ECS 165B: Database System Implementation
Lecture 2

UC Davis
March 31, 2010

Acknowledgements: design of course project for this class borrowed from CS 346 @ Stanford's RedBase project, developed by Jennifer Widom, and used with permission. Slides based on earlier ones by Raghu Ramakrishnan, Johannes Gehrke, Jennifer Widom, Bertram Ludaescher, and Michael Gertz.

Class Agenda

- Last time:
  - Logistics and course overview
  - Introduction to the DavisDB project
  - Start file and buffer management review (Chapter 9 of textbook)
- Today:
  - Finish file and buffer management review
  - File and buffer management in DavisDB
- Reading:
  - Chapter 9 of Ramarkrishnan & Gehkre
  - (or Chapter 11 of Silberschatz et al.)

Announcements

Teaching assistant:

Mingmin Chen (michen@ucdavis.edu)

Office hours: Wednesdays, 11:00-11:50am, 055 Kemper Hall

Please send your team requests to Mingmin by email (or edit the online spreadsheet) by **end of day today!**

- We will finalize teams and set up your subversion repositories tomorrow

Project overview posted!

http://www.cs.ucdavis.edu/~green/courses/ecs165b/project.html

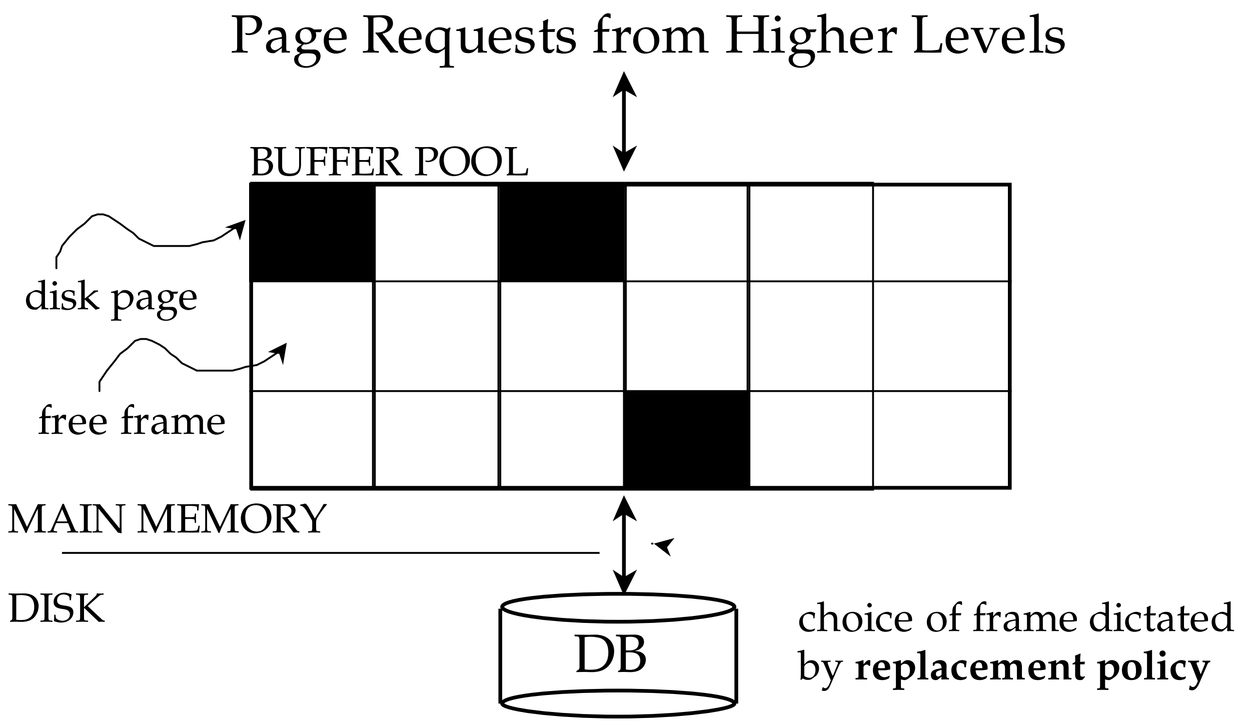
Project Part I will be posted to web page **tomorrow**, due 4/11

