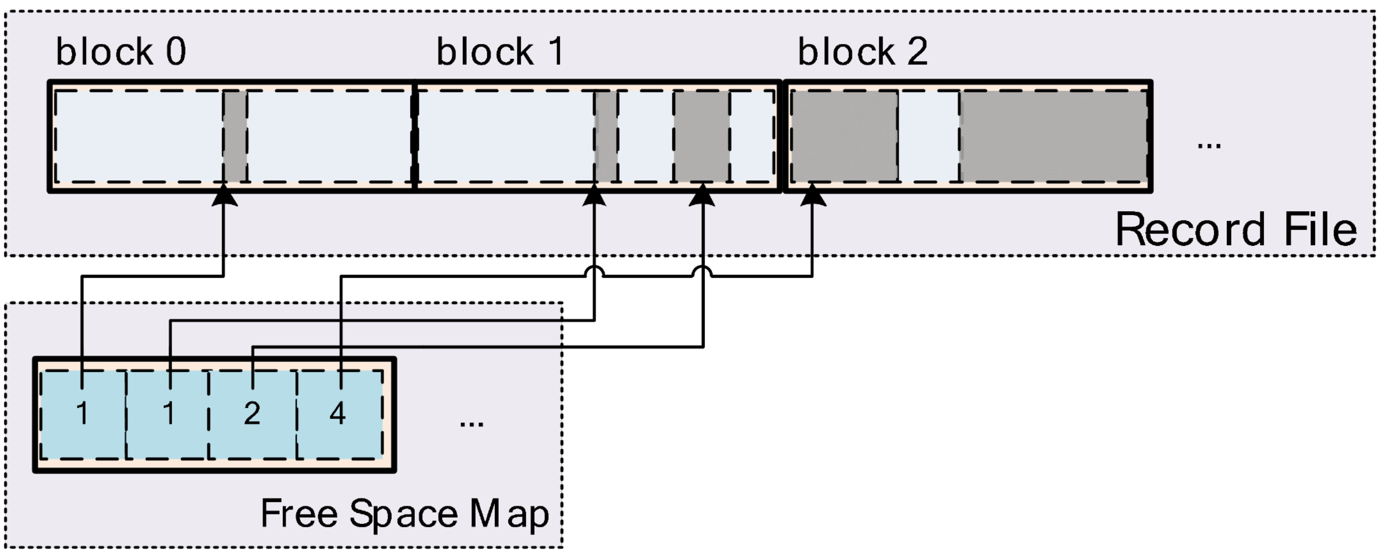
- Using special pages to track the usage of record pages
  - Allocates one free space page for N record pages
  - Free space page uses one byte to track the size of unused space size for each following page



  - Microsoft SQL Server approach

M3: Meta-File

- Using additional file to track the location and size all free spaces
  - PostgreSQL approach



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  - How records are stored?
  - Which blocks to pin
  - Working with the recovery and concurrency manager to ensure tx ACID

Responsibilities of `RecordFile`

- To decide how records are stored in a file
- To decide which block to pin (to save the cost of buffer access)
- To work with the recovery and concurrency manager to ensure tx ACID

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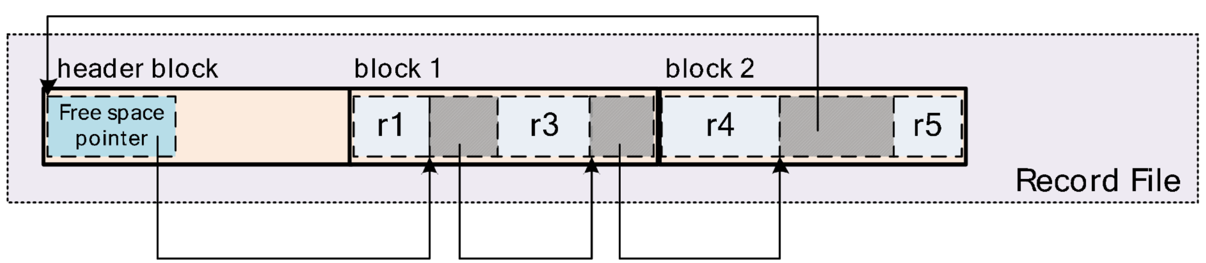
How Records are Stored?

