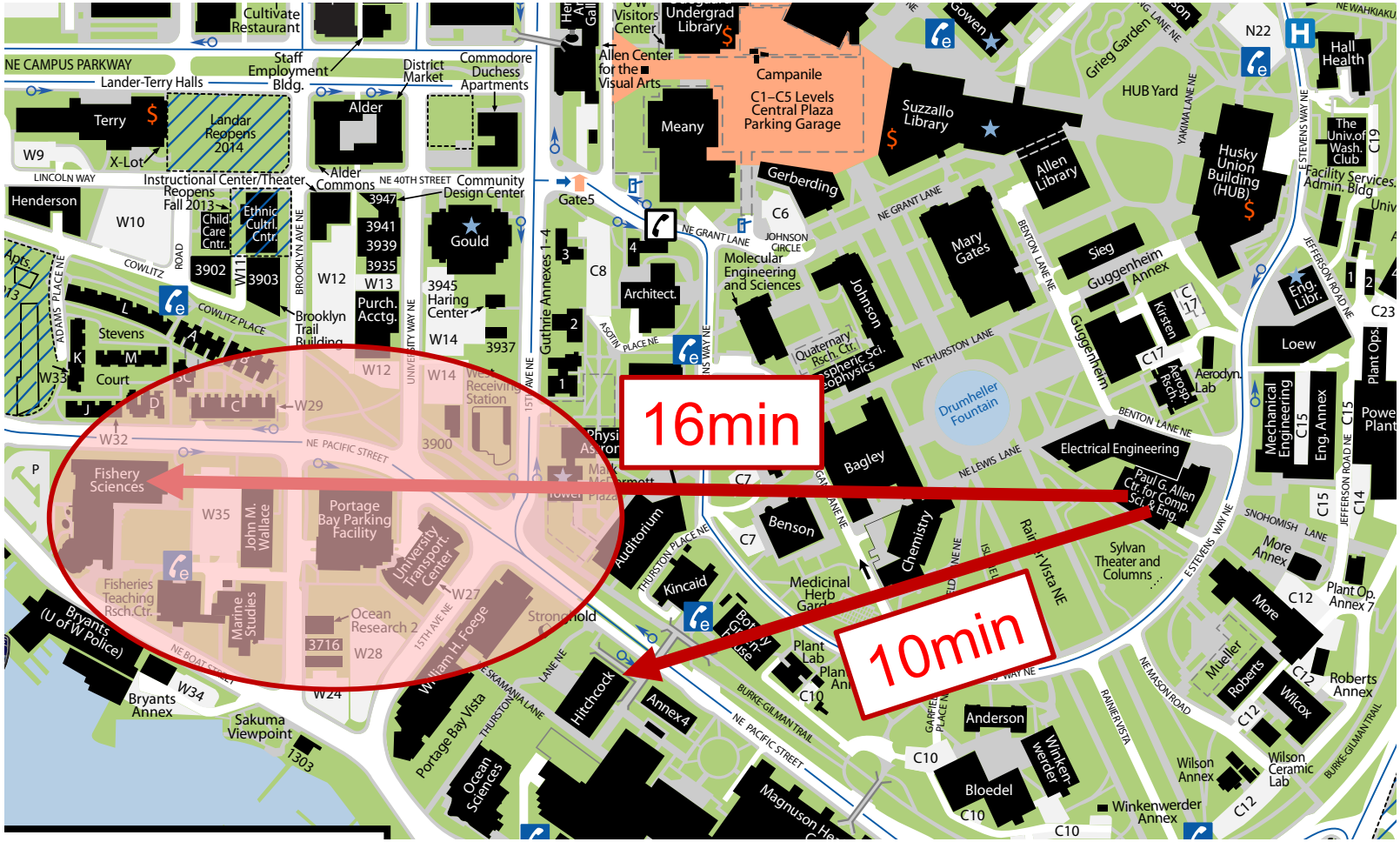
CSE 444: Database Internals

Lecture 4

Data storage and (more) buffer management

About Course Location Change



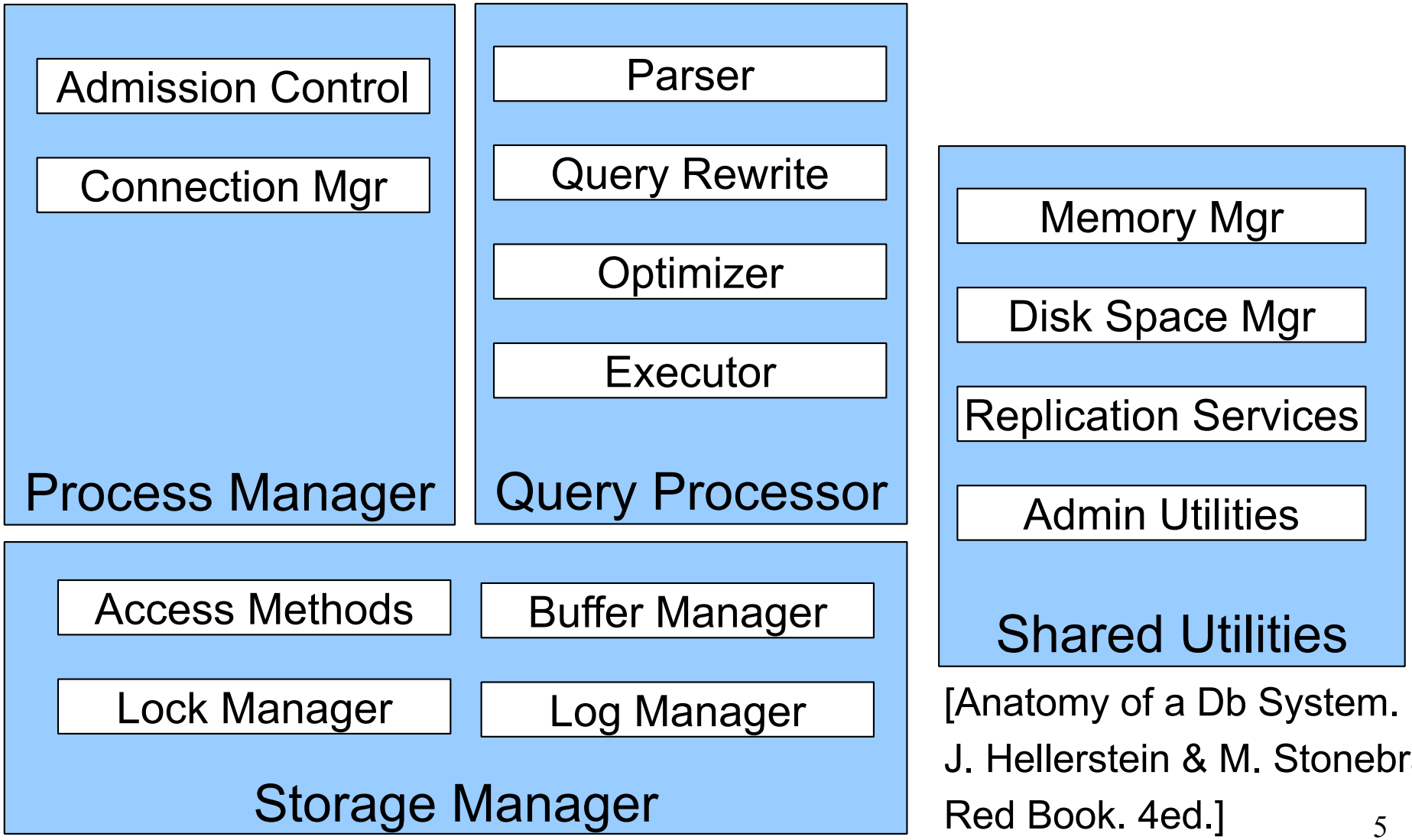
Homework Logistics

- Homework instructions are in a pdf file
- Two ways to submit:
  - Create "homeworks/hw1/" dir in gitlab. Put a single pdf or word file in that directory. Include your name. git add, commit, and push before the deadline.
  - Submit a hard copy in class or during office hours.
- Deadlines: HW1 on Friday and Lab 1 next week

