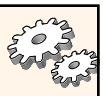
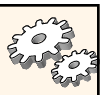


Storing Data: Disks and Files

Chapter 9

1



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!

read and write is expensive than main memory address (cache L1,L2,L3) that is expensive than registers in CPU

2

Why Not Store Everything in Main Memory?

- *Costs too much.* $100 will buy you either 300GB of RAM or 3TB of disk today.
- *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).

disk is cheap, non-volatile and large in size
main memory is faster

3

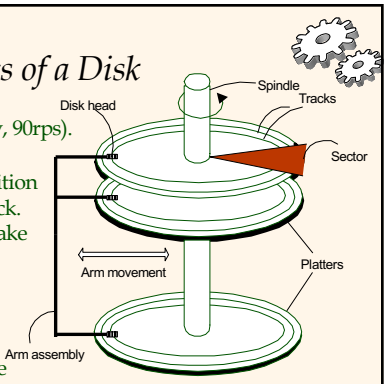
Disks

- 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!

4

In order to compensate the slow speed of disk, we retrieve large data size a time (a block maybe 1kb)

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).

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variable density disk: the farther outside, the less density the storage
because going inwards travels shorter distance given the same time interval
so this way retrieval time of a block is the same(simpler algorithm), however losing disk capacity
on contrary: constant density disk

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?

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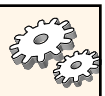
how to satisfy multiple requests:
disk scheduling algorithm:
similar to elevation algorithm(how elevator picks floors)
guarantee worst case time is whole cycle
fair to everyone

data placement problem:
what if each page is 4kb and a file is 8kb, 12kbs, 24kbs...
if two pages store randomly in disk (multiple seek time,rotation delay and transfer time)
most optimized (form a cylinder): store at the same track, same track number but different platters
if all platters in the same track and same track number is all occupied:
Then place in next cylinder (see slide below)

Arranging Pages on Disk

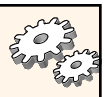


- *`Next'* block concept:
  - blocks on same track, followed by
  - blocks on same cylinder, followed by
  - blocks on adjacent cylinder
- Blocks in a file should be arranged sequentially on disk (by `next'), to minimize seek and rotational delay.
- For a sequential scan, *pre-fetching* several pages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

In real life, there are multiple tasks running at the same time, so it's not likely the case that you can read one whole cylinder without disruption (e.g read one file and write in another).

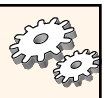
RAID

redundant arrays for independent disks



- 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

disadvantage: less disk capacity

just like disk cylinder

error correcting codes: ECCs

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

stripping at bit level, check disk stores parity bit (the number of odd bits at nth bit in all disks)
so if one disk fails and parity is odd and there are 2 1s, then the failing disk has bit of 1
if one disk fails and parity is odd and there are 3 1s, then the failing disk has bit of 0

parity check in block level

no parity disk, parity is distributed in all disks

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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.

A disk usually have 20 platters (double sided each, so 40 faces)
Disk head moves in and out
spindle drives platters to rotate

RPM (revolutions per minute)

disk movement is mechanic (can take ms)
Ram movement is electronic (super fast)

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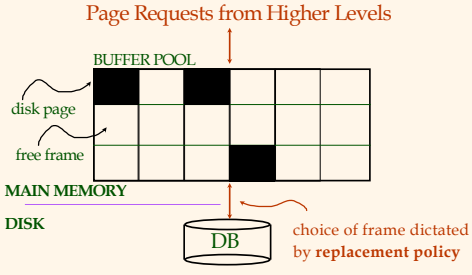
Buffer Management in a DBMS



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

page = block of consecutive virtual memory
frame = block of consecutive physical memory

Relational algebra indicates access pattern
we can utilize access patterns in
buffer replacement
pre fetching (e.g. if we perform select x>10, we know we will fetch a block of pages and look at one after another)
after looking at one page, since we know access pattern is to look at next page, we can throw MRU(most recent used) away

In a join operation, if buffer is full, we will remove the most recent used because if we jump to next tuple in the outer, we will need to join the lease

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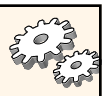
when write into buffer page, write a dirty bit beyond the content to indicate whether it's written or not

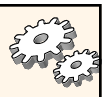
When a Page is Requested ...



- 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!*

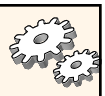
More on Buffer Management



- 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.)

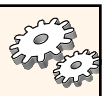
In a multi user environment, pin a page in the buffer pool to indicate its not free and cannot be replaced so buffer manager won't replace this page. if x number of users are using a page, then pin count is x.

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).

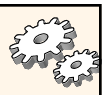
DBMS vs. OS File System

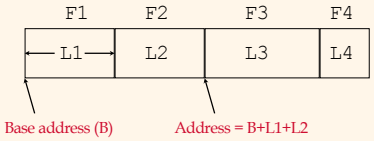


OS does disk space & buffer mgmt: why not let OS manage these tasks?

