



Storing Data: Disks and Files

Chapter 9

“Yea, from the table of my memory
I’ll wipe away all trivial fond records.”
-- Shakespeare, *Hamlet*



Data on External Storage

- ❖ **Disks:** Can retrieve random page at fixed cost
 - But reading several consecutive pages is much cheaper than reading them in random order
- ❖ **Tapes:** Can only read pages in sequence
 - Cheaper than disks; used for archival storage
- ❖ **File organization:** Method of arranging a file of records on external storage.
 - **Record id (rid)** is sufficient to physically locate record
 - **Indexes** are data structures that allow us to find the record ids of records with given values in **index search key** fields
- ❖ **Architecture:** **Buffer manager** stages pages from external storage to main memory buffer pool. File and index layers make calls to the buffer manager.

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.
 - Like sorted files, they speed up searches for a subset of records, based on values in certain (“search key”) fields
 - Updates are much faster than in sorted files.

Disks and Files



- ❖ DBMS stores information on (“hard”) disks.
- ❖ 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!

Why Not Store Everything in Main Memory



- ❖ *Costs too much.*
- ❖ *Main memory is volatile.* We want data to be saved between runs. (Obviously!)
- ❖ Typical storage hierarchy:
 - Main memory (RAM) for currently used data.
 - Disk for the main database (secondary storage).
 - Tapes for archiving older versions of the data (tertiary storage).

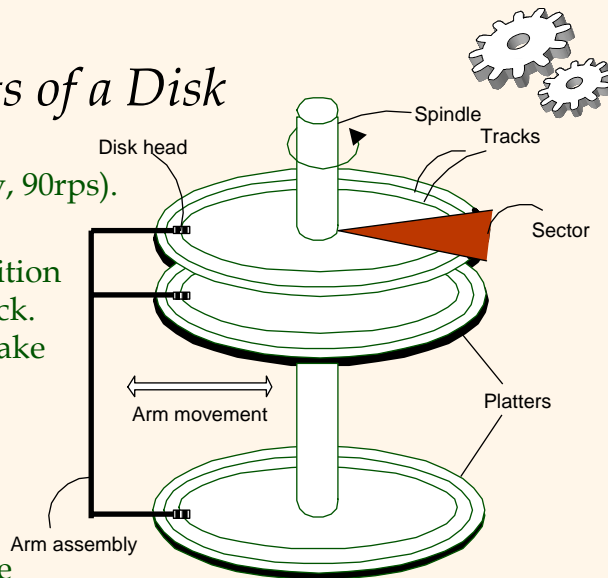
Disks



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

Components of a Disk

- ❖ The platters spin (say, 90rps).
- ❖ 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).



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 from about 1 to 20msec
 - Rotational delay varies from 0 to 10msec
 - Transfer rate is about 1msec per 4KB page
- ❖ Key to lower I/O cost: **reduce seek/rotation delays!** Hardware vs. software solutions?

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!

RAID



- ❖ Disk Array: Arrangement of several disks that gives abstraction of a single, large disk.
- ❖ Goals: Increase performance and reliability.
- ❖ Two main techniques:
 - Data striping: Data is partitioned; size of a partition is called the striping unit. Partitions are distributed over several disks.
 - Redundancy: More disks => more failures. Redundant information allows reconstruction of data if a disk fails.

RAID Levels



- ❖ Level 0: No redundancy
- ❖ Level 1: Mirrored (two identical copies)
 - Each disk has a mirror image (check disk)
 - Parallel reads, a write involves two disks.
 - Maximum transfer rate = transfer rate of one disk
- ❖ Level 0+1: Striping and Mirroring
 - Parallel reads, a write involves two disks.
 - Maximum transfer rate = aggregate bandwidth

RAID Levels (Contd.)