File and Buffer Management, Part II

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
- Request for a *sequence* of pages must be satisfied by allocating the pages sequentially on disk! Higher levels don't need to know how this is done, or how free space is managed
  - Simplifying assumption in DavisDB: no requests for *sequences*; pages are accessed one at a time
  - Part of student extension? (Part 5 of project)

Buffer Management in a DBMS



- Data must be in RAM for DBMS to operate on it!
- Table of <frameNo, pageNo> pairs is maintained

When a Page is Requested…

- If requested page is not in pool:
  - Choose a frame for *replacement*
  - If frame is dirty, write it to disk
  - Read requested page into chosen frame
- *Pin* the page and return its address
- If requests can be predicted (e.g., sequential scans), pages can be *pre-fetched* several pages at a time
  - Again, opportunity ignored in DavisDB for simplicity

More on Buffer Management

- Requestor of page must *unpin* it, and indicate whether page has been modified
  - *Dirty bit* is used for this
- Page in pool may be requested many times
  - A *pin count* is used. A page is a candidate for replacement iff its *pin count* = 0
- Concurrency control and recovery may entail additional I/O when a frame is chosen for replacement. (*Write-Ahead Log* protocol; more later…)
  - No concurrency control or recovery in DavisDB (good topic for student extension!)

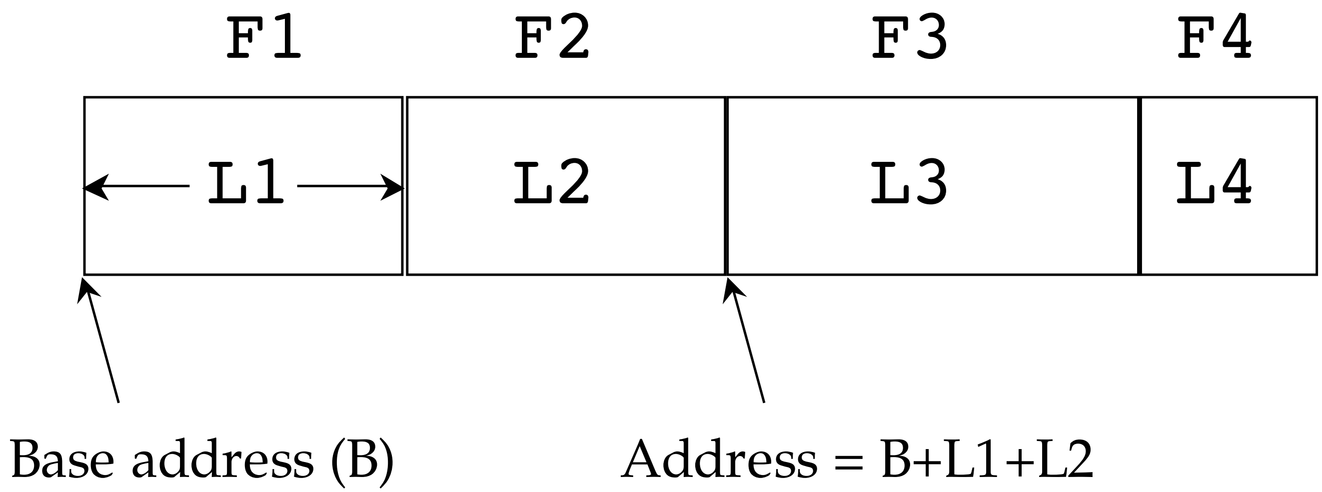
Buffer Replacement Policy

- Frame is chosen for replacement by a *replacement policy*:
  - Least-recently-used (LRU), Clock, MRU, etc
  - DavisDB uses LRU
- Policy can have big impact on # of I/O's; depends on the *access pattern*
- *Sequential flooding*: nasty situation caused by LRU + repeated page scans
  - # buffer frames < # pages in file means each page request causes an I/O. MRU much better in this situation (but not in all situations, of course).

