Storing Data: Disks and Files

Chapter 7

Storing and Retrieving Data

❖ Database Management Systems need to:
  – Store large volumes of data
  – Store data reliably (so that data is not lost!)
  – Retrieve data efficiently
❖ Alternatives for storage
  – Main memory
  – Disks
  – Tape

Why Not Store Everything in Main Memory?

❖ Costs too much. $500 will buy you either 512MB of RAM or 100GB of disk today.
❖ Main memory is volatile. We want data to be saved between runs. (Obviously!)
**Why Not Store Everything in Tapes?**

- No random access. Data has to be accessed sequentially
  - Not a great idea when accessing a small portion of a terabyte of data
- Slow! Data access times are larger than for disks

**Disks**

- Secondary storage device of choice
  - Cheap
  - Stable storage medium
  - Random access to data
- Main problem
  - Data read/write times much larger than for main memory

**Solution 1: Techniques for making disks faster**

- Intelligent data layout on disk
  - Put related data items together
- Redundant Array of Inexpensive Disks (RAID)
  - Achieve parallelism by using many disks
Solution 2: Buffer Management

- Keep “currently used” data in main memory
  - How do we do this efficiently?
- Typical storage hierarchy:
  - Main memory (RAM) for currently used data
  - Disks for the main database (secondary storage)
  - Tapes for archiving older versions of the data (tertiary storage)

Outline

- Disk technology and how to make disk read/writes faster
- Buffer management
- Storing “database files” on disk

Components of a Disk

- The platters spin (say, 100 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).
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 0.5msec 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.
Outline

- Disk technology and how to make disk read/writes faster
- Buffer management
- Storing "database files" on disk

Buffer Management in a DBMS

Page Requests from Higher Levels

- 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 if 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.
Outline

- Disk technology and how to make disk read/writes faster
- Buffer management
- Storing "database files" on disk

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)

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.
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 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.
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!
Indexes

❖ 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.

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!

<table>
<thead>
<tr>
<th>attr_name</th>
<th>rel_name</th>
<th>type</th>
<th>position</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr_name</td>
<td>Attribute_Cat</td>
<td>string</td>
<td>1</td>
</tr>
<tr>
<td>rel_name</td>
<td>Attribute_Cat</td>
<td>string</td>
<td>2</td>
</tr>
<tr>
<td>type</td>
<td>Attribute_Cat</td>
<td>string</td>
<td>3</td>
</tr>
<tr>
<td>position</td>
<td>Attribute_Cat</td>
<td>integer</td>
<td>4</td>
</tr>
<tr>
<td>name</td>
<td>Students</td>
<td>string</td>
<td>1</td>
</tr>
<tr>
<td>login</td>
<td>Students</td>
<td>string</td>
<td>2</td>
</tr>
<tr>
<td>age</td>
<td>Students</td>
<td>integer</td>
<td>3</td>
</tr>
<tr>
<td>gpa</td>
<td>Students</td>
<td>real</td>
<td>4</td>
</tr>
<tr>
<td>fid</td>
<td>Faculty</td>
<td>string</td>
<td>5</td>
</tr>
<tr>
<td>name</td>
<td>Faculty</td>
<td>string</td>
<td>1</td>
</tr>
<tr>
<td>sal</td>
<td>Faculty</td>
<td>real</td>
<td>2</td>
</tr>
</tbody>
</table>

Attr_Cat($attr_name$, $rel_name$, $type$, $position$)
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.

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.
- Sloted page format supports variable length records and allows records to move on page.

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.*