CompSci 516
Database Systems

Lecture 8
Normalization
and
Storage

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Announcements

- HW1 Deadlines!
  - Today: parser and Q1-Q3 (last late day!)
  - Q4: next Tuesday 09/24
  - Q5 (RA questions posted on Sakai): next to next Tuesday 10/01
    - Check Piazza for submission instructions

- 2 late days with penalty apply for individual deadlines
  - It is important to start HWs from day-1!

Today's topics

- Finish Normalization & BCNF
  – We will do 4NF later

- New topic: Database Internals

Acknowledgement:
The following slides have been created adapting the instructor material of the [RG] book provided by the authors Dr. Ramakrishnan and Dr. Gehrke

Recap: Functional Dependencies (FDs)

A	B	C	D
a1	b1	c1	d1
a1	b1	c1	d2
a1	b2	c2	d1
a2	b1	c3	d1

$AB \rightarrow C$

$ABD \rightarrow C$

$AB \rightarrow A$ (trivial)

But not

$AB \rightarrow D$

$A \rightarrow D$

$A \rightarrow C$

Normal Forms

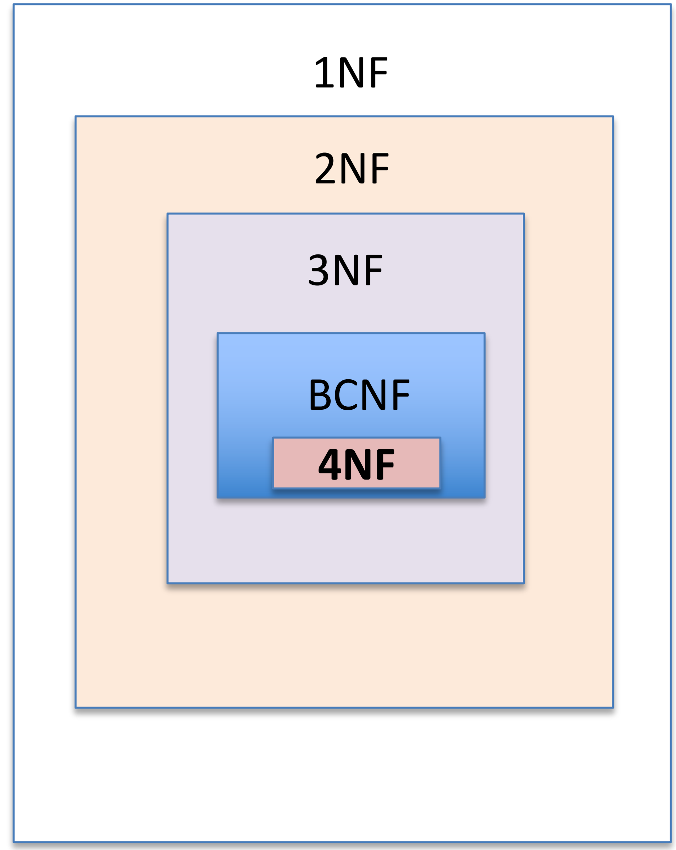
R is in 4NF

⇒ R is in BCNF

⇒ R is in 3NF

⇒ R is in 2NF (a historical one)

⇒ R is in 1NF (every field has atomic values)



Only BCNF and 4NF are covered in the class

Boyce-Codd Normal Form (BCNF)

- Relation R with FDs F is in BCNF
- if, for all $X \rightarrow A$ in F
  - $A \in X$ (called a trivial FD), or
  - X contains a key for R
    - i.e. X is a superkey

No dependencies other than from superkeys can exist!

