CS186: Introduction to Database Systems

Lecture 3 – File Management

(Book Ch: 9.5-7)

Michael Franklin
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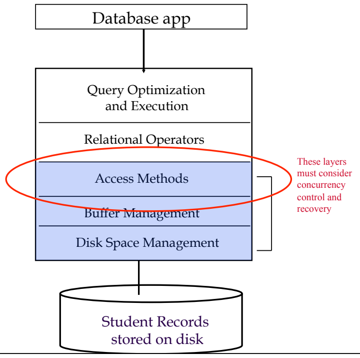
Context



These layers must consider concurrency control and recovery

Files of Records

- Disk blocks are the interface for I/O, but…
- Higher levels of DBMS operate on *records*, and *files of records*.
- FILE: A collection of pages, each containing a number of records. The File API must support:

  insert/**delete**/**modify** record

  fetch a particular record (specified by *record id*)

  scan all records (possibly with some conditions on the records to be retrieved)
- Typically: file page size = disk block size = buffer frame size

"MetaData" - System Catalogs

- How to impose structure on all those bytes??
- MetaData: "Data about Data"
- For each relation:
  - name, file location, file structure (e.g., Heap file)
  - attribute name and type, for each attribute
  - index name, for each index
  - integrity constraints
- For each index:
  - structure (e.g., B+ tree) and search key fields
- For each view: view name and definition
- Plus statistics, authorization, buffer pool size, etc.

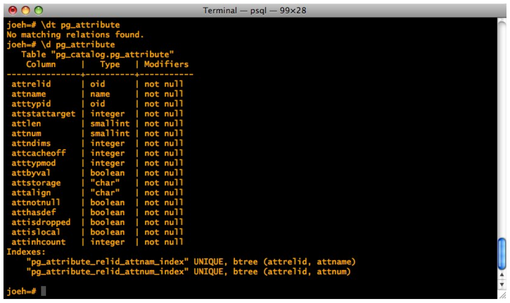
  ☛ *Q: But how to store the catalogs????*

Catalogs are Stored as Relations!

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

Attr_Cat(attr_name, rel_name, type, position, length)

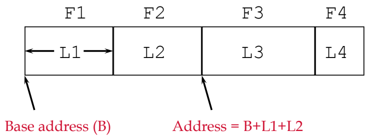
It's a bit more complicated…



```
joeh=# \dt pg_attribute
No matching relations found.
joeh=# \d pg_attribute
   Table "pg_catalog.pg_attribute"
    Column     |   Type   | Modifiers
---------------+----------+-----------
 attrelid      | oid      | not null
 attname       | name     | not null
 atttypid      | oid      | not null
 attstattarget | integer  | not null
 attlen        | smallint | not null
 attnum        | smallint | not null
 attndims      | integer  | not null
 attcacheoff   | integer  | not null
 atttypmod     | integer  | not null
 attbyval      | boolean  | not null
 attstorage    | "char"   | not null
 attalign      | "char"   | not null
 attnotnull    | boolean  | not null
 atthasdef     | boolean  | not null
 attisdropped  | boolean  | not null
 attislocal    | boolean  | not null
 attinhcount   | integer  | not null
Indexes:
    "pg_attribute_relid_attnam_index" UNIQUE, btree (attrelid, attname)
    "pg_attribute_relid_attnum_index" UNIQUE, btree (attrelid, attnum)

joeh=# 
```

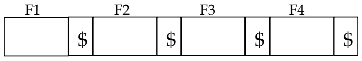
Record Formats: Fixed Length



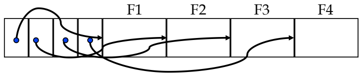
- Information about field types same for all records in a file; stored in *system catalogs.*
- Finding *i'th* field done via arithmetic.

Record Formats:Variable Length

- Two alternative formats (# fields is fixed):



Fields Delimited by Special Symbols



Array of Field Offsets

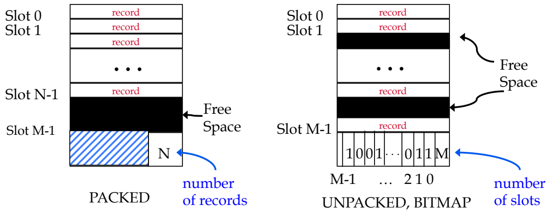
☛ Second offers direct access to i'th field, efficient storage of nulls (special *don't know* value); some directory overhead.

How to Identify a Record?

