Lecture 16: Data Storage

Wednesday, November 6, 2006

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Outline

Data Storage
- The memory hierarchy – 11.2
- Disks – 11.3
- Merge sort – 11.4

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The Memory Hierarchy

Main Memory

- Volatile
- limited address spaces
- expensive
- **average access time: 10-100 nanoseconds**

Cache:
access time 10 nano's

Disk

- 5-10 MB/S transmission rates
- 2-10 GB storage
- **average time to access a block: 10-15 msecs.**
- Need to consider seek, rotation, transfer times.
- Keep records "close" to each other.

Tape

- 1.5 MB/S transfer rate
- 280 GB typical capacity
- **Only sequential access**
- Not for operational data

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Main Memory

- Fastest, most expensive
- Today: 512MB are common on PCs
- Many databases could fit in memory
  - New industry trend: Main Memory Database
  - E.g TimesTen, DataBlitz
- Main issue is volatility
  - Still need to store on disk

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Secondary Storage

- Disks
- Slower, cheaper than main memory
- Persistent !!!
- Used with a main memory buffer

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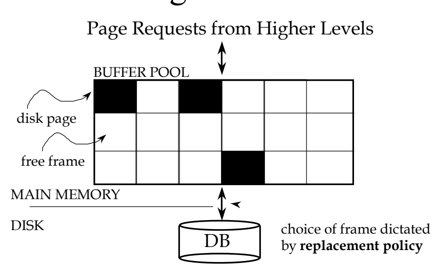
Buffer Management in a DBMS



- Data must be in RAM for DBMS to operate on it!
- Table of <frame#, pageid> pairs is maintained.
- LRU is not always good.

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Buffer Manager

Manages buffer pool: the pool provides space for a limited number of pages from disk.

Needs to decide on page replacement policy
- LRU
- Clock algorithm

Enables the higher levels of the DBMS to assume that the needed data is in main memory.

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Buffer Manager

Why not use the Operating System for the task??

- DBMS may be able to anticipate access patterns
- Hence, may also be able to perform prefetching
- DBMS needs the ability to force pages to disk.

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Tertiary Storage

- Tapes or optical disks
- Extremely slow: used for long term archiving only

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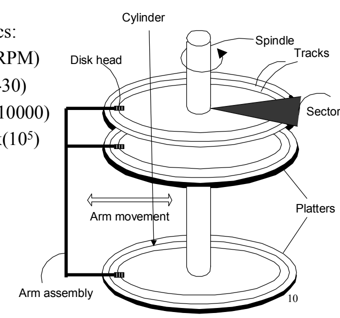
The Mechanics of Disk

Mechanical characteristics:
- Rotation speed (5400RPM)
- Number of platters (1-30)
- Number of tracks (<=10000)
- Number of bytes/track(10^5)



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Disk Access Characteristics

- Disk latency = time between when command is issued and when data is in memory
- Disk latency = seek time + rotational latency
  - Seek time = time for the head to reach cylinder
    - 10ms – 40ms
  - Rotational latency = time for the sector to rotate
    - Rotation time = 10ms
    - Average latency = 10ms/2
- Transfer time = typically 10MB/s
- Disks read/write one block at a time (typically 4kB)

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Average Seek Time

Suppose we have N tracks, what is the average seek time ?

- Getting from cylinder x to y takes time |x-y|

$$\frac{1}{N^2}\int_1^N\int_1^N |x-y|\,dydx =$$

$$\frac{1}{N^2}\int_1^N\left(\int_1^x (x-y)dy + \int_x^N (y-x)dy\right)dx =$$

$$\frac{1}{N^2}\int_1^N\left(\frac{x^2}{2} + \frac{(N-x)^2}{2}\right)dx =$$

$$\frac{1}{N^2}\left(\frac{N^3}{6} + \frac{N^3}{6}\right) = \frac{N}{3}$$

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The I/O Model of Computation

