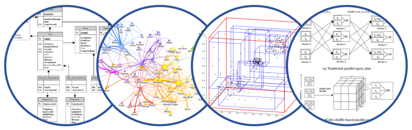

# Database System Internals

## Data Storage and (more) Buffer Management

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1

## Announcements

- Room temperature being looked into
- Lab 1 part 1 is due on tonight at 11pm
  - Don't worry about passing exact tests and implementing everything as completely as possible for intermediate stage
  - We are not grading according to tests-passed for part 1, just that the functions asked for are complete.
- Homework 1:
  - New option to submit by Gradescope pdf, or paper copy
  - We will scan your paper copies into gradescope.



2

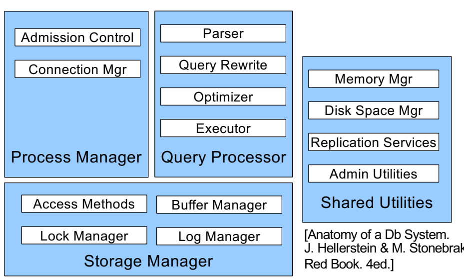
## Important Note

- Lectures show principles
- Homeworks + Quizzes test the 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!
  - Thursday section this week will be extra lab help, Q/A office hours style
- SimpleDB not designed to be bullet-proof software



3

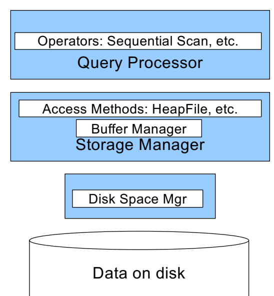
## DBMS Architecture




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



4






5

## Today: Starting at the Bottom

Consider a relation storing tweets:

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

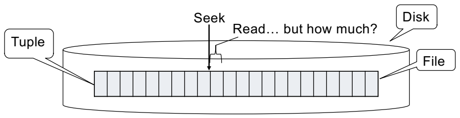
How should we store it on disk?



6

## Design Exercise

- One 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

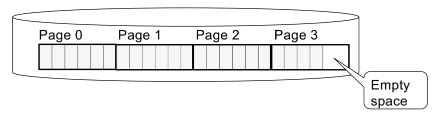





7

## First Principle: Work with Pages

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






8

## Continuing our Design

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))



9

## Page Formats

Issues to consider
- 1 page = 1 disk block = fixed size (e.g. 8KB)
- Records:
  - Fixed length
  - Variable length
- **Record id = RID**
  - Like a pointer to a tuple
  - Typically RID = (PageID, SlotNumber)

Why do we need RID's in a relational DBMS ?

See future discussion on indexes and transactions



10

## Page Formats

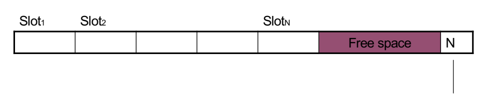
- Think how you would store tuples on a page
  - Fixed length tuples
  - Variable length tuples
- Compare your solution with your neighbor's



11

## 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)




How do we insert a new record?

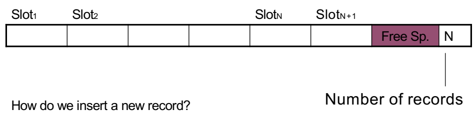
Number of records



12

## 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)




How do we insert a new record?



13

## Page Format Approach 1

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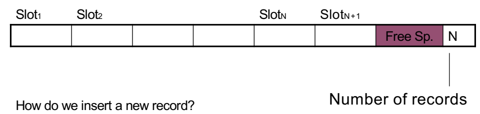


How do we insert a new record?

How do we delete a record?



14

## Page Format Approach 1

Fixed-length records: packed representation
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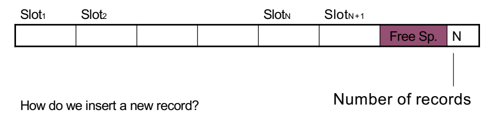



How do we insert a new record?