- The Relational Model doesn't expose "pointers", but that doesn't mean that the DBMS doesn't use them internally.
- Q: Can we use memory addresses to permanently "point" to records?
- Systems use a "Record ID" or "RecID"

Typically: *Record ID* = *<page id, slot #>*

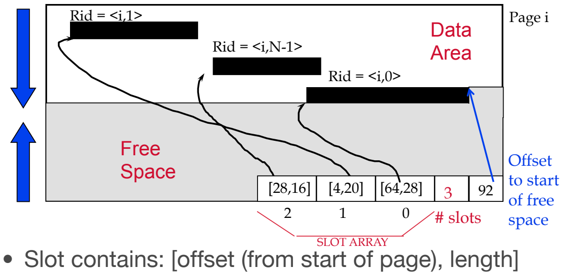
Page Formats: Fixed Length Records



In first alternative, free space management requires record movement.

Changes RIds - may not be acceptable.

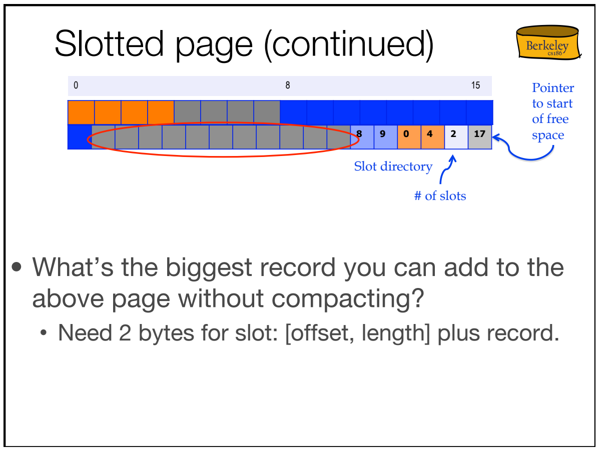
"Slotted Page" for Variable Length Records



- Slot contains: [offset (from start of page), length]
  - both in bytes
- *Record id = <page id, slot #>*
- Page is full when data space and slot array meet.

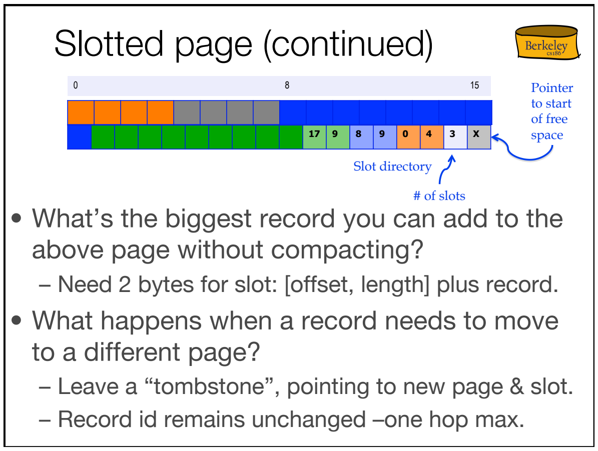
Slotted Page (continued)

- When need to allocate:
  - If enough room in free space, use it and update free space pointer.
  - Else, try to compact data area, if successful, use the freed space.
  - Else, tell caller that page is full.
- Advantages:
  - Can move records around in page without changing their record ID
  - Allows lazy space management within the page, with opportunity for clean up later



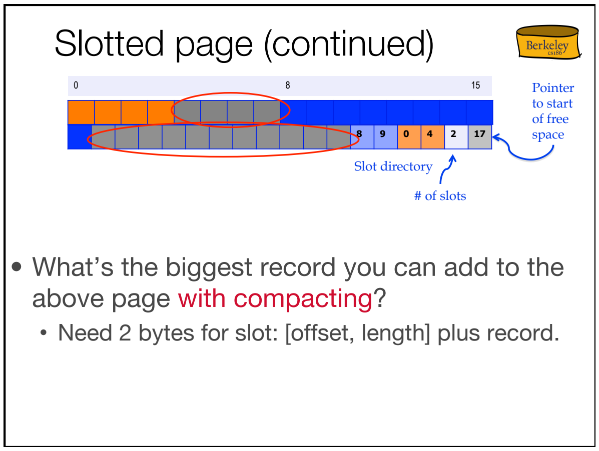
Slotted page (continued)

- What's the biggest record you can add to the above page without compacting?
  - Need 2 bytes for slot: [offset, length] plus record.



