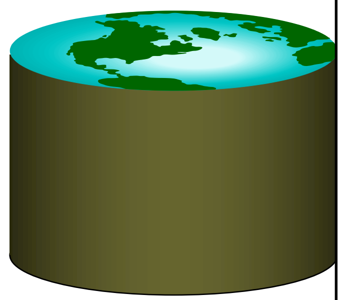
Storing Data: Disks and Files

Lecture 2
(Chapter 9)



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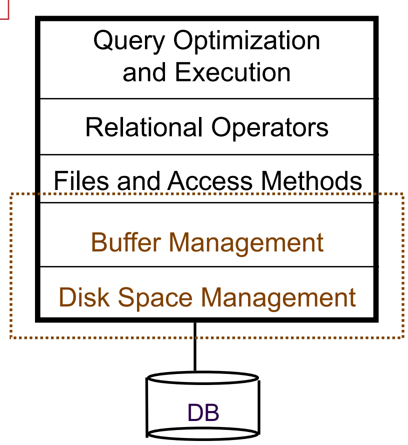
Disks, Memory, and Files

The BIG picture…



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Disks and Files

- **DBMS stores information on disks.**
  - In an electronic world, disks are a mechanical anachronism!
- **This has major implications for DBMS design!**
  - READ: transfer data from disk to main memory (RAM).
  - WRITE: transfer data from RAM to disk.
  - Both are high-cost operations, relative to in-memory operations, so must be planned carefully!

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Why Not Store Everything in Main Memory?

- ***Costs too much*. For less than $50, Dell will sell you either 4 GB of RAM or 500 GB of disk today (0.0125 $/MB memory, 0.001$/MB disk).**
- ***Main memory is volatile*. We want data to be saved between runs. (Obviously!)**
- **Typical storage hierarchy:**
  - Main memory (RAM) for currently used data.
  - Flash for secondary storage
  - Disk for secondary storage
  - Tapes for archiving older versions of the data (tertiary storage) – defunct today

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Disks

- **Secondary storage device of choice (changing).**
- ***random access*** **vs.** ***sequential*****.**
- **Data is stored and retrieved in units called** ***disk blocks*** **or** ***pages*****.**
- **Unlike RAM, time to retrieve a disk block varies depending upon location on disk.**
  - Therefore, relative placement of blocks on disk has major impact on DBMS performance!

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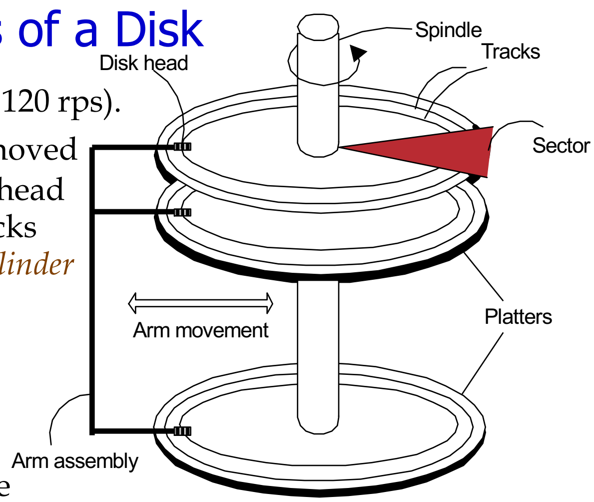
Components of a Disk



The platters spin (say, 120 rps).

The arm assembly is moved in or out to position a head on a desired track. Tracks under heads make a *cylinder* (imaginary!).

Only one head reads/writes at any one time.

- *Block size* is a multiple of *sector size* (which is fixed).