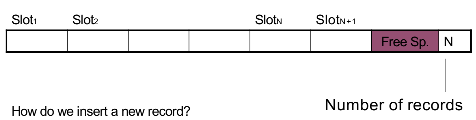
How do we delete a record? What is the problem?



15

## 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)




How do we insert a new record?

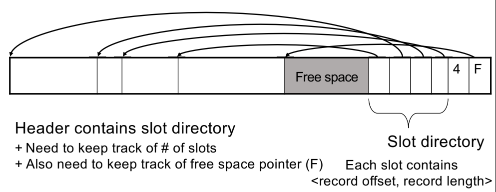
How do we delete a record? Cannot move records! (Why?)

How do we handle variable-length records?



16

## Page Format Approach 2




Header contains slot directory
+ Need to keep track of # of slots
+ Also need to keep track of free space pointer (F)

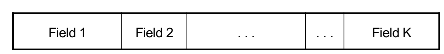
Can handle variable-length records
Can move tuples inside a page without changing RIDs
RID is (PageID, SlotID) combination



17

## Record Formats

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



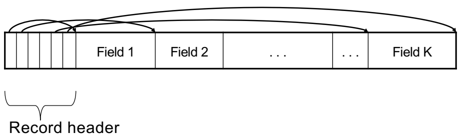

Information about field lengths and types is in the catalog



18

## Record Formats

Variable length records




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



19

## 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



21

## Continuing our Design

Our key questions:

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

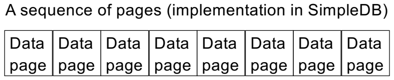
Now, how should we group pages into files?



22

## 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

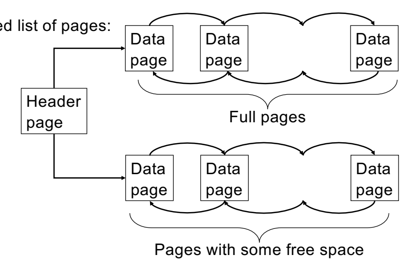
But finding free space requires scanning the file…



23

## Heap File Implementation 2

Linked list of pages:

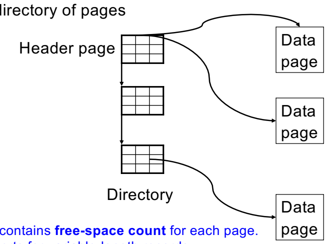





24

## Heap File Implementation 3

Better: directory of pages




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



25

## Modifications: Insert Tuple

- 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***

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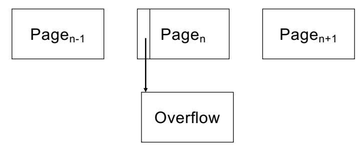
26

## Overflow Pages




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

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27

## Modifications: Deletions

- Free space by shifting records within page
  - Be careful with slots
  - RIDs for remaining tuples must NOT change
- May be able to eliminate an overflow page

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28

## Modifications: Updates

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

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29

## Continuing our Design

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

How do these files interact with rest of engine?

- Let's look back at lecture 3

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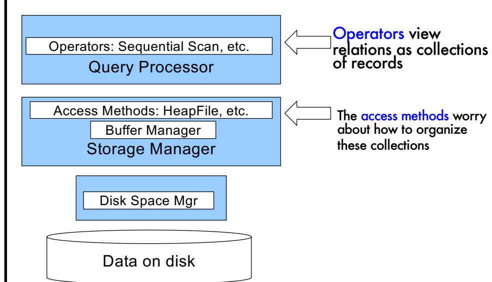
30