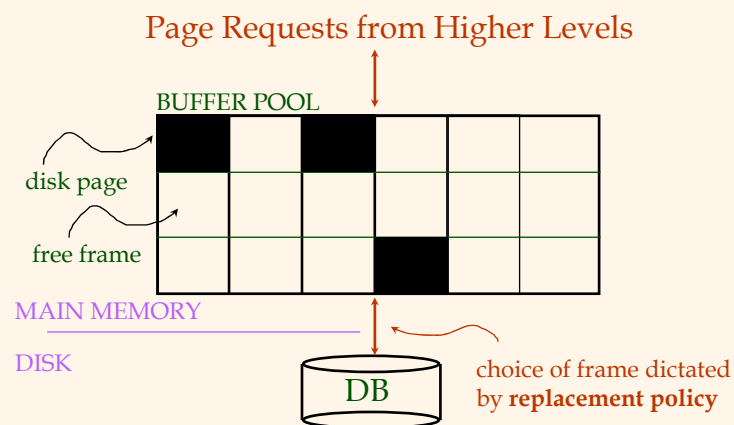
- ❖ Level 3: Bit-Interleaved Parity
 - Striping Unit: One bit. One check disk.
 - Each read and write request involves all disks; disk array can process one request at a time.
- ❖ Level 4: Block-Interleaved Parity
 - Striping Unit: One disk block. One check disk.
 - Parallel reads possible for small requests, large requests can utilize full bandwidth
 - Writes involve modified block and check disk
- ❖ Level 5: Block-Interleaved Distributed Parity
 - Similar to RAID Level 4, but parity blocks are distributed over all disks

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.

Buffer Management in a DBMS



- ❖ *Data must be in RAM for DBMS to operate on it!*
- ❖ *Table of <frame#, pageid> 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!*

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 *pin count* = 0.
- ❖ CC & recovery may entail additional I/O when a frame is chosen for replacement.
(*Write-Ahead Log* protocol; more later.)

Buffer Replacement Policy



- ❖ Frame is chosen for replacement by a *replacement policy*:
 - Least-recently-used (LRU), Clock, MRU etc.
- ❖ 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.
 - # 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).

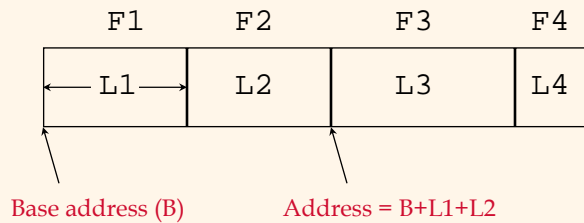
DBMS vs. OS File System



OS does disk space & buffer mgmt: why not let 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 CC & recovery),
 - adjust *replacement policy*, and pre-fetch pages based on access patterns in typical DB operations.

Record Formats: Fixed Length

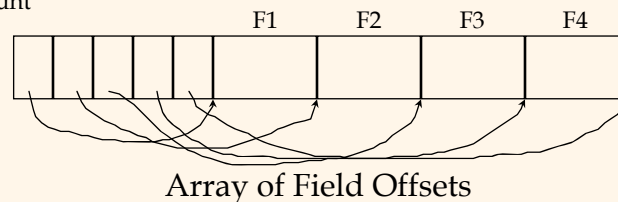
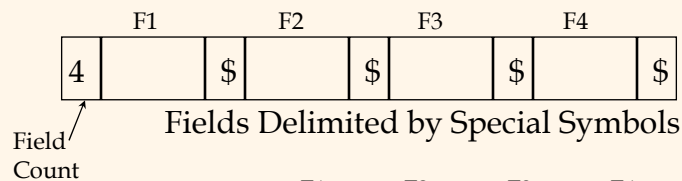


- ❖ Information about field types same for all records in a file; stored in *system catalogs*.

Record Formats: Variable Length

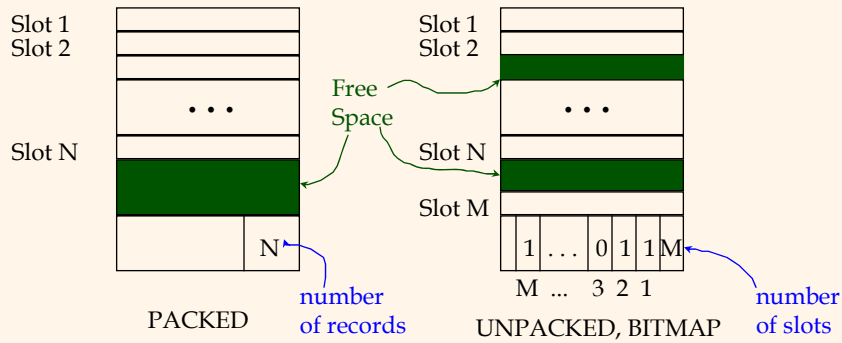


- ❖ Two alternative formats (# fields is fixed):