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Accessing a Disk Page

- **Time to access (read/write) a disk block:**
  - *seek time* (moving arms to position disk head on track)
  - *rotational delay* (waiting for block to rotate under head)
  - *transfer time* (actually moving data to/from disk surface)
- **Seek time and rotational delay dominate.**
  - Seek time varies between about 0.3 and 10msec
  - Rotational delay varies from 0 to 6msec
  - Transfer rate around .008msec per 8K block
- **Sequential vs random disk access**
- **Key to lower I/O cost: reduce seek/rotation delays! Hardware vs. software solutions?**

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Arranging Pages on Disk

- **`*Next*' block concept:**
  - blocks on same track, followed by
  - blocks on same cylinder, followed by
  - blocks on adjacent cylinder
- **Blocks in a file should be arranged sequentially on disk (by `next'), to minimize seek and rotational delay.**
- **For a sequential scan, *pre-fetching* several pages at a time is a big win!**

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Disk Space Management

- **Lowest layer of DBMS software manages space on disk (using OS file system or not?).**
- **Higher levels call upon this layer to:**
  - allocate/de-allocate a page
  - read/write a page
- **Best if a request for a *sequence* of pages is satisfied by pages stored sequentially on disk!**
  - Responsibility of disk space manager.
  - Higher levels don't know how this is done, or how free space is managed.
  - Though they may assume sequential access for files!
    - Hence disk space manager should do a decent job.

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RAID

- **RAID-0 : Data stripping, no redundancy, reliability issues**
- **RAID-1 : Mirrored, fully redundant, expensive**
- **RAID-0+1 : mirrored, stripped**
- **RAID-2 : ECC, bit level stripping, good for large requests**
- **RAID-3 : like 2 but only one disk to store checksums**
- **RAID-4 : like 3 but stripping unit is a block**
- **RAID-5 : Block interleaved, distributed parity**
- **RAID-6 : RS coding recovery from multiple (2) failures**
- **Choice : tradeoffs**
  - 0 no protection from data loss, 3 good for large transfers
  - 5 good general purpose workloads, 6 high reliability

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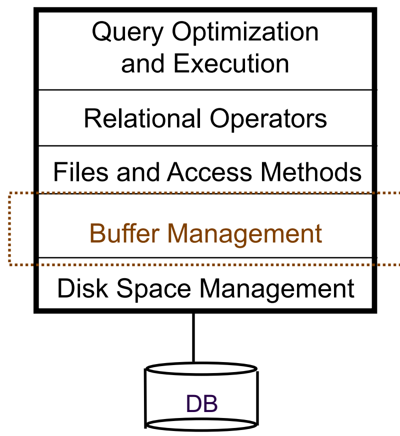
Context



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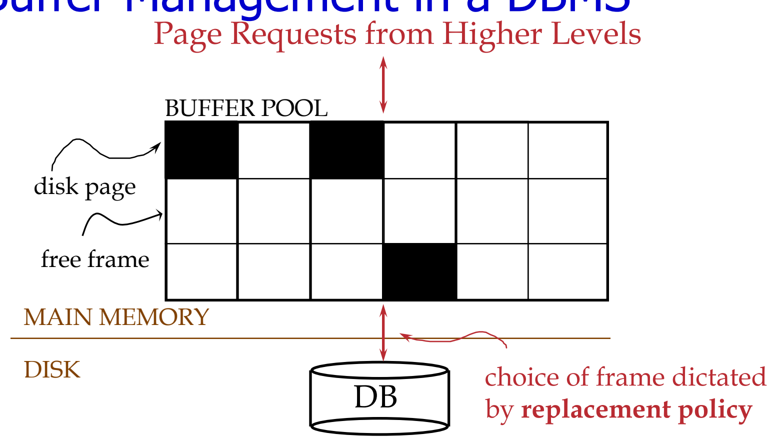
Buffer Management in a DBMS



- ***Data must be in RAM for DBMS to operate on it!***
- ***Buffer Mgr hides the fact that not all data is in RAM***

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When a Page is Requested ...

- **Buffer pool information table contains:**
  <frame#, pageid, pin_count, dirty>
- **If requested page is not in pool:**
  - Choose a frame for *replacement.*
    Only "un-pinned" pages are candidates!
  - 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!*

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More on Buffer Management

- **Requestor of page must eventually 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.
  - To pin a page, pin_count++
  - A page is a candidate for replacement iff *pin count* == 0 (*"unpinned"*)
- **CC & recovery may entail additional I/O when a frame is chosen for replacement.**
  - *Write-Ahead Log* protocol; more later!