DBMS vs. OS File System

- OS does disk space and buffer management; why not let the OS manage these tasks?
- Differences in OS support: portability issues
- Some limitations, e.g., files can't span disks
- Buffer management in DBMS requires ability to:
  - pin a page in buffer pool, force a page to disk (important for implementing concurrency control and recovery)
  - adjust *replacement policy*, and pre-fetch pages based on access patterns in typical DB operations

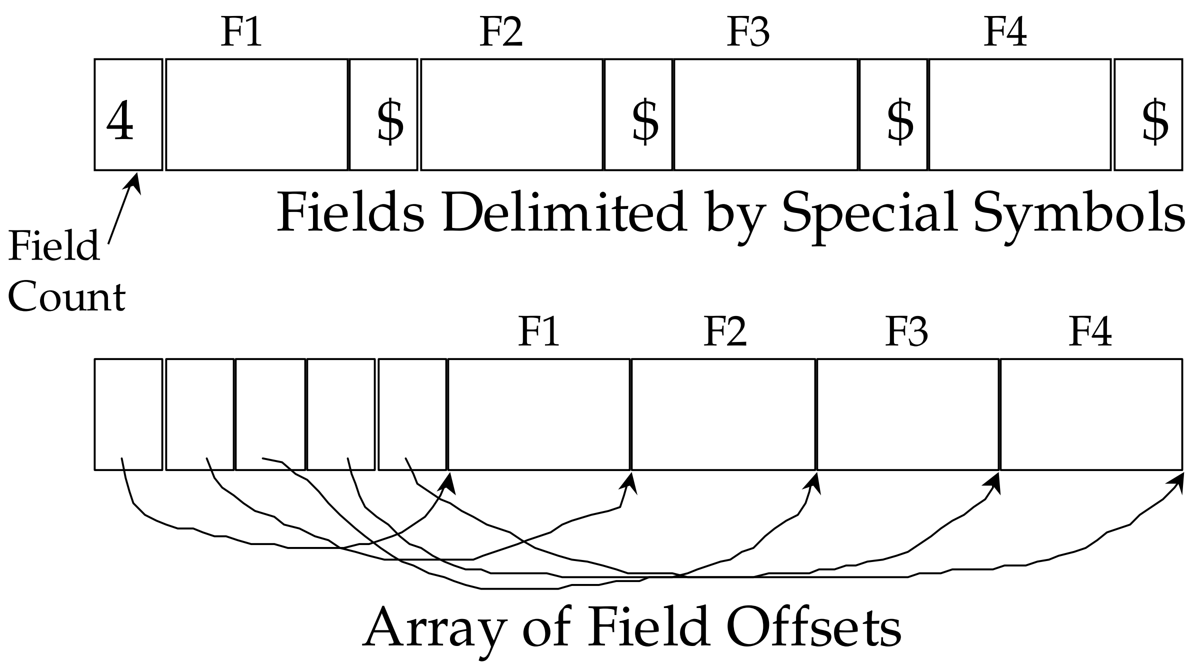
Record Formats: Fixed-Length



- Information about field types same for all records in a file; stored in *system catalogs*
- Finding *i'th* field requires scan of record
- DavisDB uses fixed-length records