Important Note

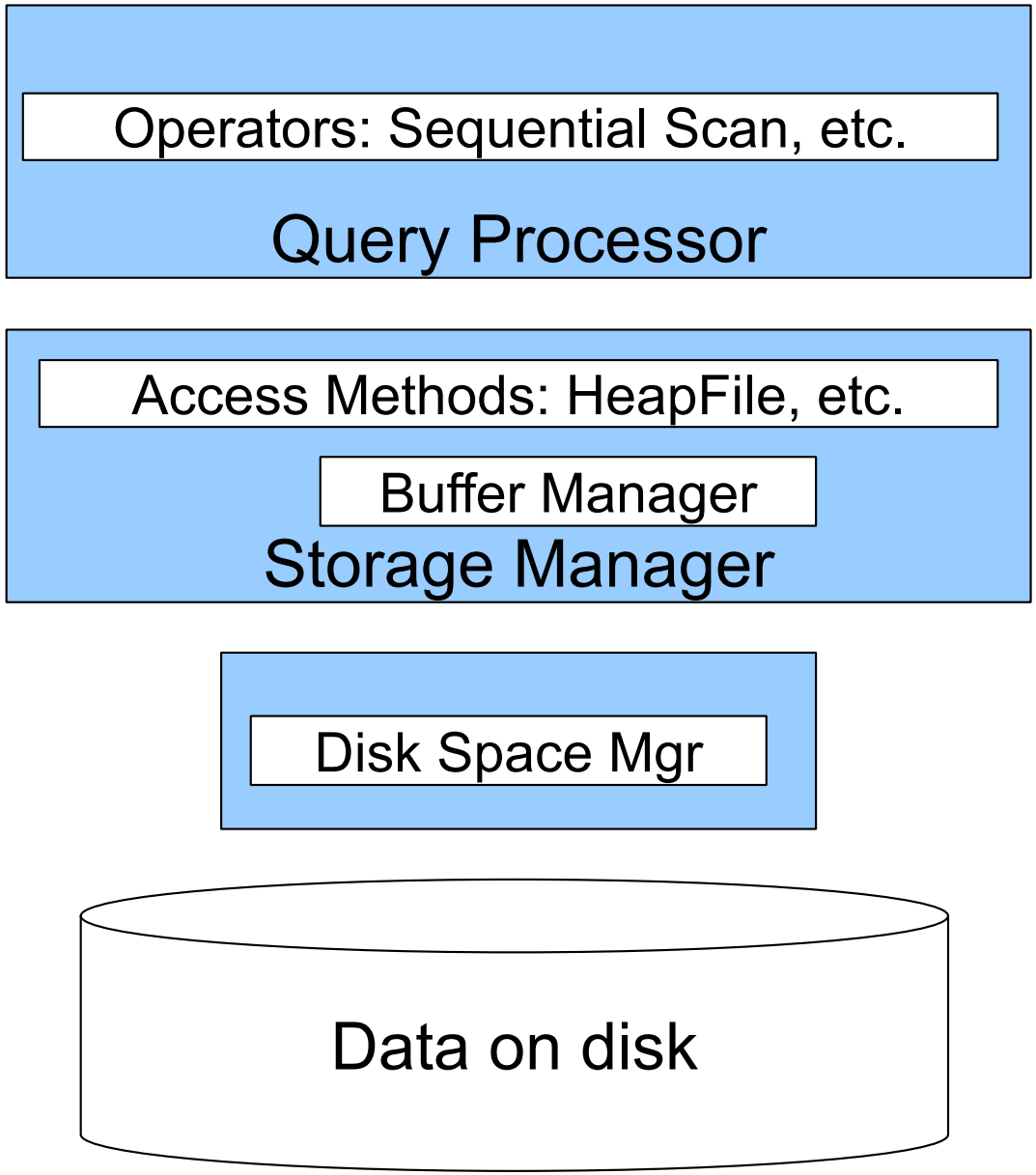
- Lectures show principles
- You need to think through what you will actually implement in SimpleDB!
  - Try to implement the simplest solutions
- If you are confused, tell us!
  - Tomorrow: Office hours instead of section

DBMS Architecture



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

DBMS Architecture



Today: Starting at the Bottom

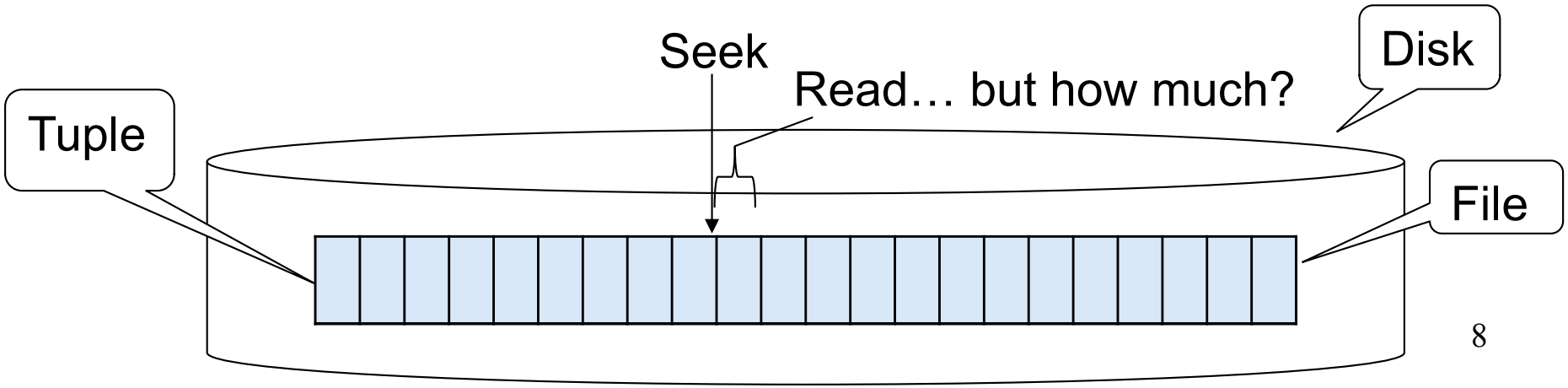
Consider a relation storing tweets:

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

How should we store it on disk?

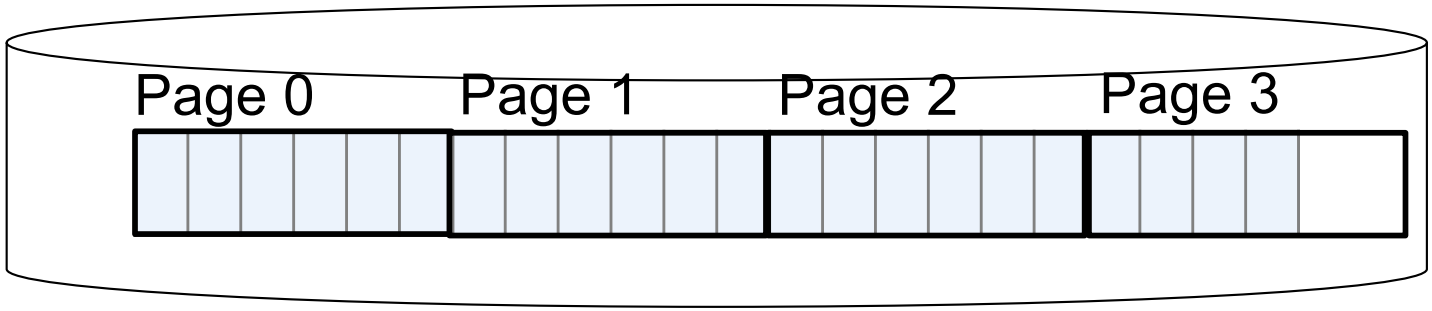
Design Exercise

- 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



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



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))

