Managing Resources, cont., Intro Query Processing

CS634
Lecture 8

These slides are not based on “Database Management Systems” 3rd ed, Ramakrishnan and Gehrke

Disk Resource: Find out about disks

- One way: read the system log as the system comes up
- Linux: the **`dmesg`** tool outputs the system log:
- Example: topcat.cs.umb.edu:

```
…
[ 1.220567] ata4.00: ATA-7: WDC WD2500JS-75NCB3, 10.02E04, max UDMA/133
[ 1.220654] ata3.00: ATA-7: WDC WD2500JS-75NCB3, 10.02E04, max UDMA/133
[ 1.228713] scsi 2:0:0:0: Direct-Access     ATA      WDC WD2500JS-75N 10.0 PQ: 0
ANSI: 5
[ 1.229069] scsi 3:0:0:0: Direct-Access     ATA      WDC WD2500JS-75N 10.0 PQ: 0
ANSI: 5
…
```

- This show two Western Digital disks (do a web search on `WDC WD2500JS-75NCB3` to find out about them: see next slide)
- It's a SATA disk, but that technology is under the SCSI umbrella in the kernel. SCSI is the older technology, and dbs2's disks are actual SCSI disks.
- Another way: look at /proc/scsi/scsi, a pseudofile maintained by the kernel, find same disk description
- We also found the system has 4GB of memory from dmesg and /proc/meminfo.

Finding out about the disks on topcat

Web search on `WDC WD2500JS-75NCB3` shows:

- We can buy this disk for $25 from Amazon, where it is identified as a

Dell JX718 WD2500JS-75NCB3 3.5" SATA 250GB 7200 Western Digital Desktop Hard Drive Dimension 3100C 3.

  - That's 7200 rpm. It's sold by Dell for its 3100c system but made by Western Digital. The picture shows it was manufactured in 2006, so 10-yr.-old technology.

- Data sheet on the disk at wdc.com. It shows average latency 4.2ms, 8 MB buffer, data transfer rates: 972 Mb/s (max) buffer to disk, 3Gb/s (max) buffer to host.
  - That 972 Mb/s = 121 MB/s, more than twice the benchmarks results below
- Benchmark results that rate this disk below average of its class on sequential reads at 48 MB/s, and rate this disk as good for its random 4KB reads at .47 MB/s.
  - That's .47/4*1000 = 120 ops/s, a bit higher than our estimate of 100 ops/s for a 7200 rpm disk

Other disks: Seagate Barracuda 7200.14 250GB: seq. read 102 MB/s, random 4KB reads .48 MB/s, considered fair sequential performance

WD VelociRaptor 250GB: seq read 164 MB/s, random 4KB reads 1.32 MB/s (a 10,000 rpm drive, so should be 10000/7200 = 1.39 faster)

So the rule-of-thumb that a 7200rpm disk gets 100 ops/sec and 100 MB/s sequential reads is approximately right.

Partitions in use for filesystems on topcat's disks

Use "df –l" to see local filesystems, look for /dev/sd* entries:

```
topcat$ df -l
Filesystem     1K-blocks    Used Available Use% Mounted on
udev             2013052       4   2013048   1% /dev
tmpfs             404784     464    404320   1% /run
/dev/sda1      236049160 6643040 217392452   3% /
… (no more /dev/… entries)
```

This shows only one disk in use for filesystems, /dev/sda, and only one partition of it, /dev/sda1.

The filesystem on /dev/sda1 is using only 3% of the diskspace, and we have plenty of room (217 GB) for expansion.

Partitions on topcat

List all partitions, whether in active use or not:

```
eoneil@topcat:~/634$ sudo lsblk -o NAME,FSTYPE,SIZE,MOUNTPOINT,LABEL
[sudo] password for eoneil:
NAME   FSTYPE   SIZE MOUNTPOINT LABEL
sda           232.9G
├─sda1 ext4   228.9G /
├─sda2            1K
└─sda5 swap       4G [SWAP]
sdb           232.9G
└─sdb1 ext2   232.8G
sr0            1024M
```

- This shows both disks, /dev/sda and /dev/sdb, and the fact that /dev/sda has two partitions in use:
  - /dev/sda1 for the root filesystem (i.e. the whole local filesystem in this case)
  - /dev/sda5 for swap space, used by the kernel for virtual memory pages, etc.
- So /dev/sdb is apparently healthy but not in use on this system