BCNF decomposition algorithm

1. Find a BCNF violation
   - That is, a non-trivial FD $X \rightarrow Y$ in R where X is not a super key of R
2. Decompose R into R_1 and R_2, where
   - R_1 has attributes $X \cup Y$
   - R_2 has attributes $X \cup Z$, where Z contains all attributes of R that are in neither X nor Y
3. Repeat until all relations are in BCNF

- Also gives a lossless decomposition!
  - Check yourself

BCNF decomposition example - 1

On blackboard

- CSJDPQV, key C, F = {JP → C, SD → P, J → S}
  - To deal with SD → P, decompose into SDP, CSJDQV.
  - To deal with J → S, decompose CSJDQV into JS and CJDQV

- Note:
  - several dependencies may cause violation of BCNF
  - The order in which we pick them may lead to very different sets of relations
  - there may be multiple correct decompositions (can pick J → S first)

- Is JP → C a violation of BCNF?

BCNF decomposition example - 2

uid → *uname*, *twitterid*
twitterid → *uid*
uid, *gid* → *fromDate*

UserJoinsGroup (*uid*, *uname*, *twitterid*, *gid*, *fromDate*)

BCNF violation: *uid* → *uname*, *twitterid*

User (*uid*, *uname*, *twitterid*)

uid → *uname*, *twitterid*
twitterid → *uid*

BCNF

Member (*uid*, *gid*, *fromDate*)

uid, *gid* → *fromDate*

BCNF

BCNF decomposition example - 3

It is not enough to only look at given FDs! You need to Consider the closure!

uid → uname, twitterid
twitterid → uid
uid, gid → fromDate

apply Armstrong's axioms and rules!

UserJoinsGroup (*uid, uname, twitterid, gid, fromDate*)

BCNF violation: *twitterid → uid*

UserId (*twitterid, uid*)

BCNF

UserJoinsGroup' (*twitterid, uname, gid, fromDate*)

twitterid → uname
twitterid, gid → fromDate

BCNF violation: *twitterid → uname*

UserName (*twitterid, uname*)

BCNF

Member (*twitterid, gid, fromDate*)

BCNF

Recap

- Functional dependencies: a generalization of the key concept
- Non-key functional dependencies: a source of redundancy
- BCNF decomposition: a method for removing redundancies
  - And gives lossless join decomposition
- BCNF = no redundancy due to FDs

But - the relation may still have redundancies! 4-NF (later)

Where are we now?

We learnt How to write queries and how to design a good schema without (some) redundancies

- ✓ Relational Model and Query Languages
  - ✓ SQL, RA, RC
  - ✓ Postgres (DBMS)
  - ✓ XML (overview)
  - ▪ HW1
- ✓ Database Normalization