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 future discussion on indexes and transactions

Design Exercise

- Think how you would store tuples on a page
  - Fixed length tuples
  - Variable length tuples

- Compare your solution with your neighbor's

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)

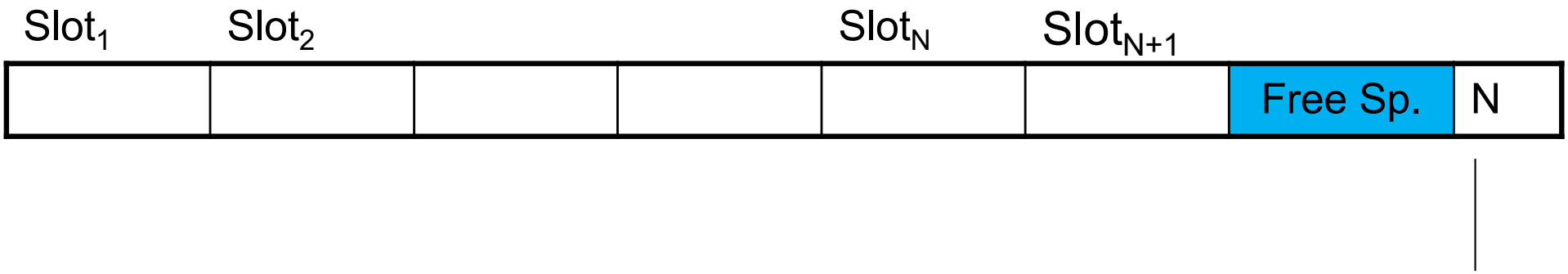
How do we insert a new record?

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)



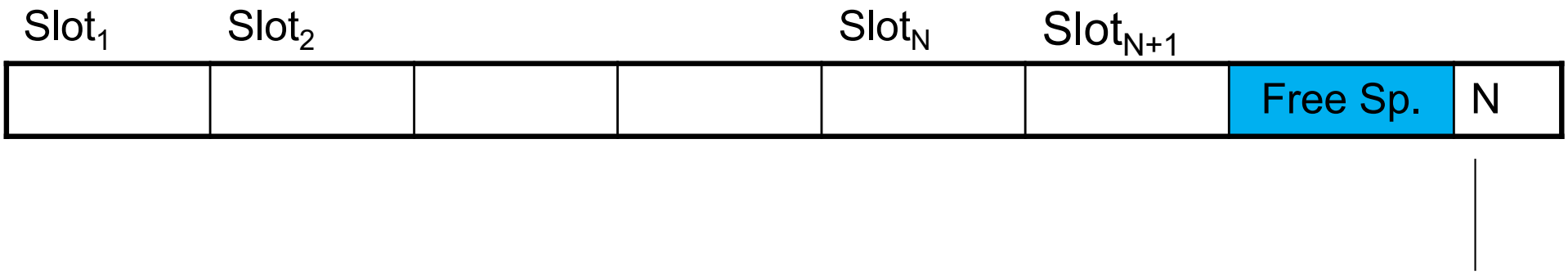
How do we insert a new record?

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?

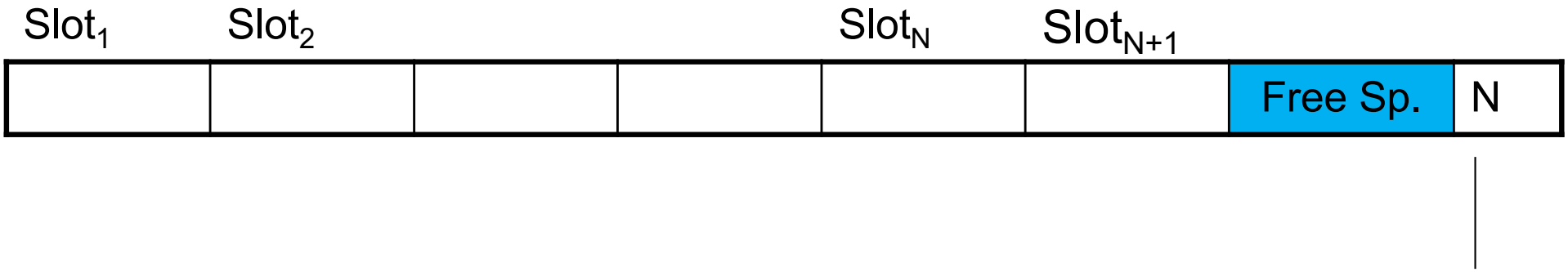
How do we delete a record?

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?

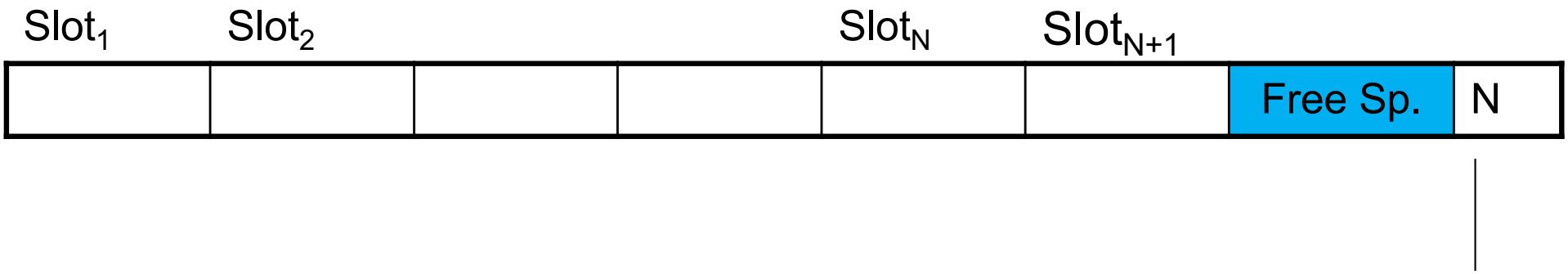
How do we delete a record? What is the problem?

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)

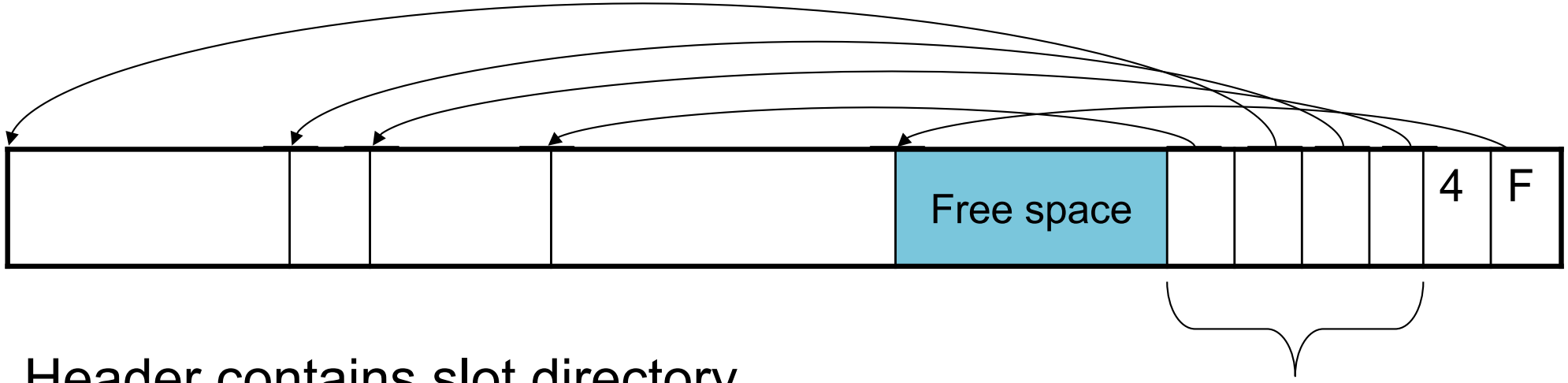


How do we insert a new record?

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

How do we handle variable-length records?