- Choices:
  - Un-spanned record
  - Homogeneous file
  - Row-oriented store
  - Fixed-length field
  - Chained free space: *O(1)* search time
- `RecordPage`: lays out records in a page
- `FileHeaderPage`: header of free-space chain



Using the Table Information

- The VanillaCore record manager needs to know the table information
- The classes `storage.metadata.TableInfo` and `sql.Schema` manage the table information
- The record manager can get this information from metadata manager

TableInfo
+ TableInfo(tblname : String, schema : Schema) + fileName() : String + tableName() : String + schema() : Schema + open(tx : Transaction) : RecordFile

Schema : Serializable
+ Schema() + addField(fldName : String, type : Type) + add(fldName : String, sch : Schema) + addAll(sch : Schema) + fields() : SortedSet<String> + hasField(fldName : String) : boolean + type(fldname : String) : Type + toString() : String + equals(obj : Object) : boolean + hashCode() : int

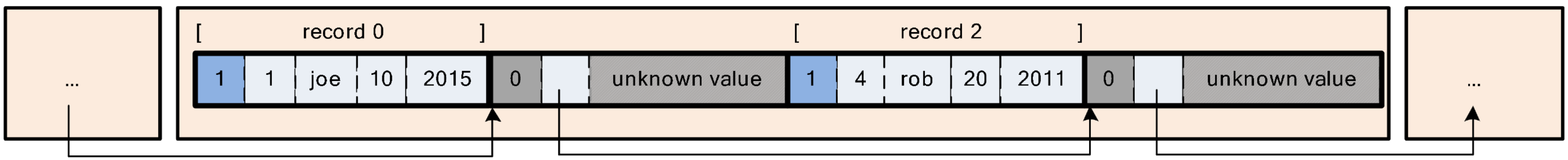
Using the Table Information

- Sample code of constructing table information

```
Schema sch = new Schema();

sch.addField("s-id", Type.INTEGER);
sch.addField("s-name", Type.VARCHAR(20));
sch.addField("major-id", Type.INTEGER);
sch.addField("grad-year", Type.BIGINT);

TableInfo ti = new TableInfo("students", sch);
```

Managing the Records in a Page

- Implements the record page as following layout
  - Minimal slot size: 4+4+8 bytes (flag, pointer to next deleted slot)



- The `RecordPage` manages the records within a page
- The `RecordId` denotes the identifier of each record

`RecordId`

- Identifier of a record
  - `id` is equal to ***slot number*** because of fixed-length implementation

RecordId
+ RecordId(blk : BlockId, id : int) + block() : BlockId + id() : int + equals(obj : Object) : boolean + toString() : String + hashCode() : int

`RecordPage`

- Extends the interface `Record`
- Manages a buffer for the currently opened data block
- Calls the concurrency control manager to ensure the isolation property

RecordPage

RecordPage : Record

+ offsetMap(sch: Schema) : Map<String, Integer>
+ recordSize(sch: Schema) : int
+ slotSize(sch: Schema) : int

+ RecordPage(blk : BlockId, ti : TableInfo , tx : Transaction, doLog : boolean)
+ close()
+ next() : boolean
+ getVal(fldName : String) : Constant
+ setVal(fldName : String, val : Constant)
+ delete(nextDeletedSlot : RecordId)
+ insertIntoNextEmptySlot() : boolean
+ insertIntoDeletedSlot(): RecordId
+ moveToId(id : int)
+ currentId() : int
+ currentBlk() : BlockId