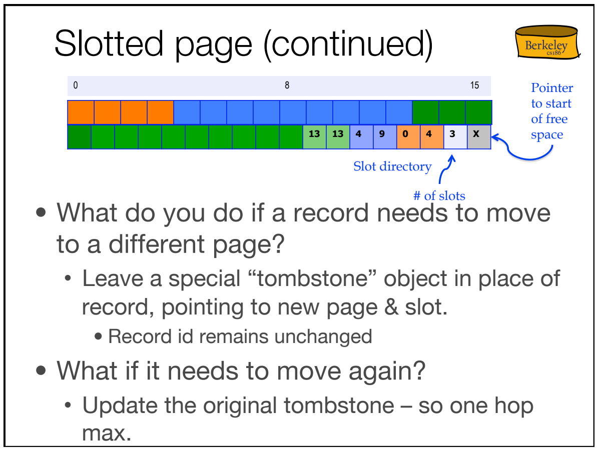
Slotted page (continued)

- What's the biggest record you can add to the above page without compacting?
  - Need 2 bytes for slot: [offset, length] plus record.
- What happens when a record needs to move to a different page?
  - Leave a "tombstone", pointing to new page & slot.
  - Record id remains unchanged –one hop max.



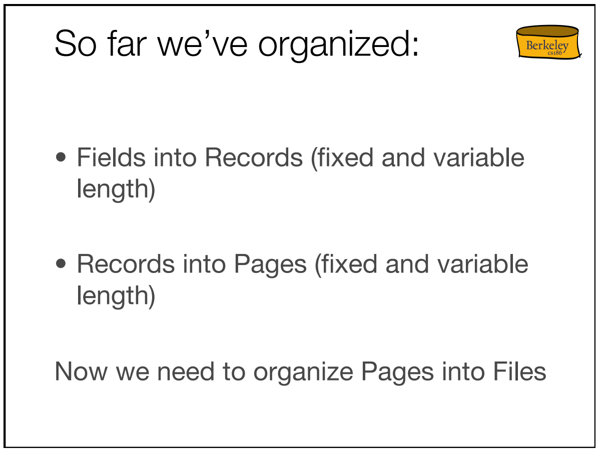
Slotted page (continued)

- What's the biggest record you can add to the above page with compacting?
  - Need 2 bytes for slot: [offset, length] plus record.



Slotted page (continued)

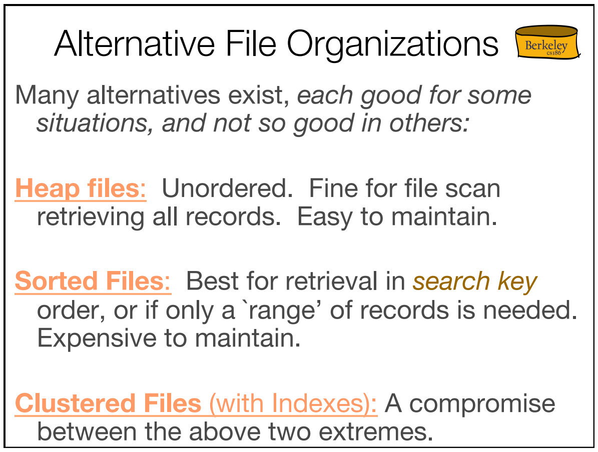
- What do you do if a record needs to move to a different page?
  - Leave a special "tombstone" object in place of record, pointing to new page & slot.
    - Record id remains unchanged
- What if it needs to move again?
  - Update the original tombstone – so one hop max.



So far we've organized:

- Fields into Records (fixed and variable length)
- Records into Pages (fixed and variable length)

Now we need to organize Pages into Files



Alternative File Organizations

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

Heap files: Unordered. Fine for file scan retrieving all records. Easy to maintain.

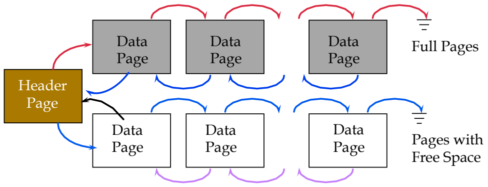
Sorted Files: Best for retrieval in *search key* order, or if only a `range' of records is needed. Expensive to maintain.

Clustered Files (with Indexes): A compromise between the above two extremes.

Unordered (Heap) Files

- Simplest file structure contains records in no particular order.
- As file grows and shrinks, 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
- Can organize as a list, as a directory, a tree, …

Heap File Implemented as a List

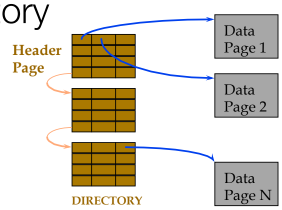


- The Heap file name and header page id must be stored persistently.

  The catalog is a good place for this.

- Each page contains 2 `pointers' 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.
- **Q: How to find a particular record in a Heap file???**

Cost Model for Analysis

- Average-case analysis; based on several simplistic assumptions.
  - Often called a "back of the envelope" calculation.
- We ignore CPU costs, for simplicity:

  B: The number of data blocks

  R: Number of records per block
- We simply count number of disk block I/O's
  - ignores gains of pre-fetching and sequential access; thus, even I/O cost is only loosely approximated.