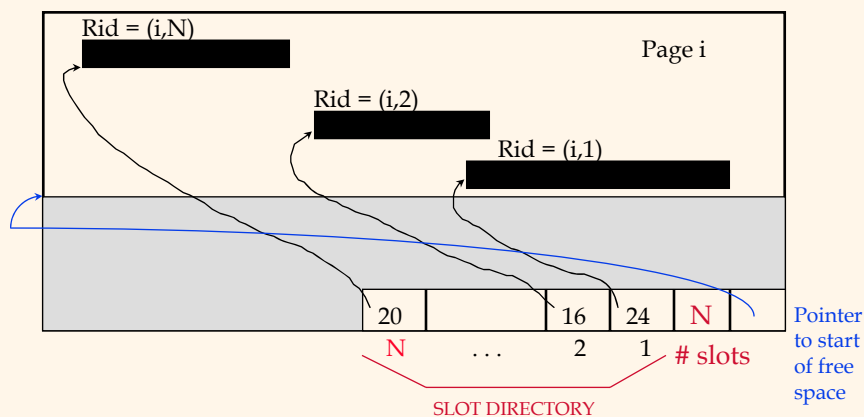
- ☒ Second offers direct access to i 'th field, efficient storage of *nulls* (special *don't know* value); small directory overhead.

Page Formats: Fixed Length Records



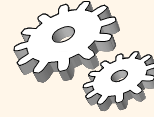
☒ Record id = $\langle \text{page id, slot \#} \rangle$. In first alternative, moving records for free space management changes rid; may not be acceptable.

Page Formats: Variable Length Records



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

Files of Records



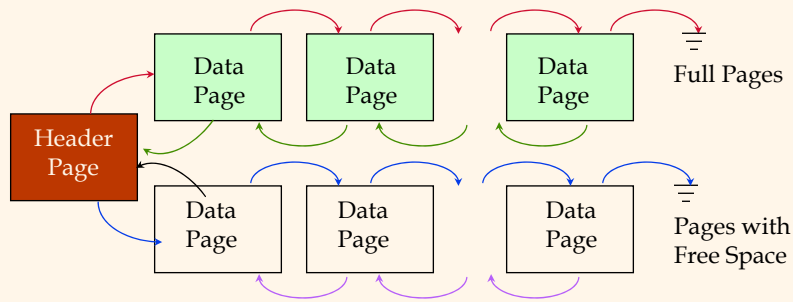
- ❖ Page or block is OK when doing I/O, but higher levels of DBMS operate on *records*, and *files of records*.
- ❖ **FILE**: A collection of pages, each containing a collection of records. Must support:
 - insert/delete/modify record
 - read a particular record (specified using *record id*)
 - scan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

Unordered (Heap) Files



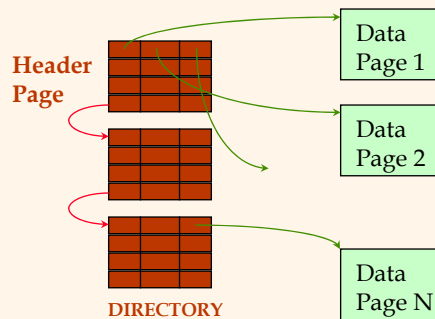
- ❖ Simplest file structure contains records in no particular order.
- ❖ As file grows and shrinks, disk pages are allocated and de-allocated.
- ❖ To support record level operations, we must:
 - keep track of the *pages* in a file
 - keep track of *free space* on pages
 - keep track of the *records* 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 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.
 - *Much smaller than linked list of all HF 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!*

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

Summary



- ❖ Disks provide cheap, non-volatile storage.
 - Random access, but cost depends on location of page on disk; important to arrange data sequentially to minimize *seek* and *rotation* delays.
- ❖ Buffer manager brings pages into RAM.
 - Page stays in RAM until released by requestor.
 - Written to disk when frame chosen for replacement (which is sometime after requestor releases the page).
 - Choice of frame to replace based on *replacement policy*.
 - Tries to *pre-fetch* several pages at a time.

Summary (Contd.)



- ❖ DBMS vs. OS File Support
 - DBMS needs features not found in many OS's, e.g., forcing a page to disk, controlling the order of page writes to disk, files spanning disks, ability to control pre-fetching and page replacement policy based on predictable access patterns, etc.
- ❖ Variable length record format with field offset directory offers support for direct access to *i*'th field and null values.
- ❖ Slotted page format supports variable length records and allows records to move on page.

Summary (Contd.)



- ❖ 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, indexes and views. (*Information that is common to all records in a given collection.*)