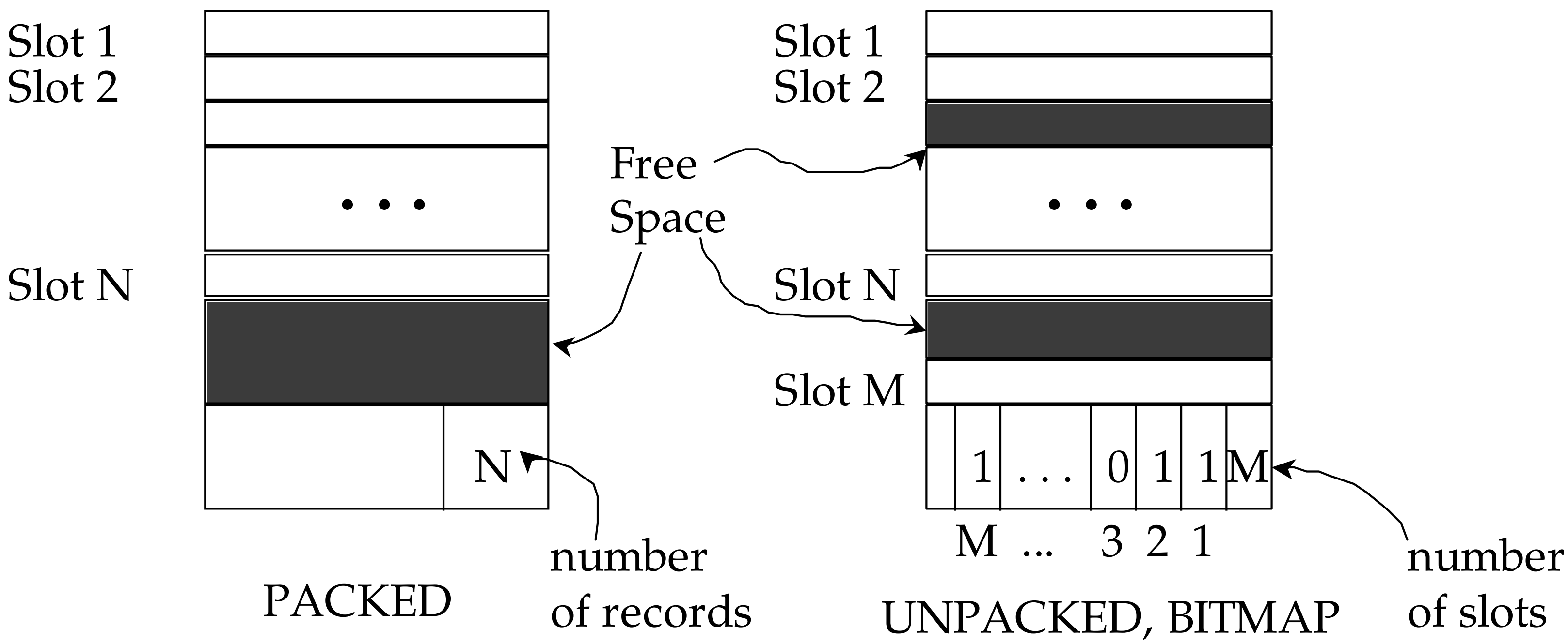
Record Formats: Variable-Length

- Two alternative formats (# fields is fixed):



