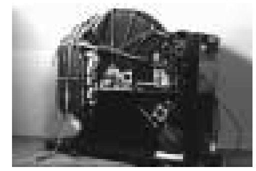
Storing Data: Disks and Files

15-415 Spring 2003, Lecture 4

(R&G Chapter 9)

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

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!

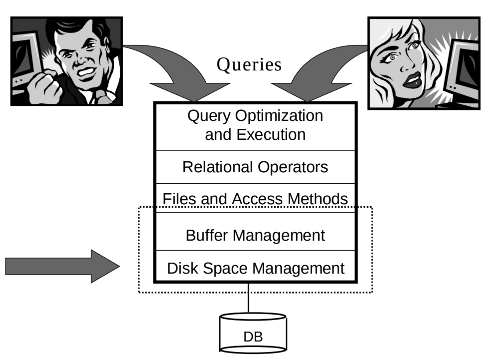
Homework 1

- **out today**
- **Due Wednesday, February 5**
- **Send questions to newsgroup!**
- **Not much coding needed – but it will take you a while to familiarize yourself with the code and do the analysis required, so...**
- **START EARLY!!!!!**

Why Not Store It All in Main Memory?

- ***Costs too much*. $100 will buy you either 0.5 GB of RAM or 100 GB of disk (EIDI/ATA) or 20GB (SCSI) today.**
  - High-end Databases today in the 10-100 TB range.
  - Approx 60% of the cost of a production system is in the disks.
- ***Main memory is volatile*. We want data to be saved between runs. (Obviously!)**
- **Note, some specialized systems do store entire database in main memory.**
  - Vendors claim 10x speed up vs. traditional DBMS running in main memory.

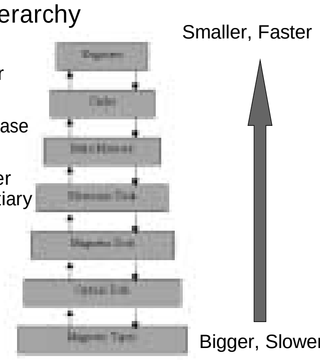
The BIG Picture



The Storage Hierarchy

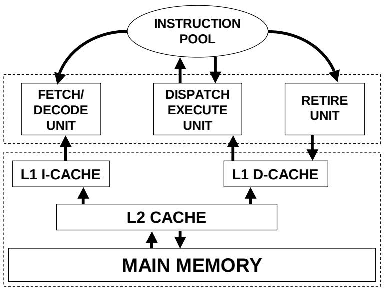
- Main memory (RAM) for currently used data.
- Disk for the main database (secondary storage).
- Tapes for archiving older versions of the data (tertiary storage).

QUESTION: Why does it have to be a hierarchy?



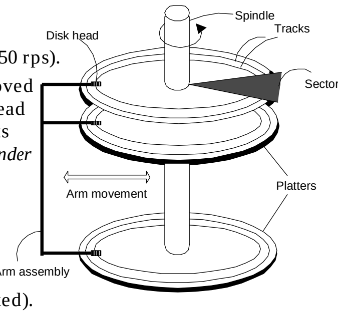
Source: Operating Systems Concepts 5th Edition

Processor/memory subsystem



– Out-of-order execution, non-blocking caches
– L1 is usually on-chip, L2 off-chip (recently: L3)

Anatomy of a Disk



The platters spin (say, 150 rps).

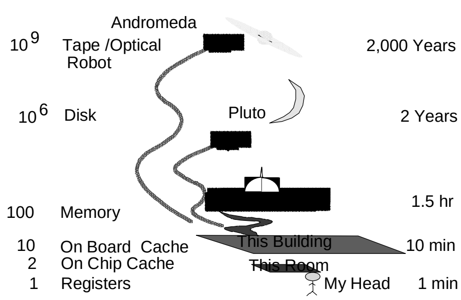
The arm assembly is moved in or out to position a head on a desired track. Tracks under heads make a *cylinder* (imaginary!).

Only one head reads/writes at any one time.

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

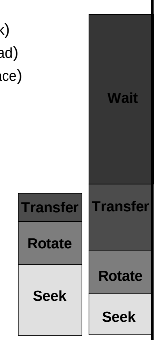
❖Newer disks have several "zones", with more data on outer tracks.

Jim Gray's Storage Latency Analogy: How Far Away is the Data?



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 < 1msec per 4KB page
- **Key to lower I/O cost: reduce seek/rotation delays! Hardware vs. software solutions?**
- **Also note: For shared disks most time spent waiting in queue for access to arm/controller**



Disks

- **Secondary storage device of choice.**
- **Main advantage over tapes: *random access* vs. *sequential*.**
  – Also, they work. (Tapes deteriorate over time)
- **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!

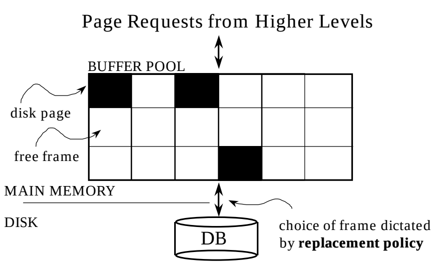
Arranging Pages on Disk

- **"*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!**
- **Also, modern controllers do their own caching.**

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! Higher levels don't need to know if/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!*
- *Buffer Mgr hides the fact that not all data is in RAM (just like hardware cache policies hide the fact that not all data is in the caches)*

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!*

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

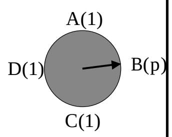
Buffer Replacement Policy

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

LRU Replacement Policy

- ***Least Recently Used (LRU)***
  - for each page in buffer pool, keep track of time last *unpinned*
  - replace the frame which has the oldest (earliest) time
  - very common policy: intuitive and simple
- **Problems?**
- ***Problem: Sequential flooding***
  - 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).

"Clock" Replacement Policy



- **An approximation of LRU.**
- **Arrange frames into a cycle, store one "reference bit" per frame**
- **When pin count goes to 0, reference bit set on.**
- **When replacement necessary:**

```
do {
    if (pincount == 0 && ref bit is off)
        choose current page for replacement;
    else if (pincount == 0 && ref bit is on)
        turn off ref bit;
    advance current frame;
} until a page is chosen for replacement;
```

Questions:
How like LRU?
Problems?

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.**
  - Note, this is changing --- OS File systems are getting smarter (i.e., more like databases!)
- **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.

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.