## How Components Fit Together

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31

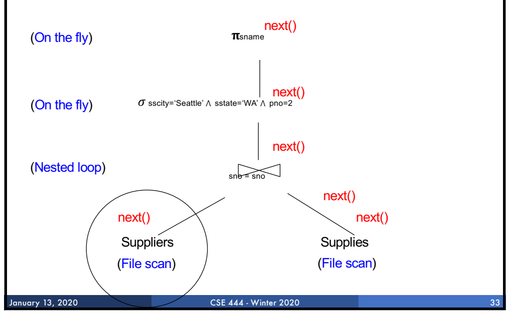
## Heap File Access Method API

- **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



32

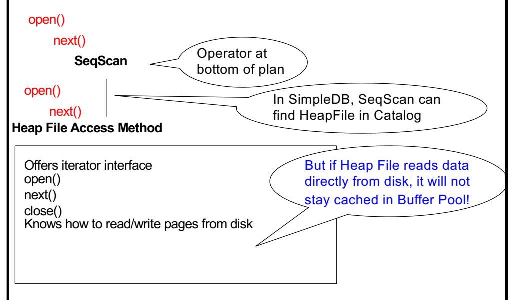
## Query Execution






33

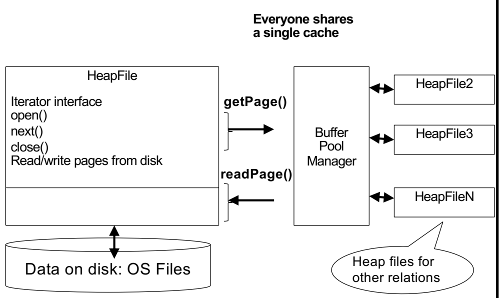
## Query Execution In SimpleDB






34

## Query Execution In SimpleDB






35

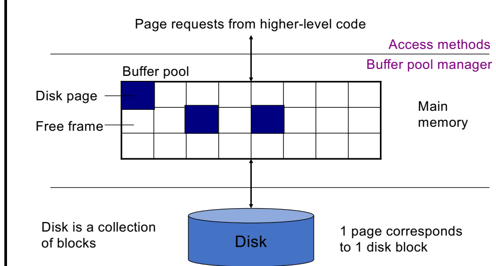
## Buffer Manager

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



36

## Buffer Manager






37

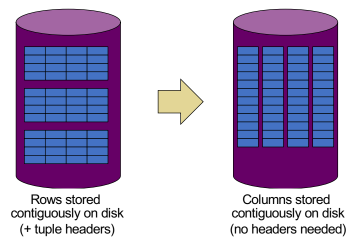
## Pushing Updates to Disk

- 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 from 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 new page to file, HeapFile adds page to file on disk and then reads it through buffer manager



38

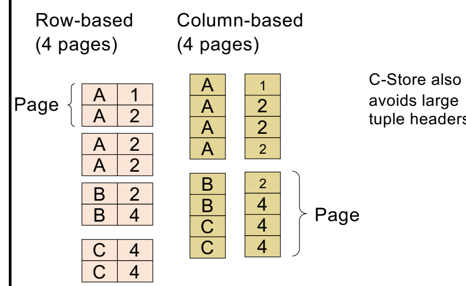
## Alternate Design: Column Store






39

## Column Store Illustration






40

## Column Store Example

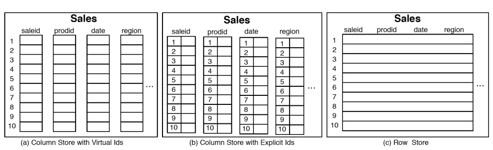



**Figure 1.1:** Physical layout of column-oriented vs row-oriented databases.

The Design and Implementation of Modern Column-Oriented Database Systems Daniel Abadi, Peter Boncz, Stavros Harizopoulos, Stratos Idreos, Samuel Madden. Foundations and Trends® in Databases (Vol 5, Issue 3, 2012, pp 197-280)



41

## Conclusion

- Row-store storage managers are most commonly used today for OLTP systems
- They offer high-performance for transactions
- But column-stores win for analytical workloads
- They are widely used in OLAP
- [Optional] Final discussion: OS vs DBMS
  - OS files vs DBMS files
  - OS buffer manager vs DBMS buffer manager



42