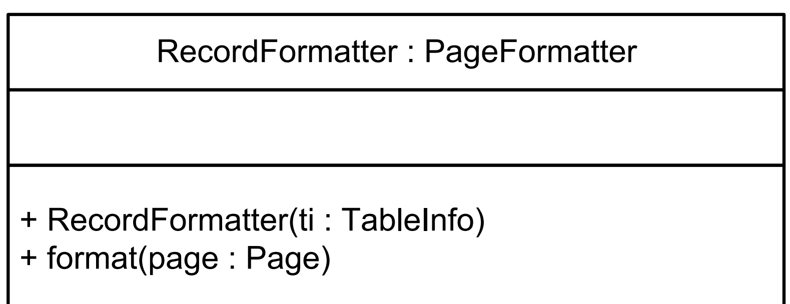
Accessing Records in a Record Page

- Sample code of using a record page

```
Transaction tx = VanillaDb.txMgr().transaction(
            Connection.TRANSACTION_SERIALIZABLE, false);
TableInfo ti = VanillaDb.catalogMgr().getTableInfo(tableName, tx);
String fileName = ti.fileName();
RecordId lastDeletedRid = ...;
BlockId blk = new BlockId(fileName, 235);
RecordPage rp = new RecordPage(blk, ti, tx, true); // pin the buffer

// Part1: read and delete
while (rp.next()) {
      Constant sid = rp.getVal("s-id");
      if (sid.equals(new IntegerConstant(50))) {
            rp.delete(lastDeletedRid);
            lastDeletedRid = new RecordId(rp.currentBlk(), rp.currentId());
      }
}

// Part 2: insert into empty slot if exist
rp.moveToId(-1); // point before the first record
boolean hasFreeSlot = rp.insertIntoNextEmptySlot();
if (hasFreeSlot) {
      rp.setVal("s-id", new IntegerConstant(65));
      ...
}
rp.close(); // unpin the buffer
tx.commit();
```

Formatting Record Page

- A record page has a specific structure
  - Partitioned into slot, with the value of the first integer in each slot as usage flag
- Formatting the record page before it can be used
- The class `RecordFormatter` performs this service, via its method `format`



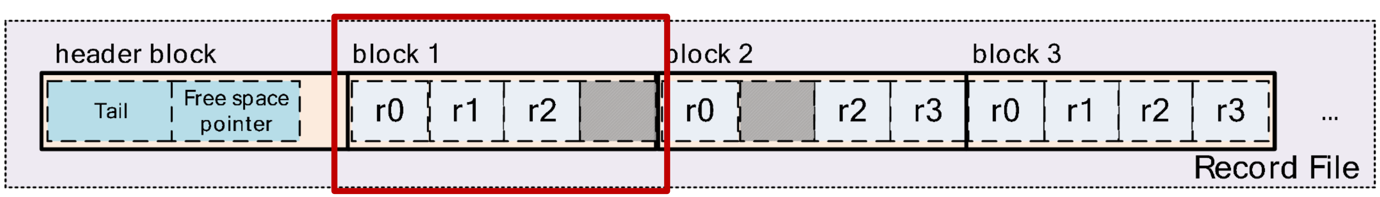
File Header

- The class `FileHeaderPage` manages the header
  - The pointer to the deleted slot chain
  - The tail slot

FileHeaderPage
+ FileHeaderPage(fileName : String, tx : Transaction) + close() + hasDataRecords() : boolean + hasDeletedSlots() : boolean + getLastDeletedSlot() : RecordId + getTailSlot() : RecordId + setLastDeletedSlot(rid : RecordId) + setTailSlot(rid : RecordId)

Managing the Records in a File

- A record file consists of several record pages
  - Data access API is similar to record pages
- Record file manages the file properties
  - File header, file size
  - Appends new block at the end of file
  - Maintains the current position in a file and uses the data manipulation methods of the record page



RecordFile

- Manages a file of records and calls the concurrency manager to ensure isolation property
- Provides methods for iterating through the records and accessing their contents

RecordFile

RecordFile: Record

+ formatFileHeader(fileName : String, tx : Transaction)

+ RecordFile(ti : TableInfo , tx : Transaction, doLog : boolean)
+ close()
+ beforeFirst()
+ next() : boolean
+ getVal(fldName : String) : Constant
+ setVal(fldName : String, val : Constant)
+ delete()
+ insert()
+ moveToRecordId(rid : RecordId)
+ currentRecordId() : RecordId
+ fileSize() : long