Page Format Approach 2



Header contains slot directory

+ Need to keep track of nb of slots

+ Also need to keep track of free space (F)

Slot directory

Each slot contains

<record offset, record length>

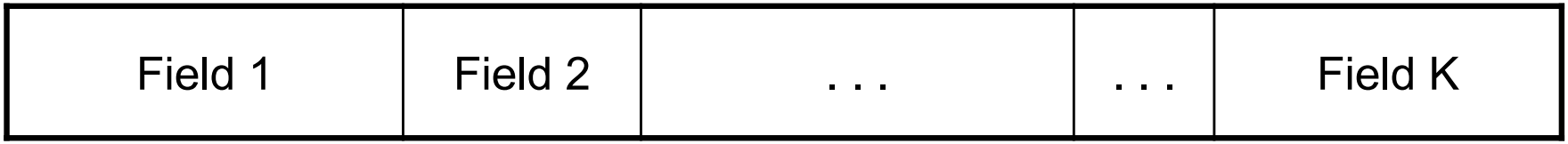
Can handle variable-length records

Can move tuples inside a page without changing RIDs

RID is (PageID, SlotID) combination

Record Formats

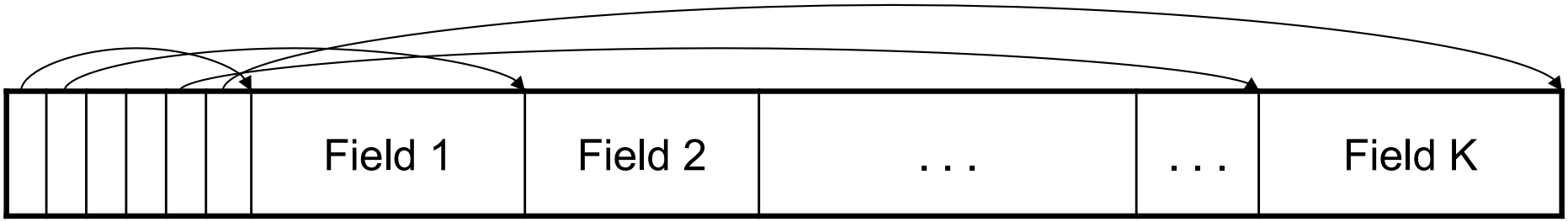
Fixed-length records => Each field has a fixed length
(i.e., it has the same length in all the records)



Information about field lengths and types is in the catalog

Record Formats

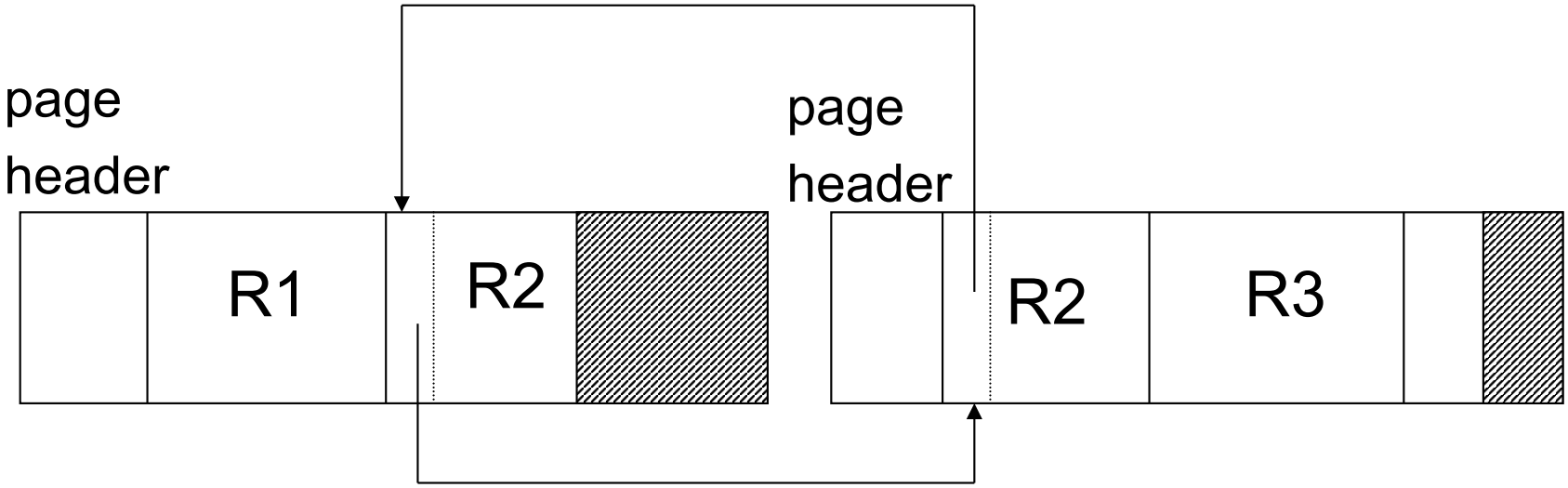
Variable length records



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

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?

Heap File Implementation 1

A sequence of pages (implementation in SimpleDB)

Data page	Data page	Data page	Data page	Data page	Data page	Data page	Data page

Some pages have space and other pages are full

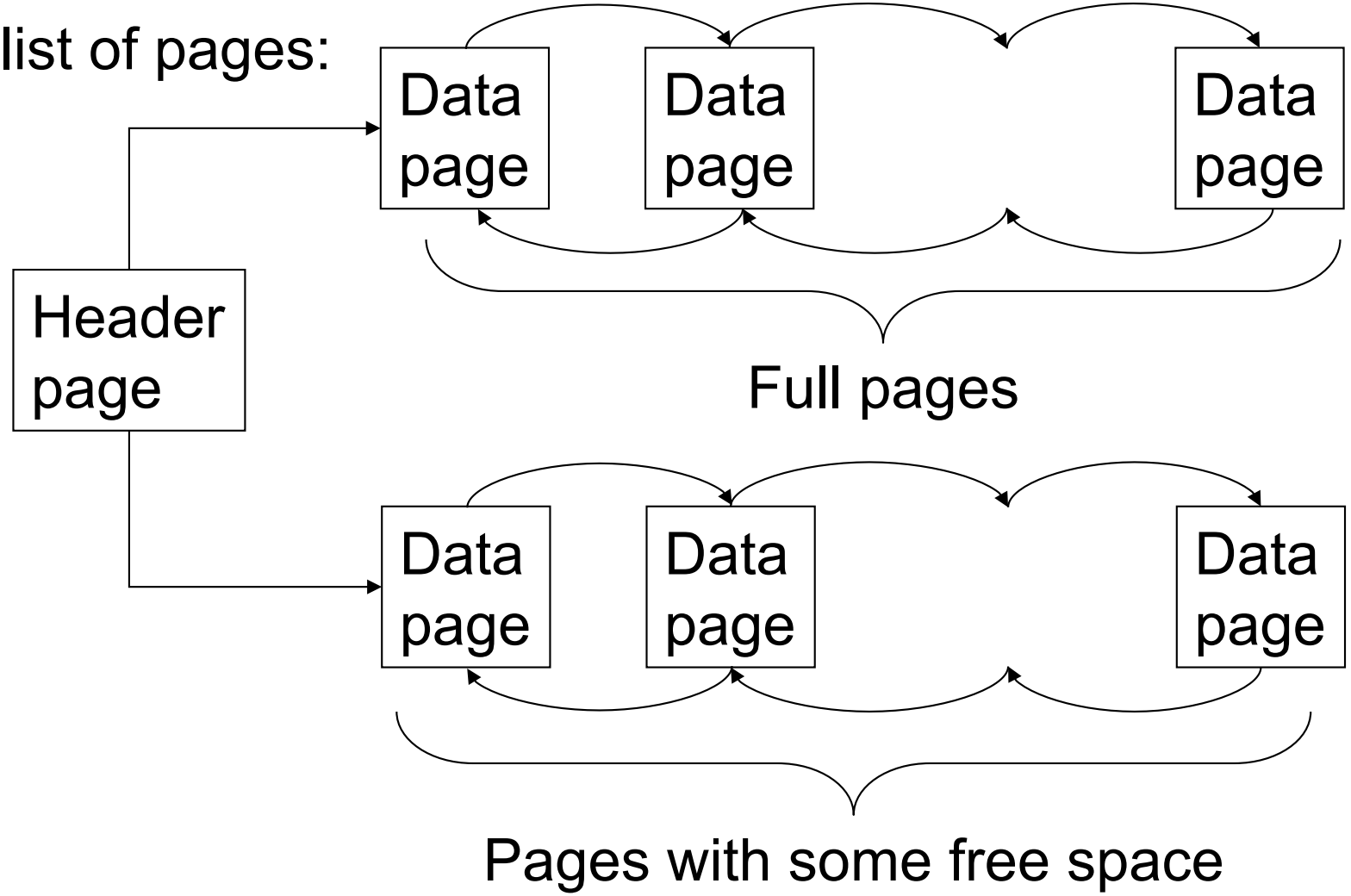
Add pages at the end when need more space