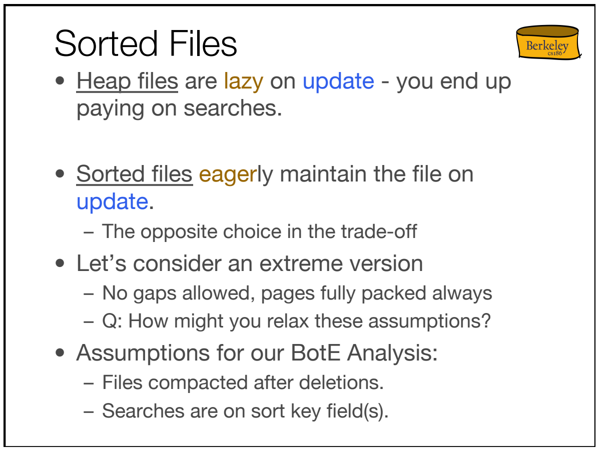
☛ *Good enough to show some overall trends!*

Some Assumptions in the Analysis

- Single record insert and delete.
- Equality selection - exactly one match (what if more or less???).
- For Heap Files we'll assume:
  - Insert always appends to end of file.
  - Delete just leaves free space in the page.
  - Empty pages are not deallocated.

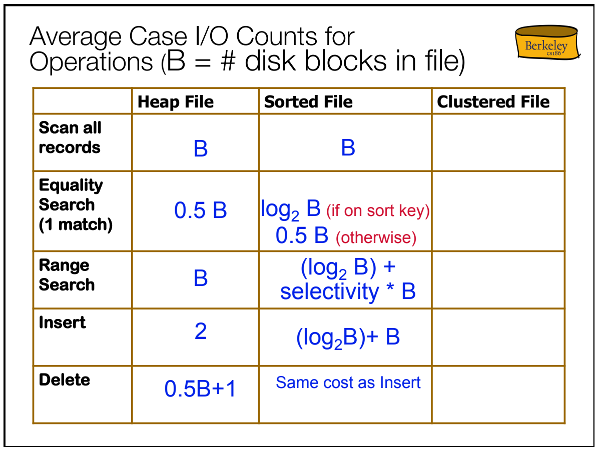
Average Case I/O Counts for Operations (B = # disk blocks in file)

	Heap File	**Sorted File**	**Clustered File**
Scan all records	B		
Equality Search (1 match)	0.5 B		
Range Search	B		
Insert	2		
Delete	0.5B+1		



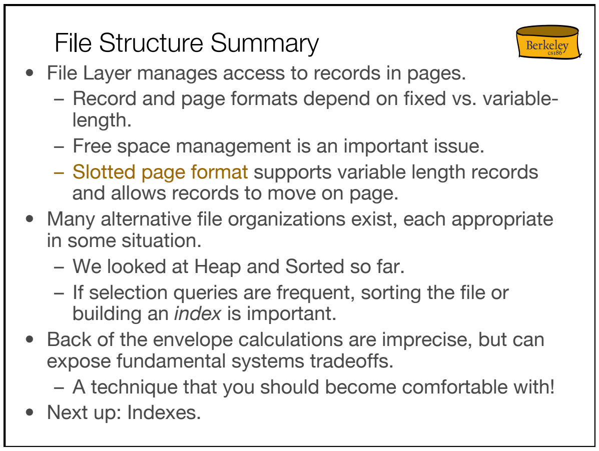
Sorted Files

- Heap files are lazy on update - you end up paying on searches.
- Sorted files eagerly maintain the file on update.
  - The opposite choice in the trade-off
- Let’s consider an extreme version
  - No gaps allowed, pages fully packed always
  - Q: How might you relax these assumptions?
- Assumptions for our BotE Analysis:
  - Files compacted after deletions.
  - Searches are on sort key field(s).



Average Case I/O Counts for Operations (B = # disk blocks in file)

	Heap File	**Sorted File**	**Clustered File**
Scan all records	B	B	
Equality Search (1 match)	0.5 B	$\log_2$ B (if on sort key) 0.5 B (otherwise)	
Range Search	B	$(\log_2$ B) + selectivity * B	
Insert	2	$(\log_2$B)+ B	
Delete	0.5B+1	Same cost as Insert	



File Structure Summary

- File Layer manages access to records in pages.
  - Record and page formats depend on fixed vs. variable-length.
  - Free space management is an important issue.
  - Slotted page format supports variable length records and allows records to move on page.
- Many alternative file organizations exist, each appropriate in some situation.
  - We looked at Heap and Sorted so far.
  - If selection queries are frequent, sorting the file or building an *index* is important.
- Back of the envelope calculations are imprecise, but can expose fundamental systems tradeoffs.
  - A technique that you should become comfortable with!
- Next up: Indexes.