# CSE 444: Database Internals

Lecture 4
Data storage and buffer management

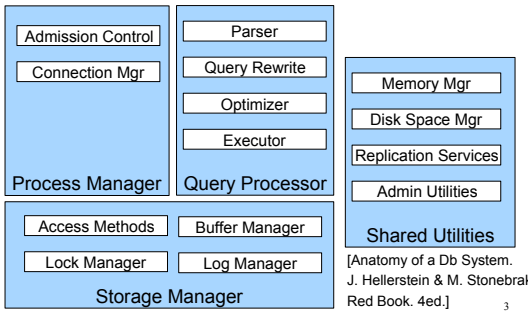


## Important Note

- Lectures show principles
- You need to think through what you will actually implement in SimpleDB!
  - Try to implement the simplest solutions
- If you are confused, tell us!



## DBMS Architecture




[Anatomy of a Db System. J. Hellerstein & M. Stonebraker. Red Book. 4ed.]



## Today: Starting at the Bottom

Consider a relation storing tweets:

```
Tweets(tid, user, time, content)
```

How should we store it on disk?



## Design Exercise

- Design choice: **One OS file for each relation**
  - This does not always have to be the case! (e.g., SQLite uses one file for whole database)
  - DBMSs can also use disk drives directly
- An OS file provides an API of the form
  - Seek to some position (or "skip" over B bytes)
  - Read/Write B bytes



## First Principle: Work with Pages

- Reading/writing to/from disk
  - Seeking takes a long time!
  - Reading sequentially is fast
- To simplify buffer manager, want to cache a collection of same-sized objects
- Solution: Read/write **pages** of data
  - A page should correspond to a disk block

## Continuing our Design

Next key questions:

- How do we organize pages into a file?
- How do we organize data within a page?

First, how could we store some tuples on a page?
Let's first assume all tuples are of the same size

```
Tweets(tid int, user char(10),
       time int, content char(140))
```



## Page Formats

Issues to consider

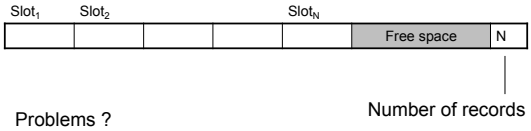
- 1 page = 1 disk block = fixed size (e.g. 8KB)
- Records:
  - Fixed length
  - Variable length
- Record id = RID
  - Typically RID = (PageID, SlotNumber)

Why do we need RID's in a relational DBMS ?
See discussion about indexes next lecture



## Page Format Approach 1

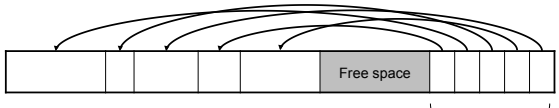
Fixed-length records: packed representation
Divide page into slots. Each slot can hold one tuple
Record ID (RID) for each tuple is (PageID,SlotNb)




Problems ?
How to handle variable-length records?
Need to move records for each deletion, changing RIDs



## Page Format Approach 2




Header contains slot directory
+ Need to keep track of nb of slots
+ Also need to keep track of free space

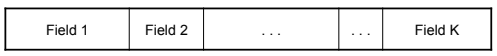
Each slot contains
<record offset, record length>

Can handle variable-length records
Can move tuples inside a page without changing RIDs
RID is (PageID, SlotID) combination



## Record Formats

Fixed-length records → Each field has a fixed length
(i.e., it has the same length in all the records)

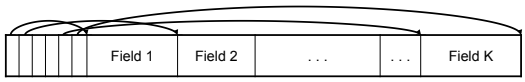



Information about field lengths and types is in the catalog



## Record Formats

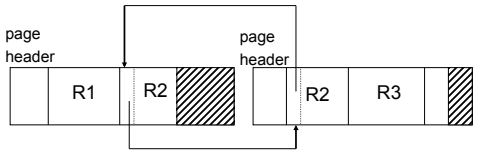
Variable length records




Record header

Remark: NULLS require no space at all (why ?)

## Long Records Across Pages




- When records are very large
- Or even medium size: saves space in blocks
- Commercial RDBMSs avoid this



## LOB

- Large objects
  - Binary large object: BLOB
  - Character large object: CLOB
- Supported by modern database systems
- E.g. images, sounds, texts, etc.
- Storage: attempt to cluster blocks together



## Continuing our Design

Next key questions:

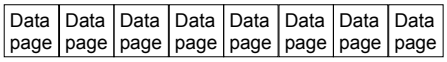
- How do we organize pages into a file?
- How do we organize data within a page?

Now, how should we group pages into files?



## Heap File Implementation 1

A sequence of pages (implementation in SimpleDB)

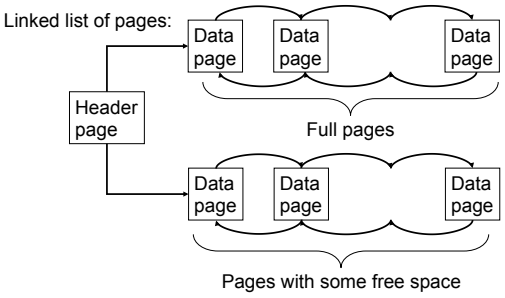



Some pages have space and other pages are full
Add pages at the end when need more space