Works well for small files

But finding free space requires scanning the file…

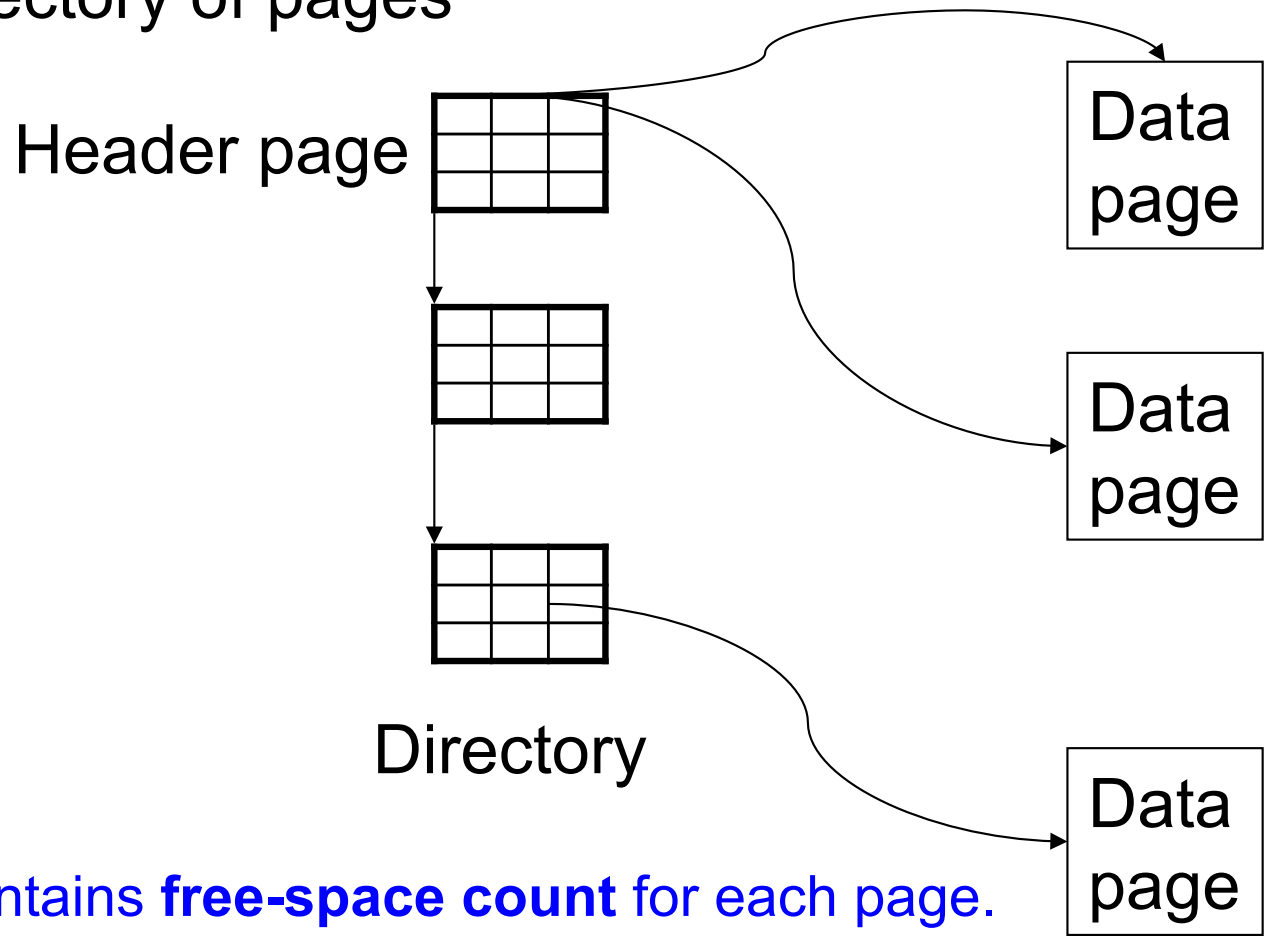
Heap File Implementation 2

Linked list of pages:



Heap File Implementation 3

Better: directory of pages



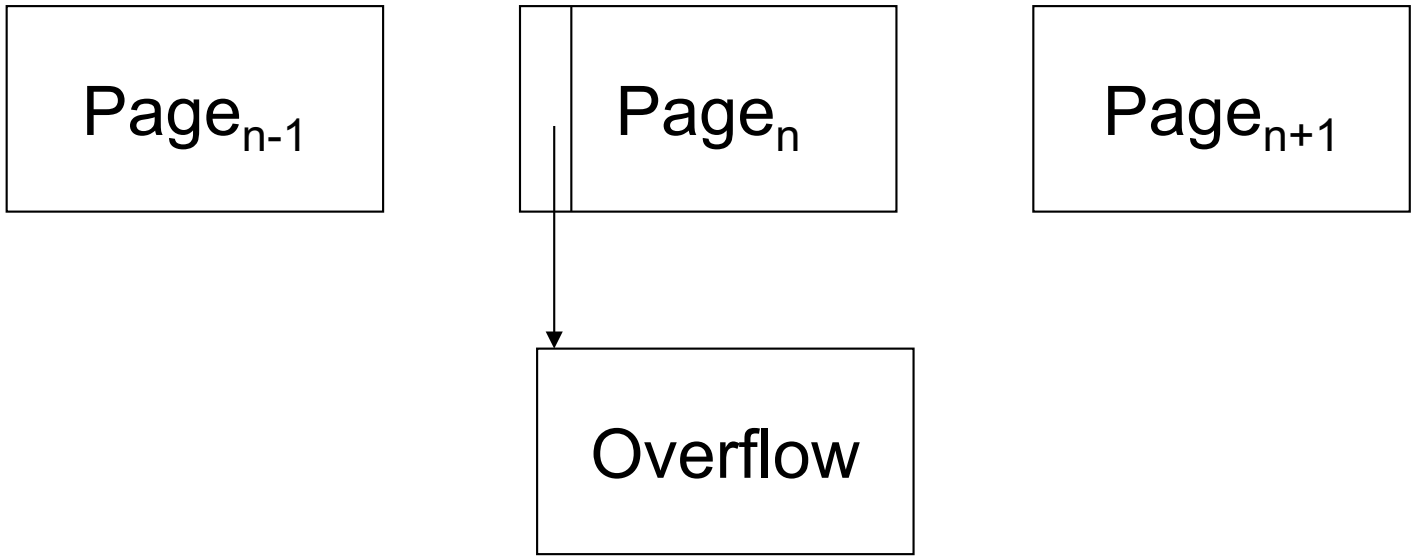
Directory contains **free-space count** for each page.