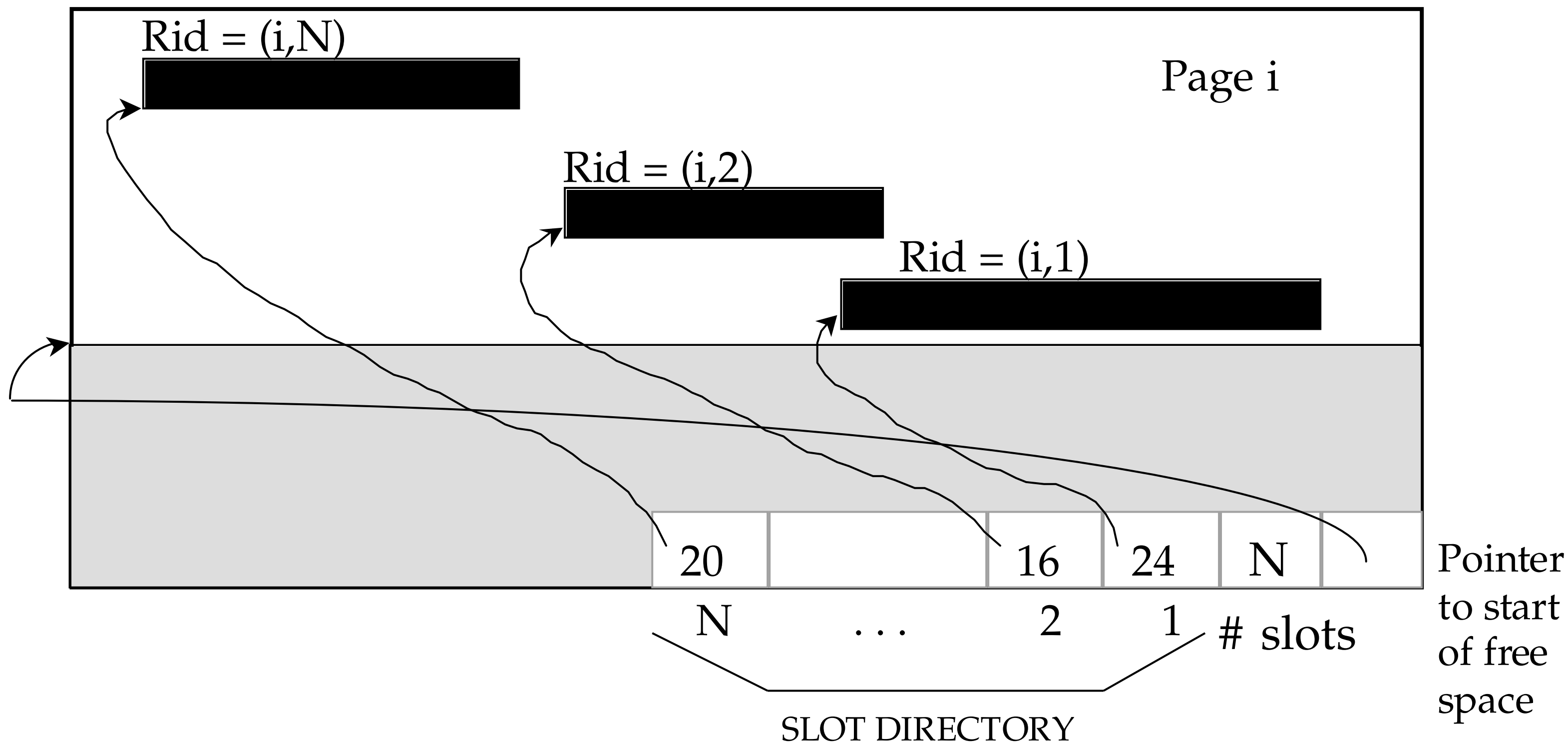
- Second offers direct access to *i'th* field, efficient storage of *nulls* (special *don't know* value); small directory overhead

Page Formats: Fixed-Length Records



- *Record id = <page id, slot #>*. In first alternative, moving records for free space management changes *record id*; may not be acceptable.

Page Formats: Variable-Length Records



- Can move records on page without changing *record id*; so, attractive for fixed-length records too!