Disks on dbs3

- One way: read the system log as the system comes up, with dmesg
- Another way: look at /proc/scsi/scsi, get same info:

```
[oracle@dbs3 scsi]$ more scsi
Attached devices:
Host: scsi0 Channel: 02 Id: 00 Lun: 00
  Vendor: DELL     Model: PERC H730 Mini   Rev: 4.25
  Type:   Direct-Access                    ANSI  SCSI revision: 05
Host: scsi0 Channel: 02 Id: 01 Lun: 00
  Vendor: DELL     Model: PERC H730 Mini   Rev: 4.25
  Type:   Direct-Access                    ANSI  SCSI revision: 05
```

- Actual disks are hidden inside two hardware RAIDs, which appear as two huge “sd” disks to the system
- Similarly on pe07, see one such hardware RAID

MySQL 5.1-5.6/Innodb: just one tablespace, v5.7: can do additional tablespaces, in theory

- Global variable (can be set in /etc/mysql/my.cnf or its included files)
- *innodb_data_home_path* gives list of files making up the one tablespace:
- The default is:

  innodb_data_file_path = ibdata1:10M:autoextend

  - Here ibdata1 is the filename relative to *innodb_data_home_dir* (if non-null) or *datadir*
  - This starts with one 10M file and lets it grow by 8M extensions

pe07's mysql (v. 5.7) has datadir = /var/lib/mysql and no setting for innodb_data_home_dir or innodb_data_file_path

  - So our data file is /var/lib/mysql/ibdata1.

- MySQL docs: [System globals index]()

MySQL Data files

pe07$ sudo ls -l /var/lib/mysql

…

```
drwxr-x--- 2 mysql mysql      4096 Mar 22  2017 hcharlesdb
drwxr-x--- 2 mysql mysql      4096 Sep 19 15:43 himani96db
drwxr-x--- 2 mysql mysql      4096 Feb 28  2017 hmatadb
-rw-r----- 1 mysql mysql      1364 Jan 25 06:05 ib_buffer_pool
-rw-r----- 1 mysql mysql  79691776 Feb 11 11:39 ibdata1
-rw-r----- 1 mysql mysql  50331648 Feb 11 11:40 ib_logfile0
-rw-r----- 1 mysql mysql  50331648 Jan 27 10:39 ib_logfile1
-rw-r----- 1 mysql mysql 549453824 Feb 12 13:20 ibtmp1
drwxr-x--- 2 mysql mysql      4096 Dec  4 15:01 inirav51db
```

…

- Here ibdata1 is the data file, and we see two redo log files too.
- Each database has a small directory here, but all the table and index pages are in the one big file.

Adding a file to the MySQL system tablespace

- To add /path/ibdata2 as a file, we freeze the current datafile by removing autoextend, specify it with a full path, and add the new file to the list, with autoextend if desired:

  innodb_data_file_path =
  /var/lib/mysql/ibdata1:80M;/path/ibdata2:50M:autoextend

- Specifically, we bring the server down, change my.cnf, and bring the server up again.
- See MySQL 5.7 manual, sec. 14.7.1.
- These added file paths may specify software or hardware RAID, or even raw partitions.

Living with a single tablespace

- With two projects sharing one server, it is common to run two instances of mysql, one for each project.
- Then each project has its own defined disks
- DBA must add up needed CPU and memory resource needs
- Or let the databases fight over memory using default memory setup that uses OS caching (more on this soon)
- Or just buy another server…

Innodb Log files

- The redo log file location is *innodb_log_group_home_dir* in my.cnf, or the datadir if this isn't set (topcat case).
- The undo log is in the main tablespace.
- If you do not specify any InnoDB log variables in my.cnf, the default is to create two redo log files named ib_logfile0 and ib_logfile1 in the MySQL data directory.
- To change the redo log location, say onto a mirrored RAID, bring down the server, which "uses up" the logs in a sense, edit the location, and bring up the server.
- Best to do this sort of setup as part of database initialization.

Basic Memory Config in MySQL

- Innodb has a buffer pool, size *innodb_buffer_pool_size*
- The size in bytes of the memory buffer InnoDB uses to cache data and indexes of its tables. The default value is 128MB (v 5.1-5.7, and in use on pe07).
- But by default (and on pe07), this buffer memory uses OS caching, i.e., each read into the cache is via a file descriptor opened without the special option to avoid OS buffering (O_DIRECT on Linux).
- This means the server is using the full memory of the server for its data, with two copies for the pages in the buffer pool, in competition with the other programs running, of course.
- The DBA can decide this is not a good idea, and change over to more traditional database buffering, that is, not allow OS buffering for buffer pages.