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Buffer Replacement Policy

- **Frame is chosen for replacement by a *replacement policy:***
  - Least-recently-used (LRU), MRU, Clock, etc.
- **Policy can have big impact on # of I/O's; depends on the *access pattern*.**

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LRU Replacement Policy

- ***Least Recently Used (LRU)***
  - for each page in buffer pool, keep track of time when last *unpinned*
  - replace the frame which has the oldest (earliest) time
  - very common policy: intuitive and simple
    - Works well for repeated accesses to popular pages
- **Problems?**
- ***Problem: Sequential flooding***
  - LRU + repeated sequential scans.
  - # buffer frames < # pages in file means each page request causes an I/O.
  - Idea: MRU better in this scenario?!

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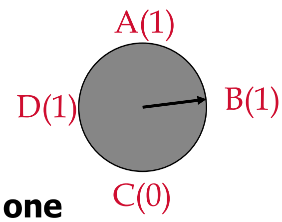
"Clock" Replacement Policy



- **An approximation of LRU**
- **Arrange frames into a cycle, store one *reference bit* *per frame***
  - Can think of this as the 2nd chance bit
- **When pin count reduces to 0, turn on ref. bit**
- **When replacement necessary**

```
do for each page in cycle {
        if (pincount == 0 && ref bit is on)
                turn off ref bit;
        else if (pincount == 0 && ref bit is off)
                choose this page for replacement;
} until a page is chosen;
```

Questions:
How like LRU?
Problems?

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DBMS vs. OS File System

OS does disk space & buffer mgmt: why not let OS manage these tasks?

- **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 & order writes (important for implementing CC & recovery)
  - adjust *replacement policy,* and pre-fetch pages based on access patterns in typical DB operations.

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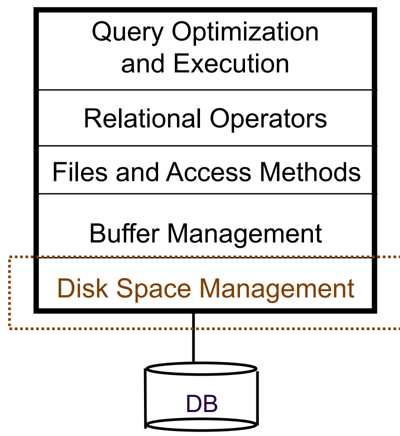
Context



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Files of Records

- **Blocks interface for I/O, but…**
- **Higher levels of DBMS operate on *records*, and *files of records*.**
- **<u>FILE</u>: A collection of pages, each containing a collection of records. Must support:**
  - insert/delete/modify record
  - fetch a particular record (specified using *record id*)
  - scan all records (possibly with some conditions on the records to be retrieved)

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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.**
  - We' ll consider 2

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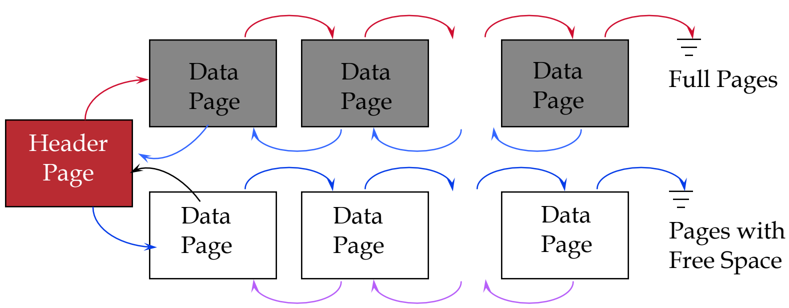
Heap File Implemented as a List



- **The header page id and Heap file name must be stored someplace.**
  - Database "catalog"
- **Each page contains 2 `pointers' plus data.**

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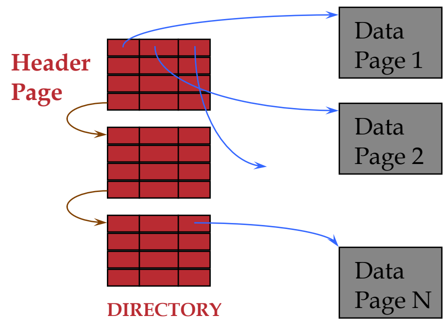
Heap File Using a Page Directory



- **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 HF pages*!