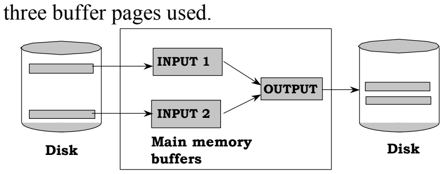
- In main memory algorithms we care about CPU time
- In databases time is dominated by I/O cost
- Assumption: cost is given only by I/O
- Consequence: need to redesign certain algorithms
- Will illustrate here with sorting

Sorting

- Illustrates the difference in algorithm design when your data is not in main memory:
  - Problem: sort 1Gb of data with 1Mb of RAM.
- Arises in many places in database systems:
  - Data requested in sorted order (ORDER BY)
  - Needed for grouping operations
  - First step in sort-merge join algorithm
  - Duplicate removal
  - Bulk loading of B+-tree indexes.

2-Way Merge-sort: Requires 3 Buffers

- Pass 1: Read a page, sort it, write it.
  - only one buffer page is used
- Pass 2, 3, …, etc.:
  - three buffer pages used.

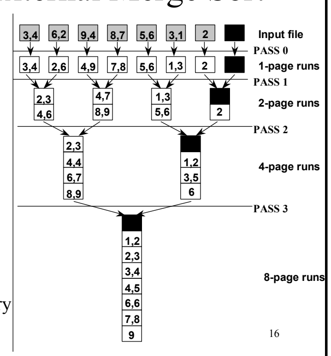


Two-Way External Merge Sort

- Each pass we read + write each page in file.
- N pages in the file => the number of passes $= \lceil \log_2 N \rceil + 1$
- So total cost is:

$$2N\left(\lceil \log_2 N \rceil + 1\right)$$

- Improvement: start with larger runs
- Sort 1GB with 1MB memory in 10 passes



Can We Do Better ?

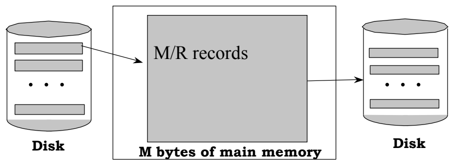
- We have more main memory
- Should use it to improve performance

Cost Model for Our Analysis

- **B:** Block size
- **M:** Size of main memory
- **N:** Number of records in the file
- **R:** Size of one record

External Merge-Sort

- Phase one: load M bytes in memory, sort
  - Result: runs of length M/R records



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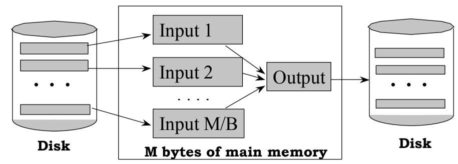
Phase Two

- Merge M/B – 1 runs into a new run
- Result: runs have now M/R (M/B – 1) records



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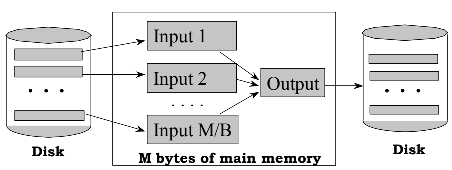
Phase Three

- Merge M/B – 1 runs into a new run
- Result: runs have now M/R $(M/B - 1)^2$ records



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Cost of External Merge Sort

- Number of passes: $1 + \lceil \log_{M/B-1} \lceil NR/M \rceil \rceil$
- Think differently
  - Given B = 4KB, M = 64MB, R = 0.1KB
  - Pass 1: runs of length M/R = 640000
    - Have now sorted runs of 640000 records
  - Pass 2: runs increase by a factor of M/B – 1 = 16000
    - Have now sorted runs of 10,240,000,000 = 10^{10} records
  - Pass 3: runs increase by a factor of M/B – 1 = 16000
    - Have now sorted runs of 10^{14} records
    - Nobody has so much data !
- Can sort everything in 2 or 3 passes !

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External Merge Sort

- The **xsort** tool in the XML toolkit sorts using this algorithm
- Can sort 1GB of XML data in about 8 minutes

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