Basic Memory Config in MySQL, cont.

- Innodb has a buffer pool, size *innodb_buffer_pool_size*
- The size in bytes of the memory buffer InnoDB uses to cache data and indexes of its tables. The default value is 128MB (v 5.1-5.7, and in use on pe07).
- Mysql can be configured to avoid OS buffering. Then the buffer pool size is extremely important.
- On a dedicated database server, you may set this to up to 80% of the machine physical memory size.
  - But of course not larger than the DB data itself.
  - Also raise *innodb_log_file_size* so total of log file sizes is *innodb_buffer_pool_size (Ref: see innodb_log_file_size docs)*
- With two mysql instances, make that <= 40% each.
- Note: quick way to find physical memory size on a UNIX/Linux system: use the “top” utility.

Basic Memory Config in Oracle

- Two kinds of memory:
  - SGA System Global area, including the database buffer caches
  - PGA Program Global area, including memory for sorts, hashing, bitmaps, and bulk loads
- Oracle offers Automatic Shared Memory Management.
  - This has two major settable parameters, for the SGA and PGA areas, called SGA_TARGET and PGA_AGGREGATE_TARGET.
  - Or you can set just MEMORY_TARGET and let Oracle decide how to subdivide it
- On a dedicated database server, you may set the sum of these to up to 80% of the machine physical memory size.
- Could be .6*Mem for SGA, .2*Mem for PGA for example
- dbs3: System memory = 64GB, sga_target = 24064M = 24G, pga_aggregate_target = 8007M = 8G

