Physical Data Organization

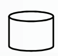
CPS 116

Introduction to Database Systems

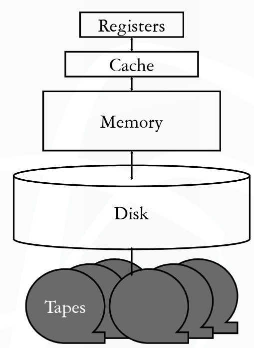
Announcements (November 5)

- Homework #3 sample solution available
- Project milestone #2 due this Saturday
  - Deadline extended because of DB2 server outage

Outline

- It's all about disks!
  - That's why we always draw databases as 
  - And why the single most important metric in database processing is the number of disk I/O's performed
- Storing data on a disk
  - Record layout
  - Block layout

Storage hierarchy



Why a hierarchy?

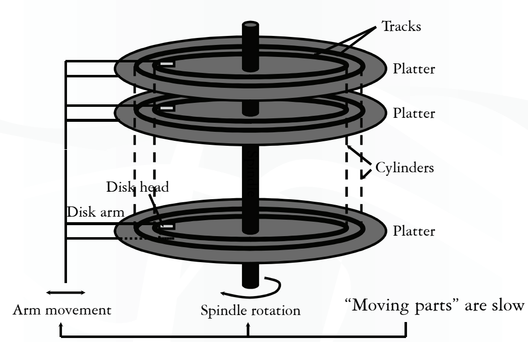
How far away is data?

Location	Cycles	Location	Time
Registers	1	My head	1 min.
On-chip cache	2	This room	2 min.
On-board cache	10	Duke campus	10 min.
Memory	100	Washington D.C.	1.5 hr.
Disk	10^6	Pluto	2 yr.
Tape	10^9	Andromeda	2000 yr.

(Source: AlphaSort paper, 1995)

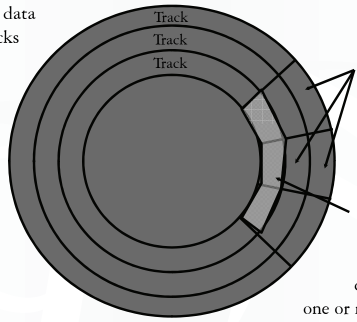
☞ I/O dominates—design your algorithms to reduce I/O!

A typical disk



Top view

7



Disk access time

8

Sum of:

- Seek time: time for disk heads to move to the correct cylinder
- Rotational delay: time for the desired block to rotate under the disk head
- Transfer time: time to read/write data in the block (= time for disk to rotate over the block)

Random disk access

9

Seek time + rotational delay + transfer time

- Average seek time
  - Time to skip one half of the cylinders?
  - Not quite; should be time to skip a third of them (why?)
  - "Typical" value: 5 ms
- Average rotational delay
  - Time for a half rotation (a function of RPM)
  - "Typical" value: 4.2 ms (7200 RPM)

Sequential disk access

10

Seek time + rotational delay + transfer time

- Seek time
  - 0 (assuming data is on the same track)
- Rotational delay
  - 0 (assuming data is in the next block on the track)
- Easily an order of magnitude faster than random disk access!

Performance tricks

11

- Disk layout strategy
  - Keep related things (what are they?) close together: same sector/block → same track → same cylinder → adjacent cylinder
- Double buffering
  - While processing the current block in memory, prefetch the next block from disk (overlap I/O with processing)
- Disk scheduling algorithm
  - Example: "elevator" algorithm
- Track buffer
  - Read/write one entire track at a time
- Parallel I/O
  - More disk heads working at the same time

Record layout

12

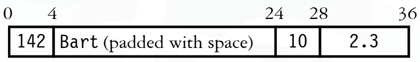
Record = row in a table

- Variable-format records
  - Rare in DBMS—table schema dictates the format
  - Relevant for semi-structured data such as XML
- Focus on fixed-format records
  - With fixed-length fields only, or
  - With possible variable-length fields

Fixed-length fields

13

- All field lengths and offsets are constant
  - Computed from schema, stored in the system catalog
- Example: `CREATE TABLE Student(SID INT, name CHAR(20), age INT, GPA FLOAT);`

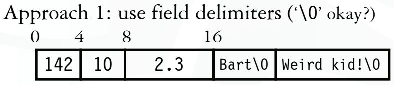


- Watch out for alignment
  - May need to pad; reorder columns if that helps
- What about `NULL`?
  - Add a bitmap at the beginning of the record

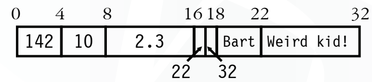
Variable-length records

14

- Example: `CREATE TABLE Student (SID INT, name VARCHAR(20), age INT, GPA FLOAT, comment VARCHAR(100));`
- Approach 1: use field delimiters ('`\0`' okay?)



- Approach 2: use an offset array



- Put all variable-length fields at the end (why?)
- Update is messy if it changes the length of a field

LOB fields

15

- Example: `CREATE TABLE Student(SID INT, name CHAR(20), age INT, GPA FLOAT, picture BLOB(32000));`
- Student records get "de-clustered"
  - Bad because most queries do not involve `picture`
- Decomposition (automatically done by DBMS and transparent to the user)
  - *Student*(*SID*, *name*, *age*, *GPA*)
  - *StudentPicture*(*SID*, *picture*)

Block layout

16

How do you organize records in a block?

- NSM (N-ary Storage Model)
  - Most commercial DBMS
- PAX (Partition Attributes Across)
  - Ailamaki et al., *VLDB* 2001

NSM

17

- Store records from the beginning of each block
- Use a directory at the end of each block
  - To locate records and manage free space
  - Necessary for variable-length records

Why store data and directory at two different ends?

Both can grow easily

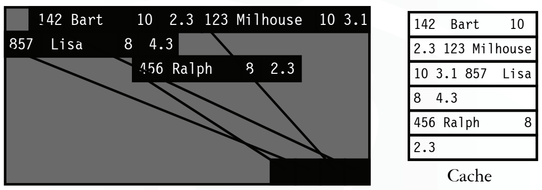
Options

18

- Reorganize after every update/delete to avoid fragmentation (gaps between records)
  - Need to rewrite half of the block on average
- What if records are fixed-length?
  - Reorganize after delete
    - Only need to move one record
    - Need a pointer to the beginning of free space
  - Do not reorganize after update
    - Need a bitmap indicating which slots are in use

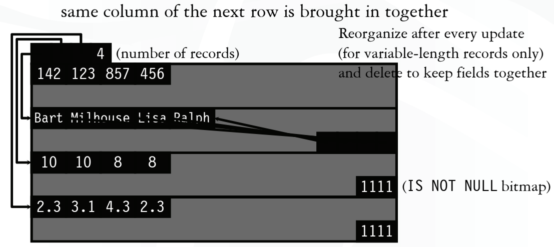
Cache behavior of NSM

- Query: `SELECT SID FROM Student WHERE GPA > 2.0;`
- Assumption: cache line size < record size
- Lots of cache misses
  - `SID` and `GPA` are not close enough by memory standards



PAX

- Most queries only access a few columns
- Cluster values of the same columns in each block
  - When a particular column of a row is brought into the cache, the same column of the next row is brought in together



Summary

- Storage hierarchy
  - Why I/O's dominate the cost of database operations
- Disk
  - Steps in completing a disk access
  - Sequential versus random accesses
- Record layout
  - Handling variable-length fields
  - Handling `NULL`
  - Handling modifications
- Block layout
  - NSM: the traditional layout
  - PAX: a layout that tries to improve cache performance