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 by shifting records within page
  - 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

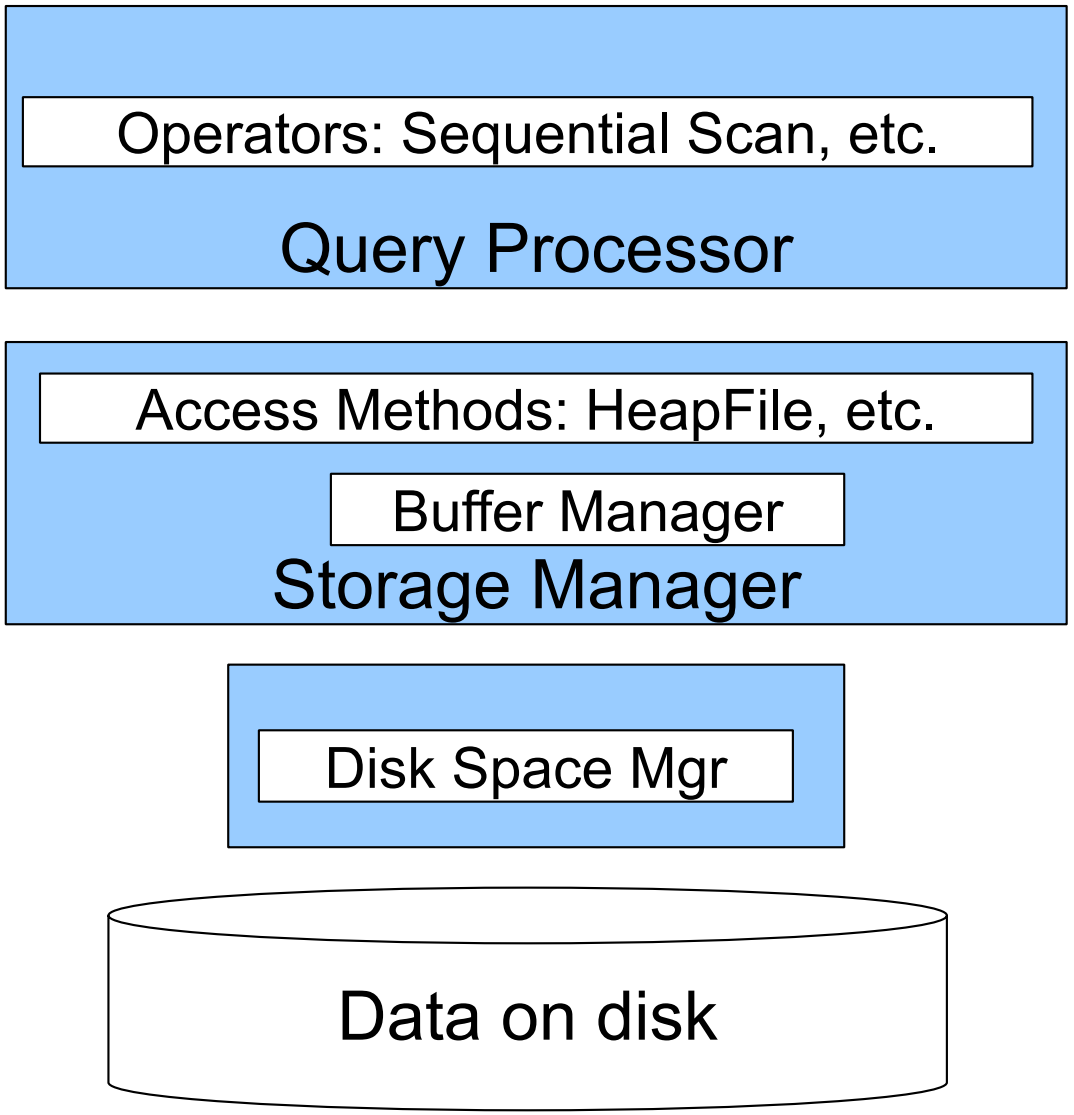
Continuing our Design

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

How Components Fit Together



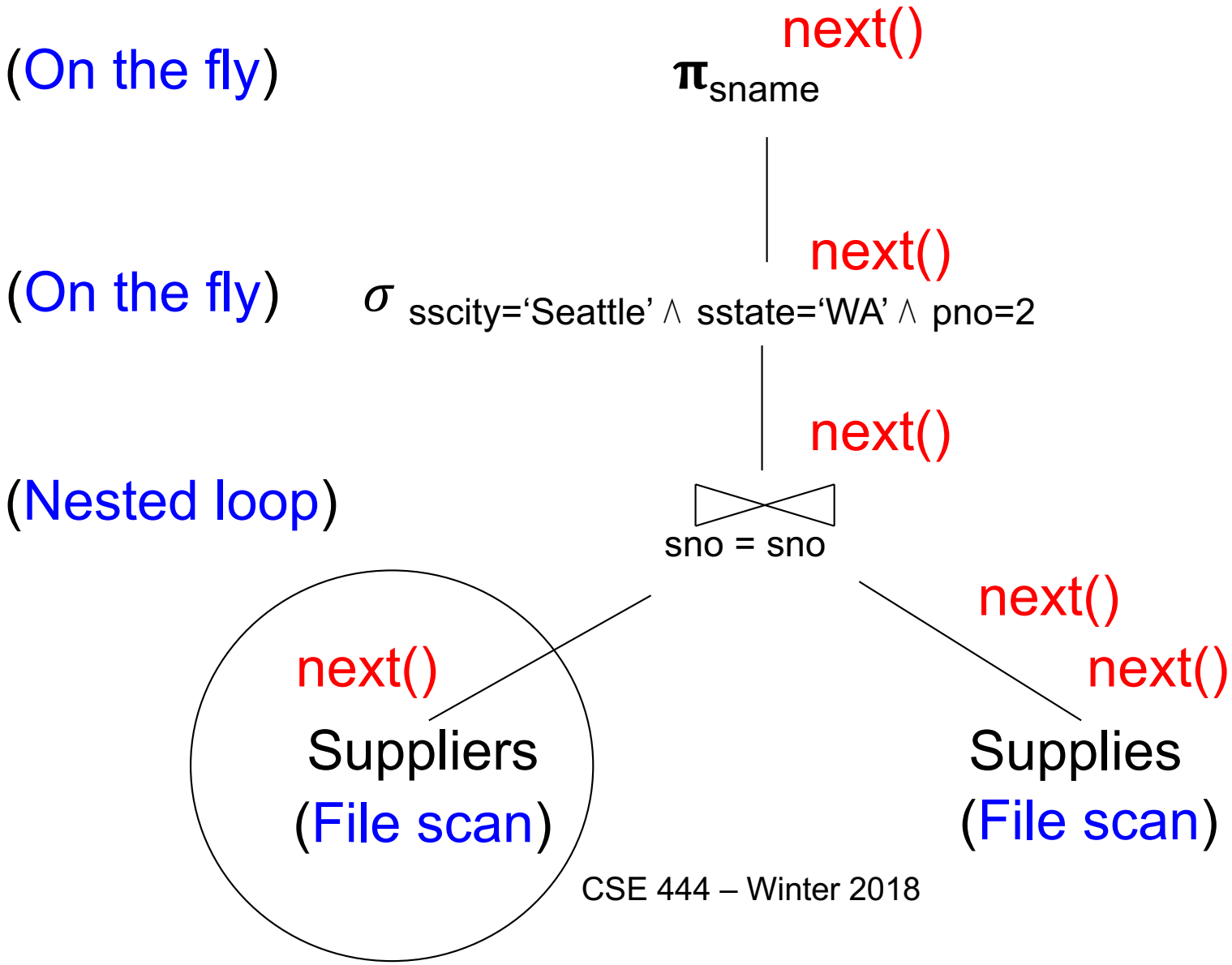
Operators view relations as collections of records