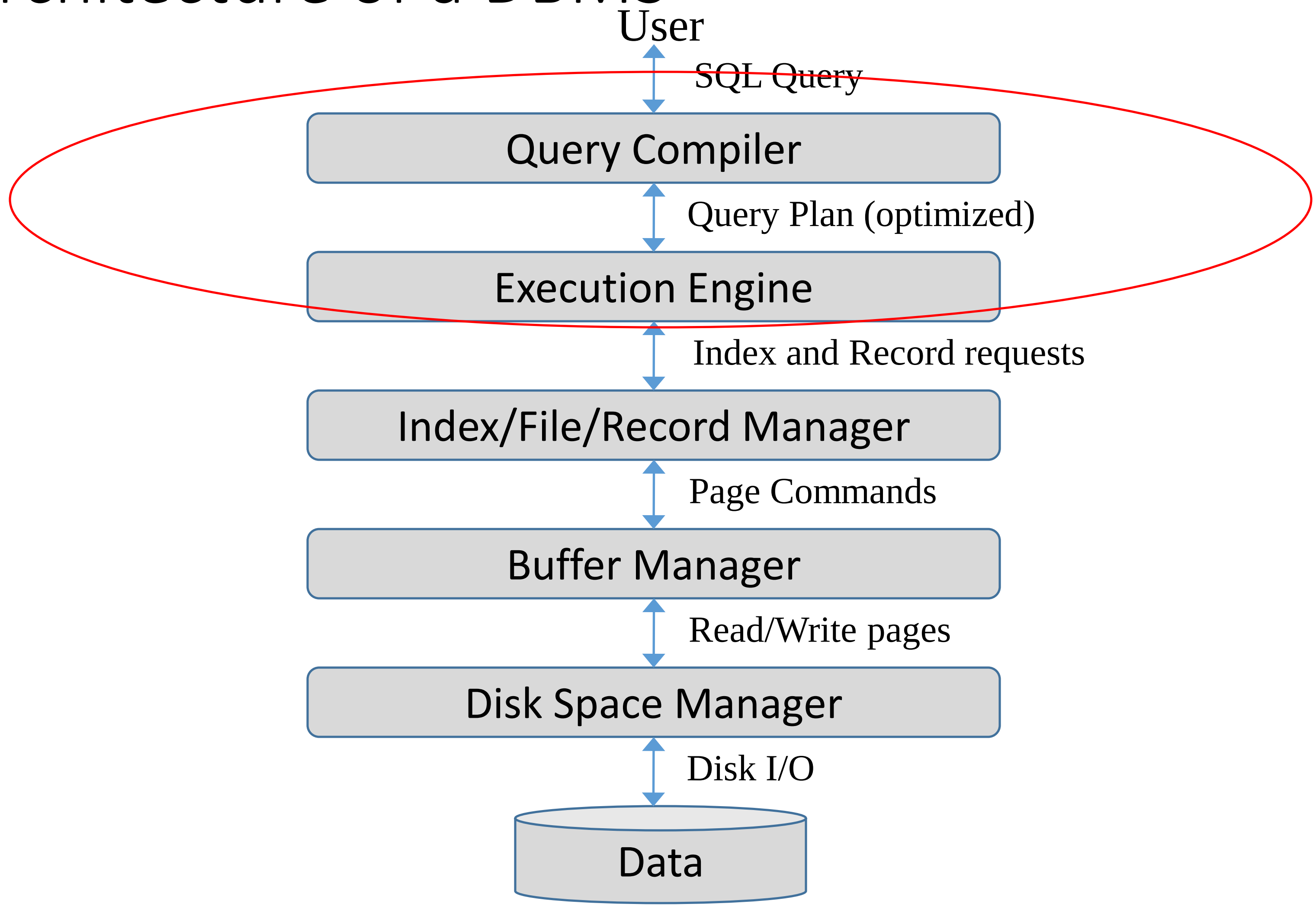
Oracle Memory Config

- If lots of complex queries or sorting, up the PGA size
- Some people think a good DBA should take over memory tuning
- But that involves a lot of parameters.
- Most important is overriding ridiculously small default memory sizing

Query Evaluation Overview

Slides based on "Database Management Systems" 3rd ed, Ramakrishnan and Gehrke

Architecture of a DBMS



A first course in database systems, 3rd ed, Ullman and Widom

The two major parts of the DB engine

- QP = query processor, top two boxes on last slide
- Storage manager = rest of boxes
- See “index and record requests” flowing between
- Can be more specific, see list, pg. 283:
- Actions on “files”: file scan, search with equality selection, search with range selection, insert record, delete record
- Files listed: heap files, sorted files, clustered files, heap file with unclustered tree index, heap file with unclustered hash index.
- An index on its own is a sorted file.

Where are the tables?

- A <u>table</u> could be held in a heap file with multiple indexes. A file only has at most one currently relevant index, the one in use.
- The database can use multiple indexes for a single query, but that would mean the QP first working with (say) two indexes and then working with the results from that plus the table data file.
- So a file can be a simplification of a table (ignoring all but one of its indexes, or all of them) or an index itself
- The API can be called an ISAM (in one of its meanings), indexed sequential access method, allowing scans and lookup, range scan if tree-based.

Storage Engine API

- If a QP and storage engine hue to an API, then different storage engines can be “plugged in” to the database
- Example: MS SQL Server can access Excel files via the OLE-DB API. Also via ODBC.
    - That is, there is an Excel OLE-DB “provider” (you don’t need the whole Excel GUI).
- Example: MySQL has various storage engines—MyISAM and Innodb, etc.
    - New one (Nov ‘12): ClouSE uses Amazon S3 cloud storage. But seems to be a dead project now. S3 is actively used for backup of mysql data. Can’t just put the mysql datafile on S3.

Query Evaluation Overview

- SQL query first translated to relational algebra (RA)
  - Tree of RA operators, with choice of algorithm among available implementations for each operator
- Main issues in query optimization
  - For a given query, what plans are considered?
  - Algorithm to search plan space for cheapest (estimated) plan
  - How is the cost of a plan estimated?
- Objective
  - Ideally: Find best plan
  - Practically: Avoid worst plans!
- We will study the System R approach

Example Schema

Sailors

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
58	rusty	10	35.0

Boats

bid	name	color
101	interlake	red
103	clipper	green

Reserves

sid	bid	day
22	101	10/10/96
58	103	11/12/96

Example Query

Sailors (*sid*: integer, *sname*: string, *rating*: integer, *age*: real)
Reserves (*sid*: integer, *bid*: integer, *day*: dates)
Boats(*bid*: integer, *name*: string, *color*: string)

- *Find names of sailors who have rating 10 and who reserved a red boat.*

select sname from sailors s, reserves r, boats b
where s.sid = r.sid and r.bid = b.bid -- join conditions
and s.rating = 10 and b.color = 'red'

RA: on board: see joins, selection, projection operators

See Fig. 12.3, pg. 406 and Fig. 12.6, pg. 410 for similar diagrams.

Statistics and Catalogs

- To choose an efficient plan, the QP needs information about the relations and indexes involved

- ***Catalogs*** contain information such as:
  - Tuple count (NTuples) and page count (NPages) for each relation
  - Distinct key value count (NKeys) for each index, INPages
  - Index height, low/high key values (Low/High) for each tree index
  - Histograms of the values in some fields (optional)

- Catalogs updated periodically
  - Updating statistics when data change too expensive
  - Approximate information used, slight inconsistency is ok
  - Both Oracle and mysql have an "analyze table" command for gathering stats, for use after a table load or massive update.
  - Both Oracle and mysql (v. 5.6+) store stats across DB shutdown/startup and automatically update them periodically.