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Indexes (a sneak preview)

- **A Heap file allows us to retrieve records:**
  - by specifying the *rid*, or
  - by scanning all records sequentially
- **Sometimes, we want to retrieve records by specifying the *values in one or more fields*, e.g.,**
  - Find all students in the “CS” department
  - Find all students with a gpa > 3
- **Indexes are file structures that enable us to answer such value-based queries efficiently.**

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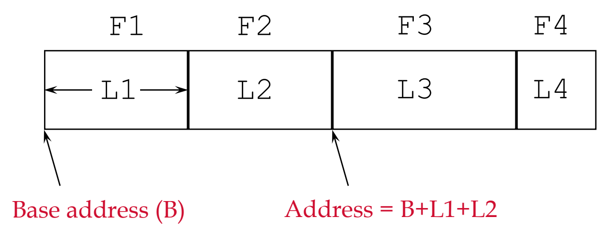
Record Formats: Fixed Length



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

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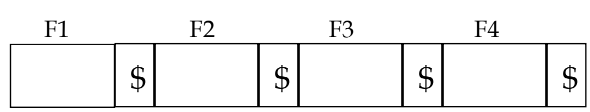
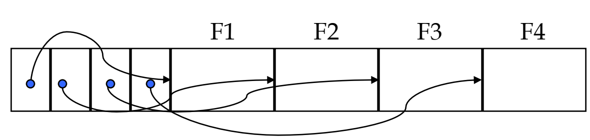
Record Formats: Variable Length

- **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); small directory overhead.

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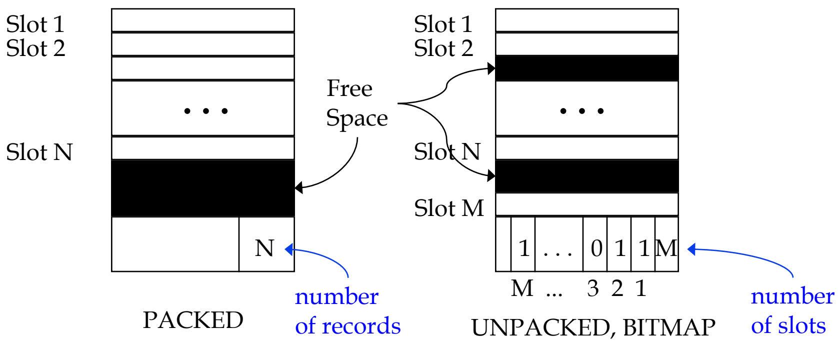
Page Formats: Fixed Length Records



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

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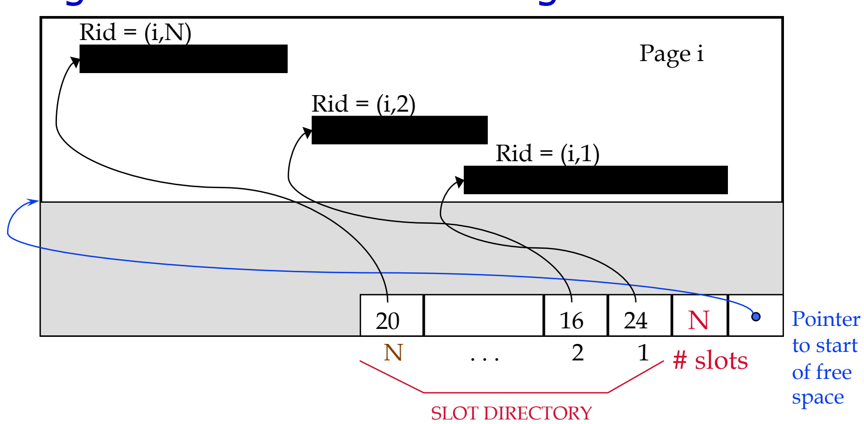
Page Formats: Variable Length Records



- ***Can move records on page without changing rid; so, attractive for fixed-length records too.***

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System Catalogs

- **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.**

☛ *Catalogs are themselves stored as relations*!

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Attr_Cat(attr_name, rel_name, type, position)

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

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