Files of Records

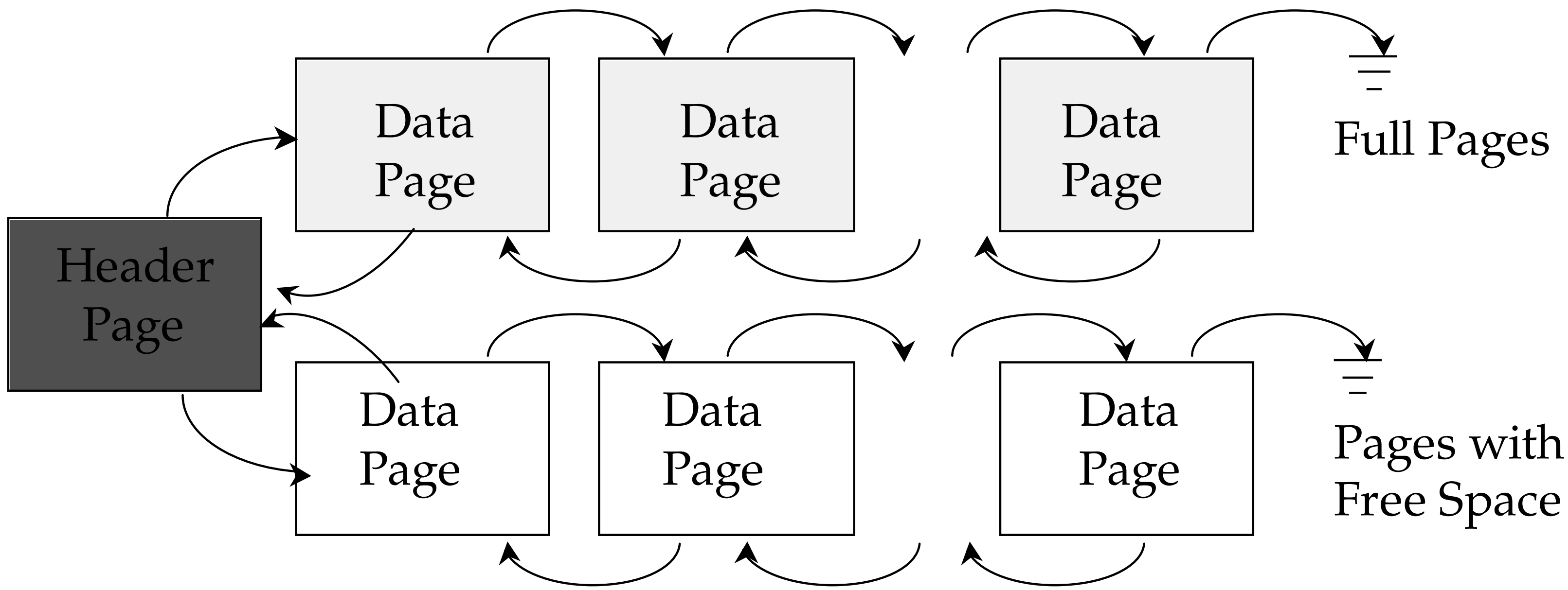
- Page or block is OK when doing I/O, but higher levels of DBMS operate on *records*, and *files of records*.

- **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)

Unordered (Heap) Files

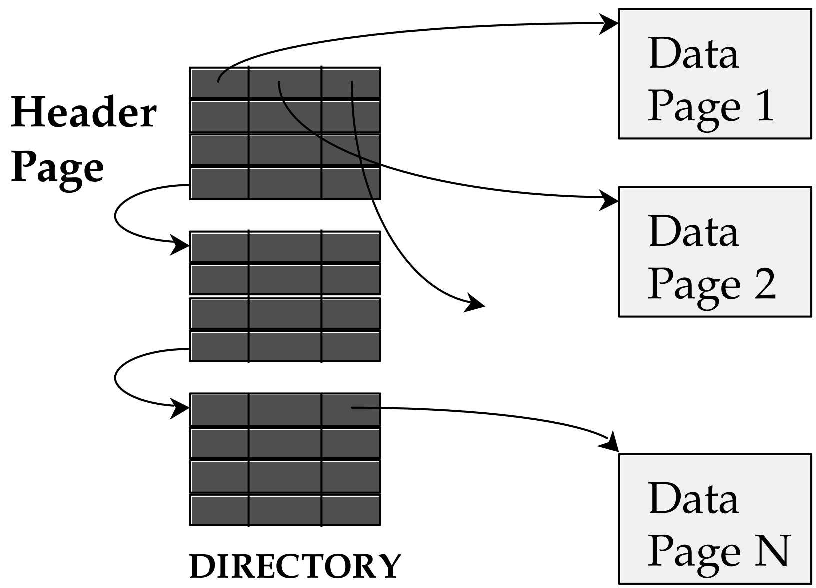
- Simplest file structure contains records in no particular order
- As file grows and shrinks, disk pages are allocated and de-allocated
- To support record-level operations, we must:
  - keep track of the *pages* in a file
  - keep track of *free space* on pages
  - keep track of the *records* on a 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 two "pointers" (*page ids*) plus data

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 is just one alternative
  - Much smaller than linked list of all heap file pages!