- 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.

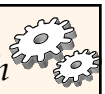
Record Formats: Fixed Length



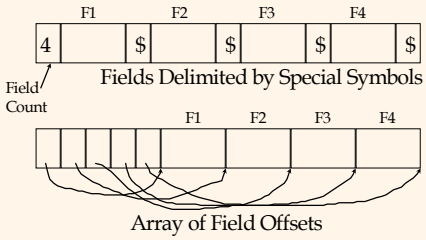


- Information about field types same for all records in a file; stored in *system catalogs.*
- Finding *i'th* field does not require scan of record.

Record Formats: Variable Length



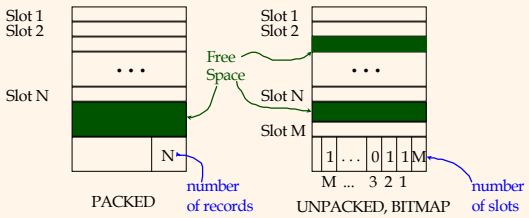
- Two alternative formats (# fields is fixed):



n+1 delimiters for boundaries

☛ 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 rid; may not be acceptable.*

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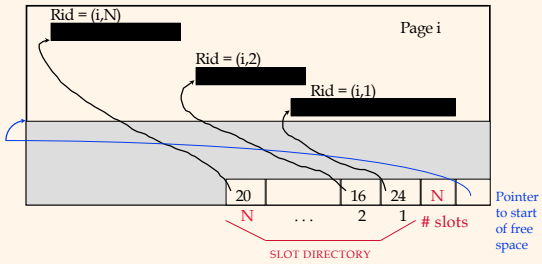
slots grow downwards and the directory of bit vectors grow upwards until they meet

Packed: free space is at the buttom. If one slot is deleted, the below slots shift upwards

cons: the record consists of page id and slot number. For example, a previous register is pointing to slot number 2, now slot 2 is deleted, slot 3 is now in place of slot 2, slot 4 is in place of slot 3, slot 5 is in place of slot 4. All records are pointing to the wrong contents.

Page Formats: Variable Length Records



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

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defragmentation: split a large record into multiple and store in gaps

very costly.

record sparing in multiple pages: save spaces, and a record can be multiple pages long

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)

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Unordered (Heap) Files

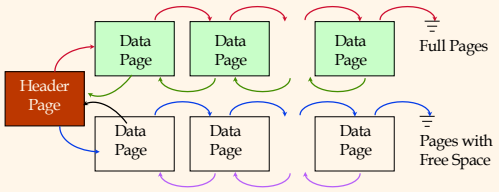
- Simplest file structure contains records in no particular order.
- As file grows and shrinks, disk pages are allocated and de-allocated.
- To support record level operations, we must:
  - keep track of the *pages* in a file
  - keep track of *free space* on pages
  - keep track of the *records* on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

Sorted files are good for read only (more time to write because everytime you write, whole tree needs to be resorted agai, less time to read)

Unsorted files are good for write only (less time to write, more time to read)

What if we want both read and write: Index!

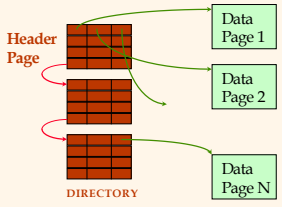
Heap File Implemented as a List



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

Pro: insertion takes constant time O(1)
deletion, assertion, update takes O(n) - traverse the list to find the correct node

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!*

In Unix, if a file is 2 pages long, use heap list.
For file larger than 2 pages long, use directory.
Directory indicates where each data page is located, so finding only takes constant time.

System Catalogs The catalogs of all relations

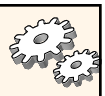
- For each index:
  - structure (e.g., B+ tree) and search key fields
- For each relation:
  - name, file name, file structure (e.g., Heap file)
  - attribute name and type, for each attribute
  - index name, for each index
  - integrity constraints
- For each view:
  - view name and definition
- Plus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

attribute catalog

Attr_Cat(attr_name, rel_name, type, position)

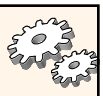
attr_name	rel_name	type	position
attr_name	Attribute_Cat	string	1
rel_name	Attribute_Cat	string	2
type	Attribute_Cat	string	3
position	Attribute_Cat	integer	4
sid	Students	string	1
name	Students	string	2
login	Students	string	3
age	Students	integer	4
gpa	Students	real	5
fid	Faculty	string	1
fname	Faculty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

Summary



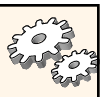
- Disks provide cheap, non-volatile storage.
  - Random access, but cost depends on location of page on disk; important to arrange data sequentially to minimize *seek* and *rotation* delays.
- Buffer manager brings pages into RAM.
  - Page stays in RAM until released by requestor.
  - Written to disk 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.*)