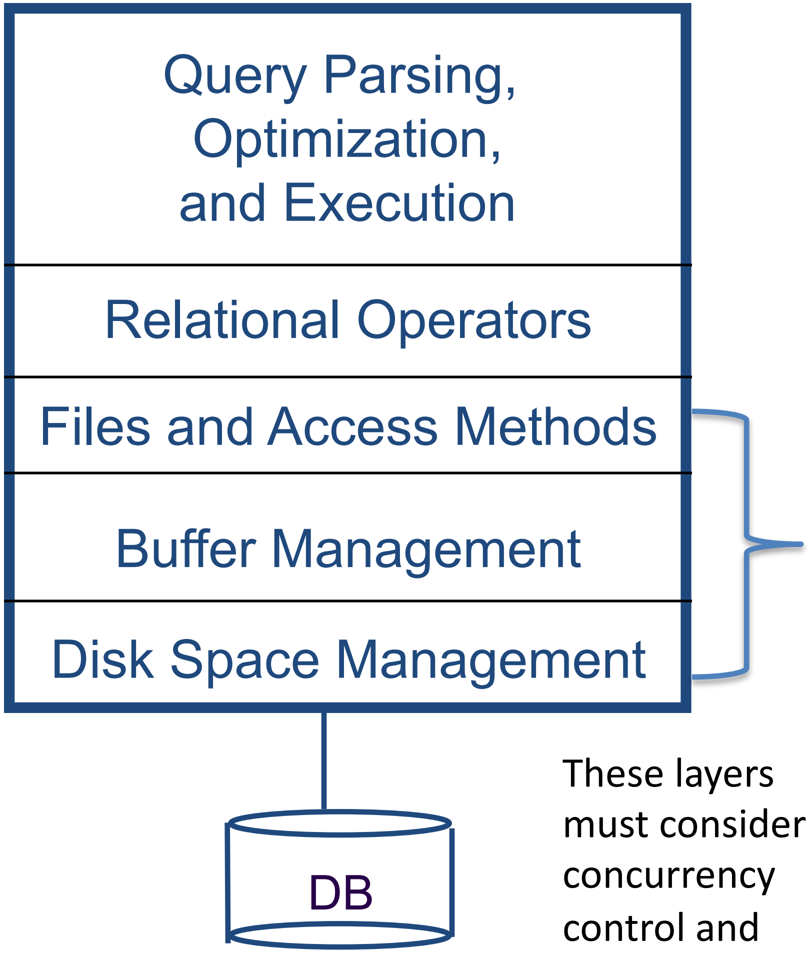
Next

- DBMS Internals (i.e., how a database system works!)
  - Storage
  - Indexing
  - Query Evaluation
  - Operator Algorithms
  - External sort
  - Query Optimization

Storage

DBMS Architecture

- A typical DBMS has a layered architecture
- The figure does not show the concurrency control and recovery components
  - to be done in “transactions”
- This is one of several possible architectures
  - each system has its own variations



These layers must consider concurrency control and recovery

Data on External Storage

- Data must persist on disk across program executions in a DBMS
  - Data is huge
  - Must persist across executions
  - But has to be fetched into main memory when DBMS processes the data

- The unit of information for reading data from disk, or writing data to disk, is a page

- Disks: Can retrieve random page at fixed cost
  - But reading several consecutive pages is much cheaper than reading them in random order

Disk Space Management

- Lowest layer of DBMS software manages space on disk
- Higher levels call upon this layer to:
  - allocate/de-allocate a page
  - read/write a page
- Size of a page = size of a disk block

  = data unit
- Request for a sequence of pages often satisfied by allocating contiguous blocks on disk
- Space on disk managed by Disk-space Manager
  - Higher levels don’t need to know how this is done, or how free space is managed