The access methods worry about how to organize these collections

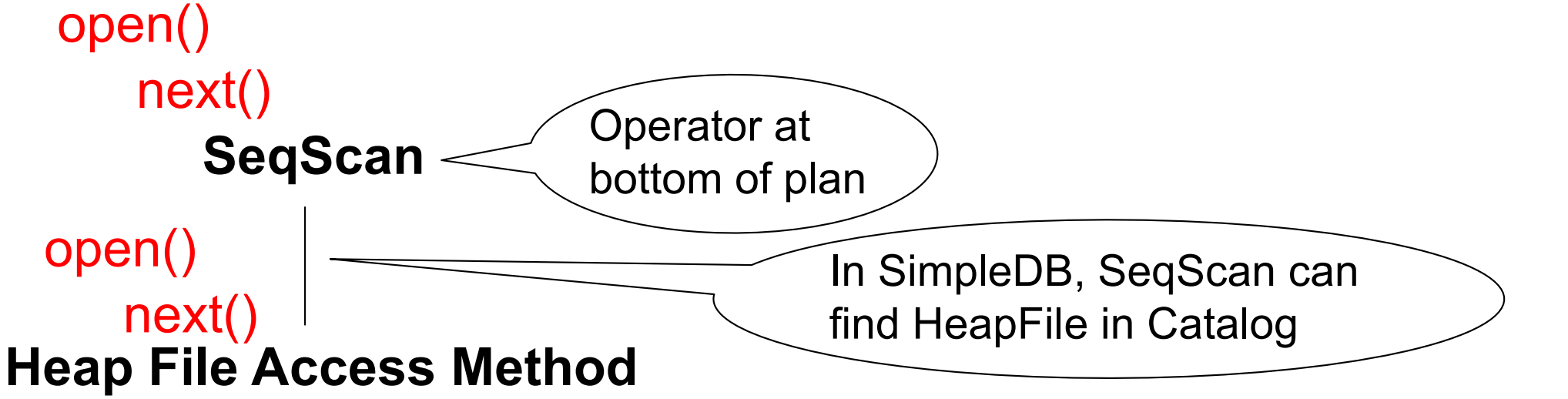
Heap File Access Method API

- **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

Query Execution
How it all Fits Together



Query Execution In SimpleDB



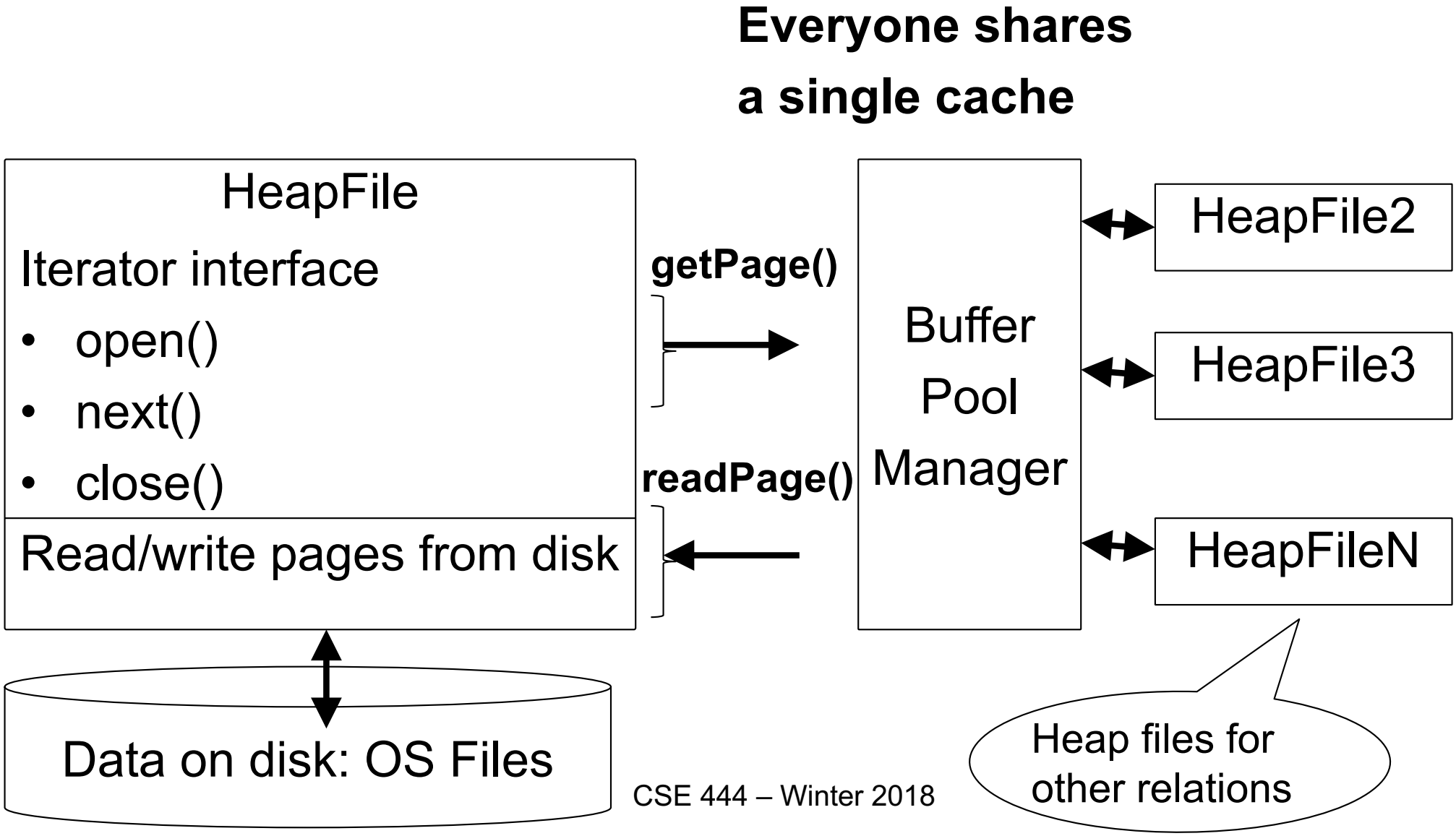
Offers iterator interface

- open()
- next()
- close()

Knows how to read/write pages from disk

But if Heap File reads data directly from disk, it will not stay cached in Buffer Pool!