Methods for Relational Operator Evaluation

Techniques:

- Indexing
  - Choose an index based on conditions in WHERE clause or join conditions
- Scan or Iteration
  - Reading a file entirely: file can refer to both data records file or index file
- Partitioning
  - Partition the input tuples and replace an expensive operation by similar operations on smaller inputs

Access Paths

- An access path is a method of retrieving tuples:
  - File scan
  - Index scan using an index that matches a condition
- A tree index matches (a conjunction of) terms that involve every attribute in a prefix of the search key
  - E.g., tree index on <a, b, c> matches the selection a=5 AND b=3, and a=5 AND b>6, but not b=3
- A hash index matches (a conjunction of) terms attribute = value for every attribute in the search key of the index
  - E.g., hash index on <a, b, c> matches a=5 AND b=3 AND c=5
  - but it does not match b=3, or a=5 AND b=3

Example of matching indexes

Pg. 399: fix error Sailors→ Reserves on line 8

Reserves (<u>*sid*: integer, *bid*: integer, *day*: dates</u>, *rname*: string) ← rname column added here

with indexes:

- Index1: Hash index on (rname, bid, sid)
  - Matches: rname='Joe' and bid = 5 and sid=3
  - Doesn't match: rname='Joe' and bid = 5
- Index2: Tree index on (rname, bid, sid)
  - Matches: rname='Joe' and bid = 5 and sid=3
  - Matches: rname='Joe' and bid = 5, also rname = 'Joe'
  - Doesn't match: bid = 5
- Index3: Tree index on (rname)
- Index4: Hash index on (rname)
  - These two match any conjunct with rname='Joe' in it

Executing Selections

- Find the *most selective access path*, retrieve tuples using it
  - Then, apply any remaining terms that don't match the index
- *Most selective access path:* index or file scan estimated to require the fewest page I/Os
  - Consider *day<8/9/94 AND bid=5 AND sid=3*

- If we have B+ tree index on *day*, use that access path
  - Then, *bid=5* and *sid=3* must be checked for each retrieved tuple
  - *day* condition is primary conjunct

- Alternatively, use hash index on *<bid, sid>* first
  - Then, *day<8/9/94* must then be checked

Example Schema

Sailors (*sid*: integer, *sname*: string, *rating*: integer, *age*: real)
Reserves (*sid*: integer, *bid*: integer, *day*: date, *rname*: string)

- Similar to old schema; *rname* added–name for the reservation itself
- Makes reserves even more clearly an entity (recall earlier discussion in class 2)
- Reserves:
  - 40 bytes long tuple, 100K records, 100 tuples per page, 1000 pages
- Sailors:
  - 50 bytes long tuple, 40K tuples, 80 tuples per page, 500 pages

Using an Index for Selections

- Cost influenced by:
  - Number of qualifying tuples
  - Whether the index is clustered or not
  - Cost of finding qualifying data entries is typically small
  - E.g.,

```
SELECT  *
FROM    Reserves R
WHERE   R.rname < 'C%'
```

- Assuming uniform distribution of names, 10% of tuples qualify, that is 10000 tuples
  - With a clustered index, cost is little more 100 I/Os
  - If not clustered, up to10K I/Os!

Executing Projections

- Expensive part is removing duplicates
  - DBMS don’t remove duplicates unless DISTINCT is specified

```
SELECT   DISTINCT R.sid, R.bid
FROM     Reserves R
```

- Sorting Approach
  - Sort on <sid, bid> and remove duplicates
  - Cheap if an index with both R.sid and R.bid in the search key exists
- Hashing Approach
  - Hash (hash function h1) on <sid, bid> to create partitions
  - Load partitions into memory one at a time, build in-memory hash structure using hash function h2, and eliminate duplicates

Executing Joins: Index Nested Loops

foreach tuple r in R do
    foreach tuple s in S where $r_i == s_j$ do
        add <r, s> to result

- Cost = M + (M*p_R) * (cost of finding matching S tuples)
- M = number of pages of R, p_R = number of R tuples per page

- If relation has index on join attribute, make it inner relation
  - For each outer tuple, cost of probing inner index is 1.2 for hash index, 2-4 for B+, plus cost to retrieve matching S tuples
  - Clustered index typically single I/O
  - Unclustered index 1 I/O per matching S tuple