Accessing Records in a Record File

- Sample code of using a record file

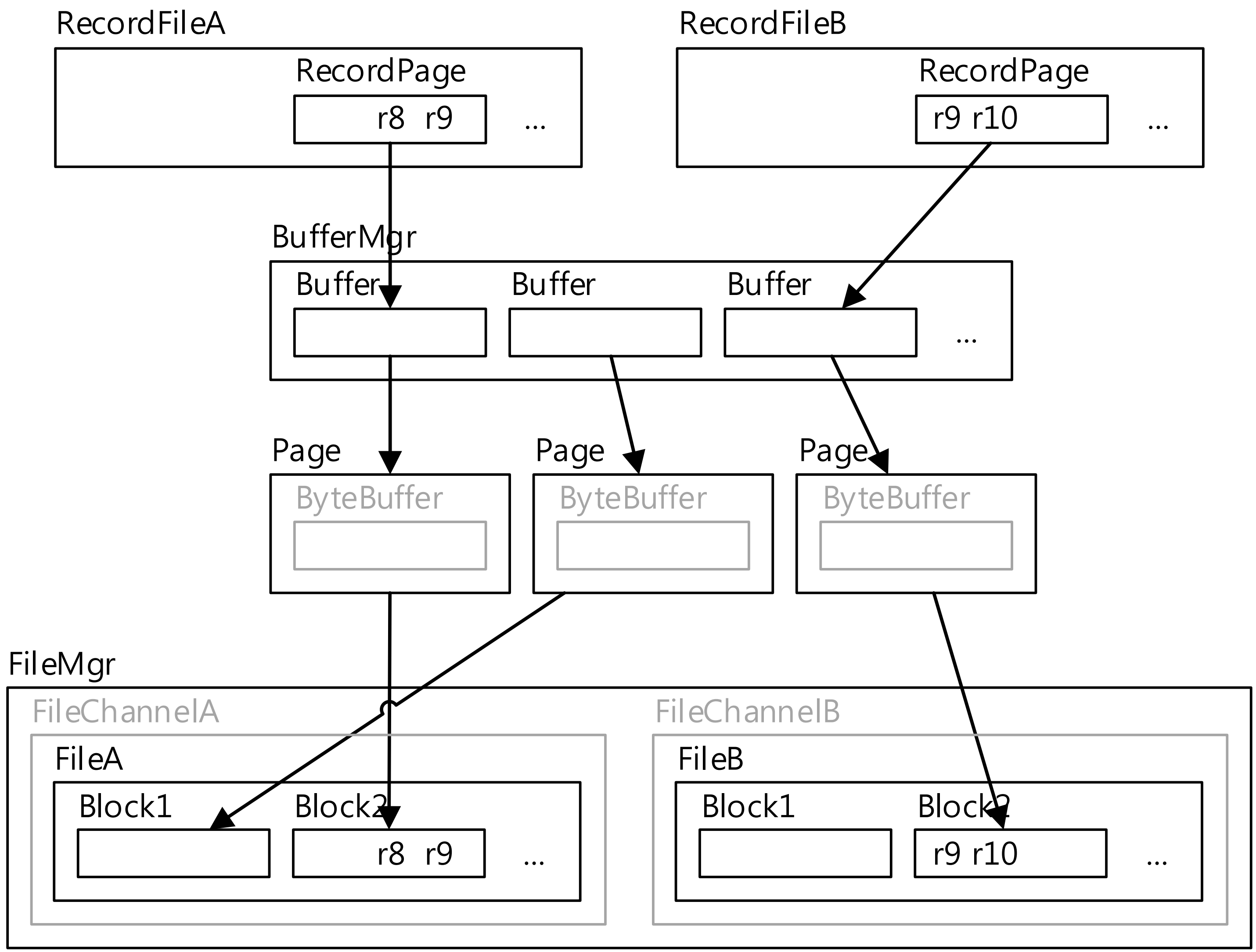
```
Transaction tx = VanillaDb.txMgr().transaction(
           Connection.TRANSACTION_SERIALIZABLE, false);
TableInfo ti = ...;
RecordFile rf = ti.open(tx, true);
rf.beforeFirst();

// Part 1: reads records and delete records
while (rf.next())
     if (rf.getVal("s-id").equals(new IntegerConstant(50)))
          rf.delete();
rf.close();

// Part 2: insert new record
rf = ti.open(tx, true);
for (int id = 0; id < 100; id++) {
     rf.insert();
     rf.setVal("s-id", new IntegerConstant(id));
     rf.setVal("s-name", new VarcharConstant("student" + id));
     rf.setVal("major-id", new IntegerConstant((id % 3 + 1) * 10));
     rf.setVal("grad-year", new BigIntConstant(2016));
}
rf.close();
```

Caution:

When inserting a new record, all the fields should have inserted values.

Otherwise, the user might read some unpredictable value

Recap of Data Access Layers



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Which Block to Pin?

- Each `RecordFile` instance pins only two pages:
  - `RecordPage` corresponding to the current position
  - `FileHeaderPage`
- Unpin upon `close()`
  - This is why a JDBC user should close a `ResultSet` as soon as possible

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Tx Support

- C and I by working with ConcurrencyManager
  - All read/write from/to files and blocks must obtain appropriate locks first via `concurrencyMgr.read/modifyXxx()`
- A and D by working with RecoveryManager
  - All set values are logged via `recoveryMgr.logXxx()`
  - By virtue of WAL implementation in memory-management layer

References

- Database page layout of PostgreSQL. http://www.postgresql.org/docs/8.0/static/storage-page-layout.html
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