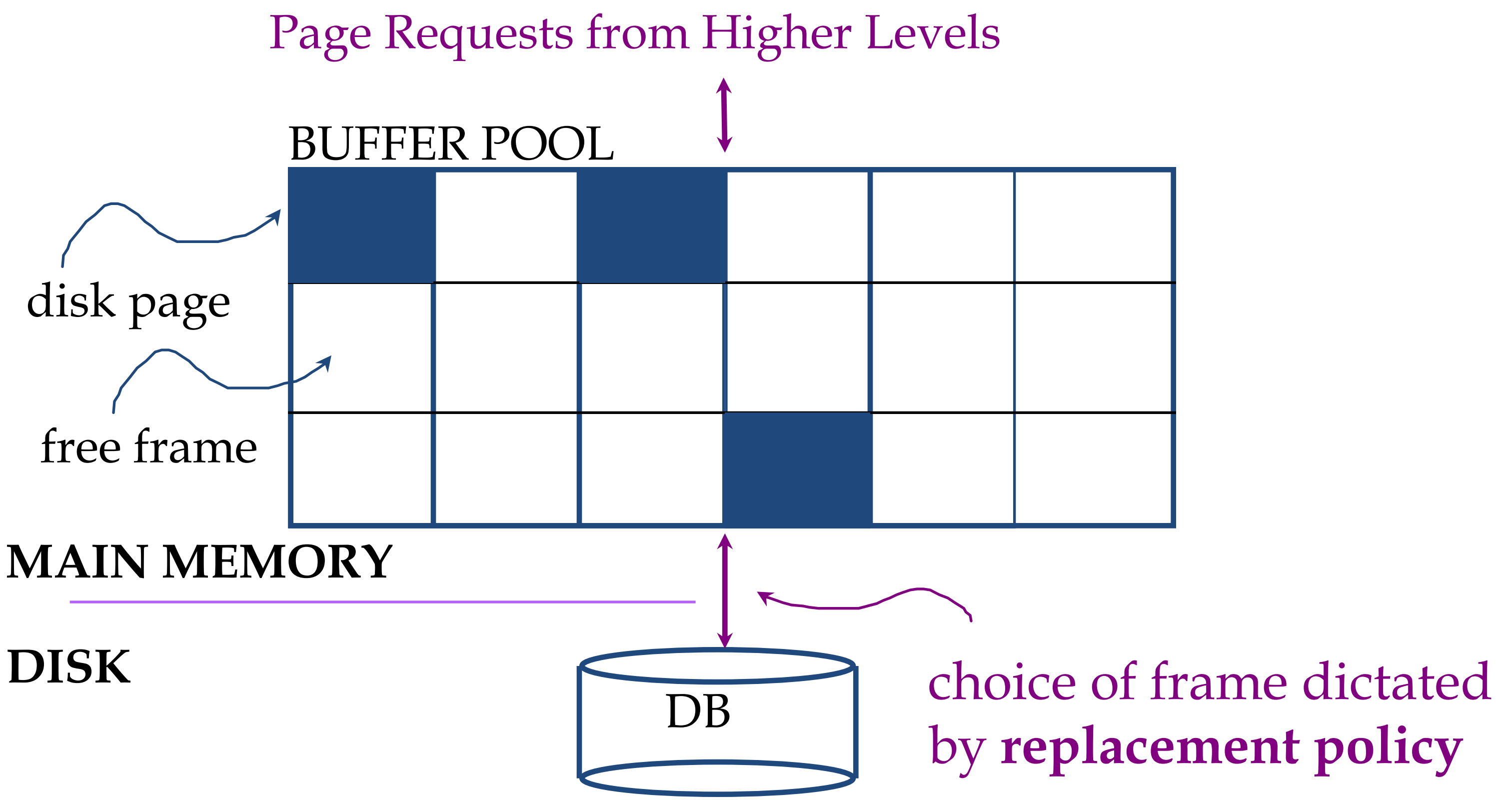
Buffer Management

Suppose

- 1 million pages in db, but only space for 1000 in memory
- A query needs to scan the entire file
- DBMS has to
  - bring pages into main memory
  - decide which existing pages to replace to make room for a new page
  - called Replacement Policy
- Managed by the Buffer manager
  - Files and access methods ask the buffer manager to access a page mentioning the “record id” (soon)
  - Buffer manager loads the page if not already there

Buffer Management

Buffer pool = main memory is partitioned into frames
either contains a page from disk or is a free frame



- Data must be in RAM for DBMS to operate on it
- Table of <frame#, pageid> pairs is maintained

When a Page is Requested ...

For every frame, store

- a dirty bit:
  - whether the page in the frame has been modified since it has been brought to memory
  - initially 0 or off

- a pin-count:
  - the number of times the page in the frame has been requested but not released (and no. of current users)
  - initially 0
  - when a page is requested, the count in incremented
  - when the requestor releases the page, count is decremented
  - buffer manager only reads a page into a frame when its pin-count is 0
  - if no frame with pin-count 0, buffer manager has to wait (or a transaction is aborted -- later)

When a Page is Requested ...

- Check if the page is already in the buffer pool
- if yes, increment the pin-count of that frame
- If no,
  - Choose a frame for replacement using the replacement policy
  - If the chosen frame is dirty (has been modified), write it to disk
  - Read requested page into chosen frame
- Pin (increase pin-count of) the page and return its address to the requestor

- If requests can be predicted (e.g., sequential scans), pages can be pre-fetched several pages at a time
- Concurrency Control & recovery may entail additional I/O when a frame is chosen for replacement

Buffer Replacement Policy

- Frame is chosen for replacement by a replacement policy

- Least-recently-used (LRU)
  - add frames with pin-count 0 to the end of a queue
  - choose from head

- Clock (an efficient implementation of LRU)
- First In First Out (FIFO)
- Most-Recently-Used (MRU) etc.