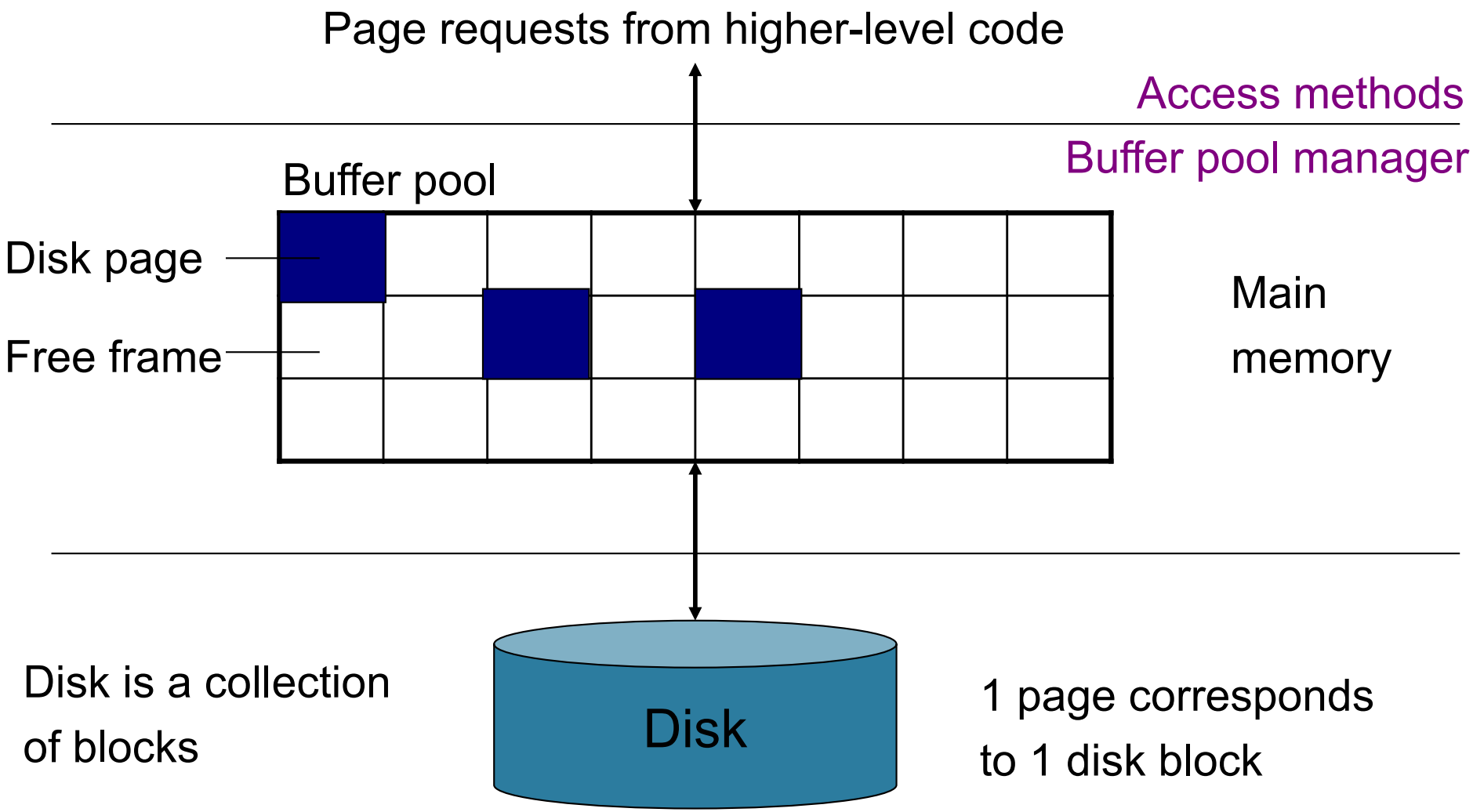
Query Execution In SimpleDB



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

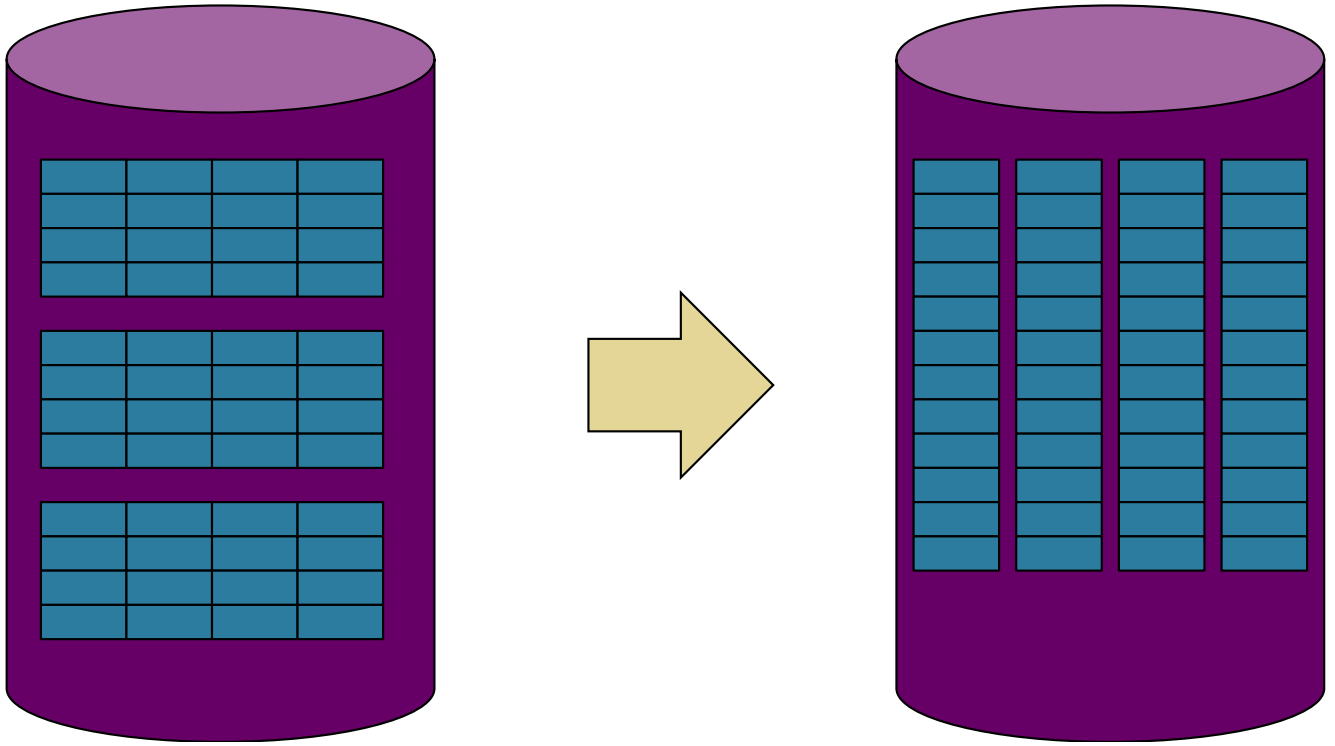
Buffer Manager



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

Alternate Storage Manager Design: Column Store



Rows stored contiguously on disk (+ tuple headers)

Columns stored contiguously on disk (no headers needed)

Column Store Illustration

Row-based (4 pages)

Page

A	1
A	2

A	2
A	2

B	2
B	4

C	4
C	4

Column-based (4 pages)

A	1
A	2
A	2
A	2

B	2
B	4
C	4
C	4

Page

C-Store also avoids large tuple headers

Column Store Example

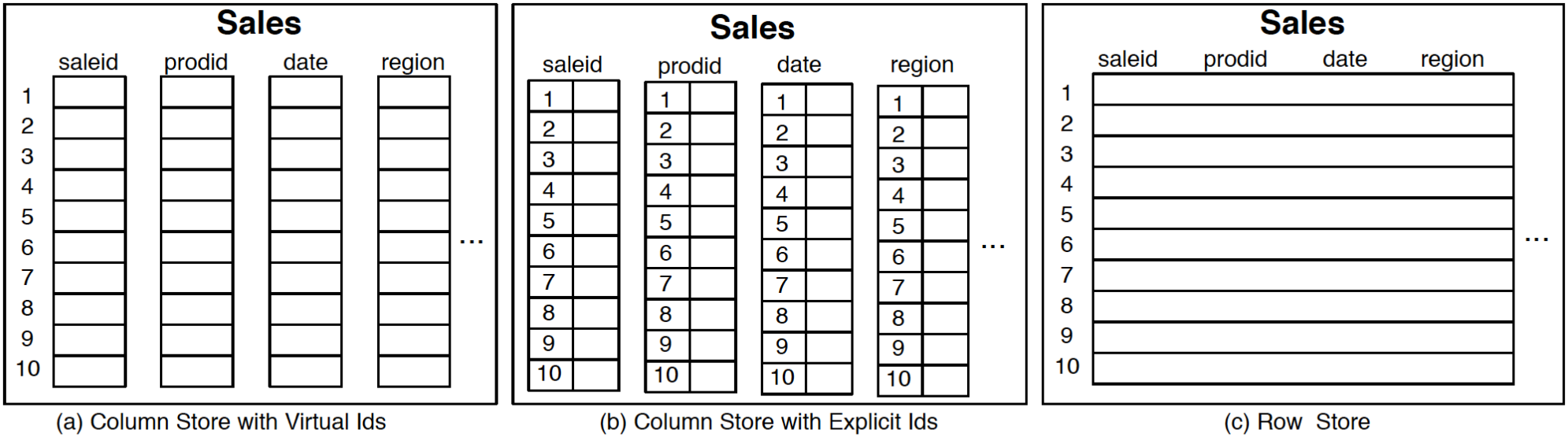


Figure 1.1: Physical layout of column-oriented vs row-oriented databases.

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)

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