System Catalogs

- For each index:
  - structure (e.g., B+-tree) and search key fields
- For each relation
  - name, file name, file structure (e.g., heap file)
  - attribute name and type, for each attribute
  - index name, for each index
  - integrity constraints
- For each view:
  - view name and definition
- Plus statistics, authorization, buffer pool size, etc
  - *Catalogs are themselves stored as relations!*

Example: System Catalog Table for Attributes

attr_name	rel_name	type	position
attr_name	Attribute_Cat	string	1
rel_name	Attribute_Cat	string	2
type	Attribute_Cat	string	3
position	Attribute_Cat	integer	4
sid	Students	string	1
name	Students	string	2
login	Students	string	3
age	Students	integer	4
gpa	Students	real	5
fid	Faculty	string	1
fname	Faculty	string	2
sal	Faculty	real	3

Summary

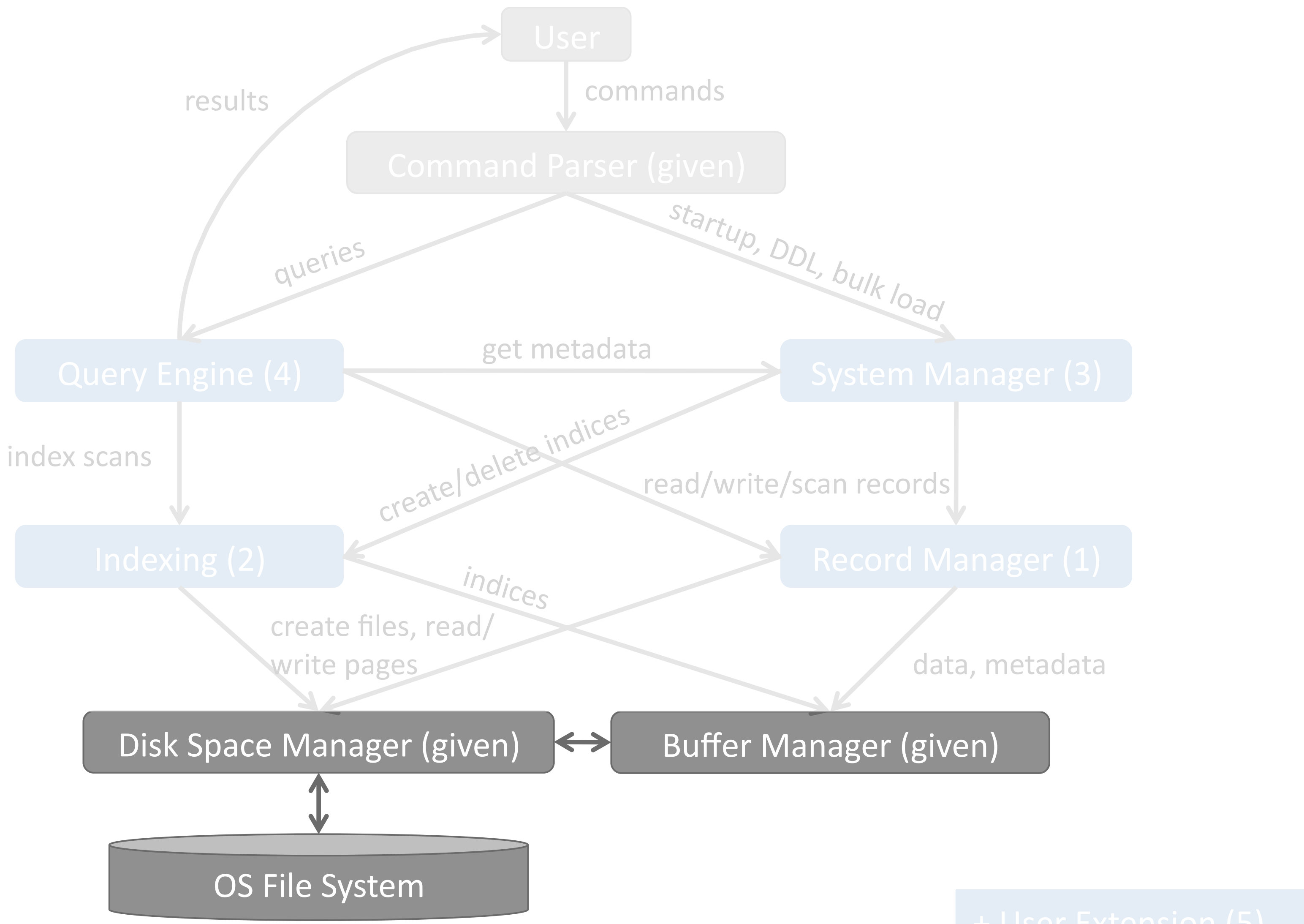
- Disks provide cheap, non-volatile, but slow storage
  - Random access, but cost depends on location of page on disk; important to arrange data sequentially to minimize *seek* delays
    - DavisDB isn't very smart about this
- Buffer manager brings pages into RAM
  - Page stays in RAM until released by requestor
  - Written to disk when frame chosen for replacement (which is some time after requestor releases the page)
  - Choice of frame to replace based on *replacement policy*
  - Tries to *pre-fetch* several pages at a time
    - DavisDB doesn't worry about this