Buffer Replacement Policy

- Policy can have big impact on # of I/O's
- Depends on the access pattern
- Sequential flooding: Nasty situation caused by LRU + repeated sequential scans
  - What happens with 10 frames and 9 pages?
  - What happens with 10 frames and 11 pages? (check yourself!)
  - # buffer frames < # pages in file means each page request in each scan causes an I/O
  - MRU much better in this situation (but not in all situations, of course)

DBMS vs. OS File System

- Operating Systems do disk space and buffer management too:
- Why not let OS manage these tasks?

- DBMS can predict the page reference patterns much more accurately
  - can optimize
  - adjust replacement policy
  - pre-fetch pages – already in buffer + contiguous allocation
  - pin a page in buffer pool, force a page to disk (important for implementing Transactions concurrency control & recovery)

- Differences in OS support: portability issues

- Some limitations, e.g., files can't span disks

Next..

- How are pages stored in a file?
- How are records stored in a page?
  - Fixed length records
  - Variable length records
- How are fields stored in a record?
  - Fixed length fields/records
  - Variable length fields/records

Files of Records

- Page or block is OK when doing I/O, but higher levels of DBMS operate on records, and files of records
- FILE: A collection of pages, each containing a collection of records
- Must support:
  - insert/delete/modify record
  - read a particular record (specified using record id)
  - scan all records (possibly with some conditions on the records to be retrieved)

File Organization

- File organization: Method of arranging a file of records on external storage
  - One file can have multiple pages
  - Record id (rid) is sufficient to physically locate the page containing the record on disk
  - Indexes are data structures that allow us to find the record ids of records with given values in index search key fields
- NOTE: Several uses of “keys” in a database
  - Primary/foreign/candidate/super keys
  - Index search keys

Alternative File Organizations

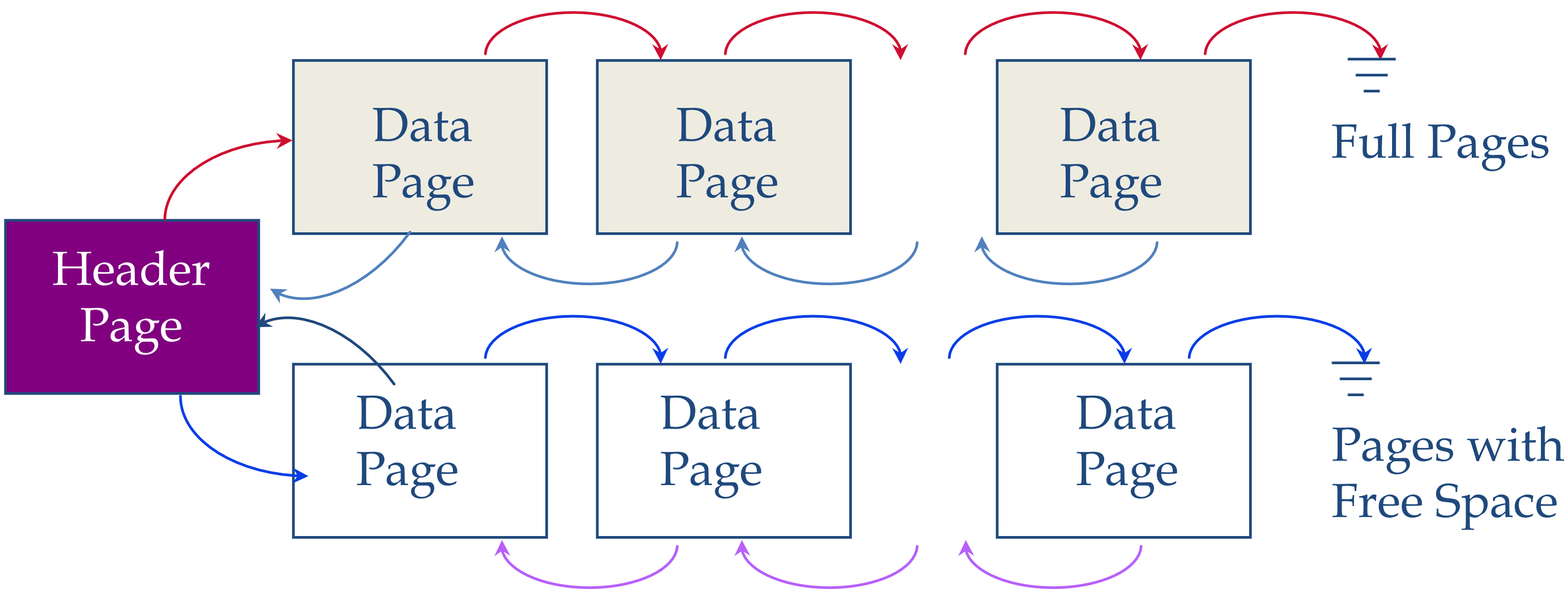
Many alternatives exist, each ideal for some situations, and not so good in others:

- Heap (random order) files: Suitable when typical access is a file scan retrieving all records
- Sorted Files: Best if records must be retrieved in some order, or only a "range" of records is needed.
- Indexes: Data structures to organize records via trees or hashing
  - Next lecture!

Unordered (Heap) Files

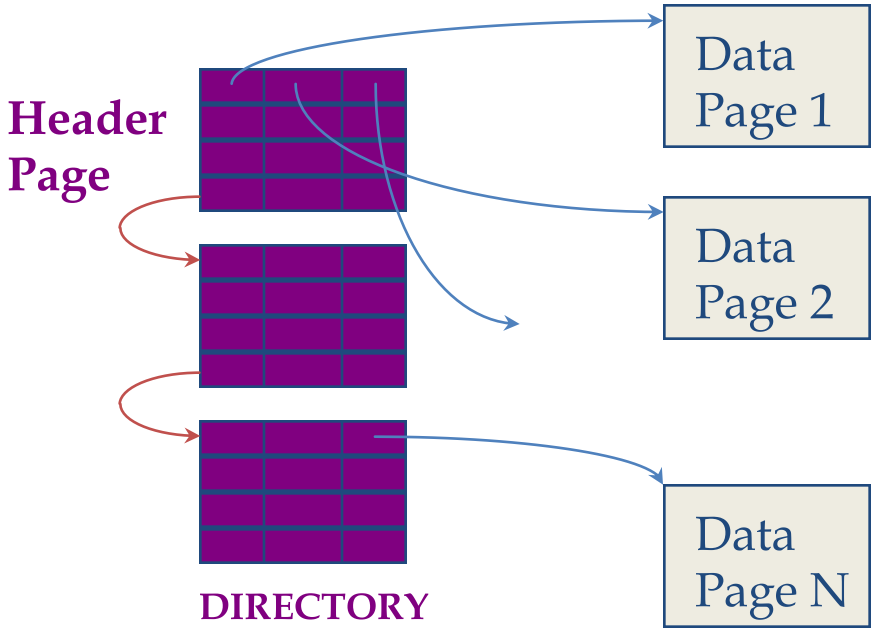
- Simplest file structure contains records in no particular order
- As file grows and shrinks, disk pages are allocated and de-allocated
- To support record level operations, we must:
  - keep track of the pages in a file
  - keep track of free space on pages
  - keep track of the *records* on a page
- There are many alternatives for keeping track of this

Heap File Implemented as a List



- The header page id and Heap file name must be stored someplace
- Each page contains 2 `pointers' plus data
- Problem?
  - to insert a new record, we may need to scan several pages on the free list to find one with sufficient space

Heap File Using a Page Directory



- The entry for a page can include the number of free bytes on the page.
- The directory is a collection of pages
  - linked list implementation of directory is just one alternative
  - Much smaller than linked list of all heap file pages!