Works well for small files
But finding free space requires scanning the file



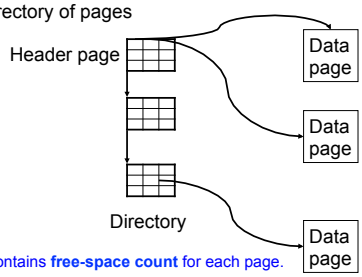
## Heap File Implementation 2






## Heap File Implementation 3

Better: directory of pages



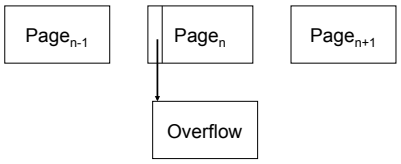

Directory contains **free-space count** for each page.
Faster inserts for variable-length records

## Modifications: Insertion

- File is unsorted (= ***heap file***)
  - add it wherever there is space (easy ☺)
  - add more pages if out of space
- File is sorted
  - Is there space on the right page ?
    - Yes: we are lucky, store it there
  - Is there space in a neighboring page ?
    - Look 1-2 pages to the left/right, shift records
  - If anything else fails, create ***overflow page***



## Overflow Pages




- After a while the file starts being dominated by overflow pages: time to reorganize



## Modifications: Deletions

- Free space in page, shift records
  - Be careful with slots
  - RIDs for remaining tuples must NOT change
- May be able to eliminate an overflow page

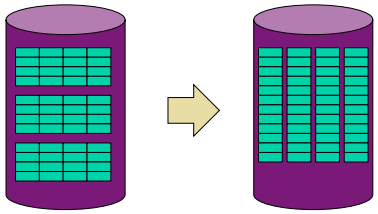


## Modifications: Updates

- If new record is shorter than previous, easy ☺
- If it is longer, need to shift records
  - May have to create overflow pages



## Alternate Storage Manager Design: Column Store



Rows stored contiguously on disk (+ tuples headers)

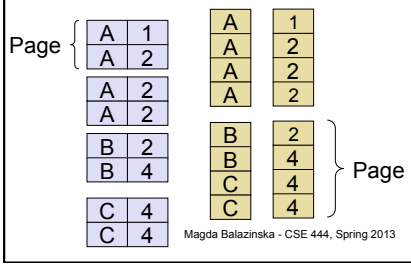
Columns stored contiguously on disk (no headers needed)



## More Detailed Example

Row-based (4 pages)

Column-based (4 pages)




C-Store also avoids large tuple headers

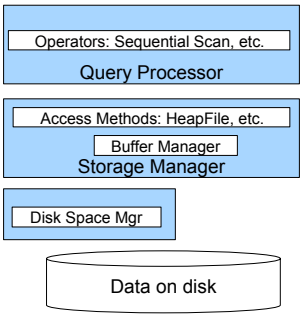
## Continuing our Design

We know how to store tuples on disk in a heap file

How do these files interact with rest of engine?



## How Components Fit Together




- **Operators:** Process data
- **Access methods**: Organize data to support fast access to desired subsets of records
- **Buffer manager**: Caches data in memory. Reads/ writes data to/from disk as needed
- **Disk-space manager**: Allocates space on disk for files/access methods

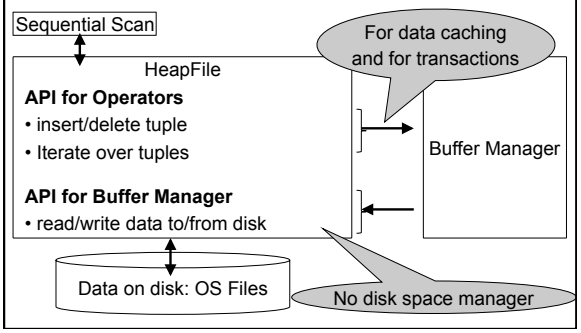


## Access Methods

- Operators view relations as collections of records
- The access methods worry about how to organize these collections



## HeapFile In SimpleDB




## Heap File Access Method API

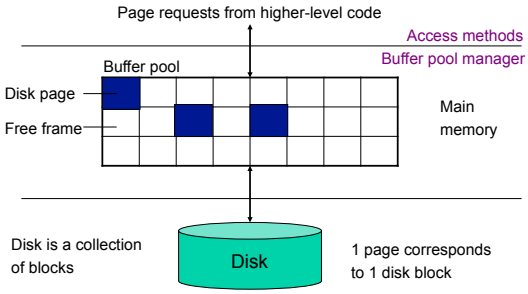
- **Create** or **destroy** a file
- **Insert** a record
- **Delete** a record with a given rid (rid)
  - rid: unique tuple identifier (more later)
- **Get** a record with a given rid
  - Not necessary for sequential scan operator
  - But used with indexes (more next lecture)
- **Scan** all records in the file



## Pushing Updates to Disk

- When inserting a tuple, HeapFile inserts it on a page but does not write the page to disk
- When deleting a tuple, HeapFile deletes tuple form a page but does not write the page to disk
- The buffer manager worries when to write pages to disk (and when to read them from disk)
- When need to add a new page to the file, HeapFile adds page to the file on disk and then gets it again through the buffer manager

## Buffer Manager






## Buffer Manager

- Brings pages in from memory and caches them
- Eviction policies
  - Random page (ok for SimpleDB)
  - Least-recently used
  - The "clock" algorithm (see whiteboard or book)
- Keeps track of which **pages are dirty**
  - A dirty page has changes not reflected on disk
  - Implementation: Each page includes a dirty bit



## Conclusion

- Row-store storage managers are most commonly used today
- They offer high-performance for transactions
- But column-stores win for analytical workloads
- They are gaining traction in that area

- Final discussion: OS vs DBMS
  - OS files vs DBMS files
  - OS buffer manager vs DBMS buffer manager