Summary (Continued)

- File layer keeps track of pages in a file, and supports abstraction of a collection of records.
  - Pages with free space identified using linked list or directory structure (similar to how pages in file are kept track of)
- Indexes support efficient retrieval of records based on the values in some fields
- Catalog relations store information about relations, indices, and views. (*Information that is common to all records in a given collection.*)

File and Buffer Management in DavisDB

File and Buffer Management in DavisDB



Paged File Component (Provided)

- Paged File Component has two functions:
  - provides in-memory buffer pool of pages/frames
  - performs low-level file I/O at the granularity of pages
- Overview will be posted tomorrow:

  http://www.cs.ucdavis.edu/~green/courses/ecs165b/pageFile.html

  For now, see Doxygen docs:

  http://www.cs.ucdavis.edu/~green/courses/ecs165b/docs/annotated.html
- Where it all begins: **PageFileManager**…

PageFileManager

- Your code will create **one** instance of this class
- Manages the buffer pool of in-memory pages
  - allocate/de-allocate "scratch" pages
  - coordinates with file handle objects to bring pages to/from disk
  - uses LRU replacement policy
- Used to create/open/close/remove page files
  - Returns **FileHandle** object to manage pages within a file

FileHandle

- Returned by PageFileManager, used to:
  - allocate/de-allocate pages in the file
  - pages identified by logical **page number** rather than physical offset
  - mark page as dirty
  - force page to disk
  - scan pages in file

Coding Tip: Don't Forget to Free Memory!

- DBMS is a long-running process; memory leaks are unacceptable
- Every **new** must have a matching **delete**
- With some coding discipline, can avoid many problems
  - When possible, put **new** and **delete** close together in the code, so that a human can easily verify correctness
  - Memory must **always** be freed, even when handling exceptional conditions
- Use tools like **valgrind** to track down memory leaks
- We will check for memory leaks when grading your projects

Coding Tip: Pinning/Unpinning Pages

- Whenever you access a page, you must remember to unpin it after you're done (else you leak the page)
- **Best coding practice**: do both tasks nearby, ideally in the same function, so that correctness can easily be verified

```
FileHandle* file;
PageHandle page;

ReturnCode code = file->getFirstPage(&page);
if (code == RC_OK) {
    // … do stuff with page …
    file->unpinPage(page.pageNo);
}
```

- Same goes for memory allocation/de-allocation
  - make it easy to match every **new** with its corresponding **delete**