CSE544
Database Architecture

Tuesday, February 1^{st}, 2011

Slides courtesy of Magda Balazinska

Where We Are

- **What we have already seen**
  - **Overview of the relational model**
    - Motivation and where model came from
    - Physical and logical independence
  - **How to query a database**
    - Relational calculus
    - SQL
  - **Transactions**

- **Where we go from here**
  - **How can we efficiently implement this model?**

References

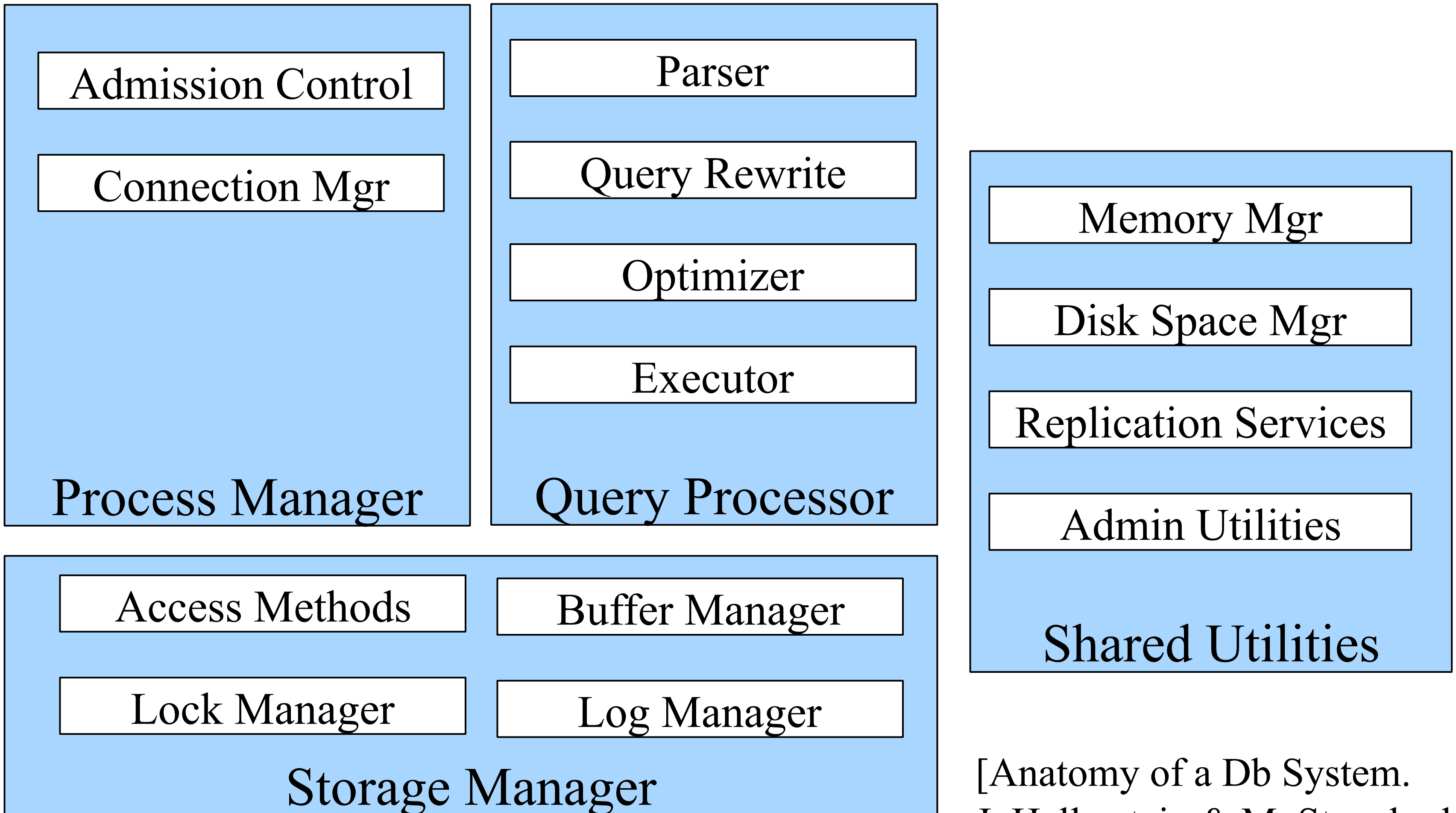
- Anatomy of a database system. J. Hellerstein and M. Stonebraker. In Red Book (4th ed).
- Operating system support for database management. Michael Stonebraker. Communications of the ACM. Vol 24. Number 7. July 1981. Also in Red Book (3rd ed and 4th ed).

Outline

DBMS architecture

- Main components of a modern DBMS
- Process models
- Storage models
- Query processor (we will cover this part in lecture 6)

DBMS Architecture



[Anatomy of a Db System.
J. Hellerstein & M. Stonebraker.
Red Book. 4ed.]

Process Model

Why not simply queue all user requests?
(and serve them one at the time)

Alternatives

1. **Process per connection**
2. **Server process** (thread per connection)
   - OS threads or DBMS threads
3. **Server process with I/O process**

Advantages and problems of each model?

Process Per Connection

- **Overview**
  - DB server forks one process for each client connection
- **Advantages**
  - Easy to implement (OS time-sharing, OS isolation, debuggers, etc.)
  - Provides more physical memory than a single process can use
- **Drawbacks**
  - Need OS-supported "shared memory" (for lock table, for buffer pool)
    - Since all processes access the same data on disk, need concurrency control
  - Not scalable: memory overhead and expensive context switches

Server Process

- **Overview**
  - DB assigns one thread per connection (from a thread pool)
- **Advantages**
  - Shared structures can simply reside on the heap
  - Threads are lighter weight than processes (memory, context switching)
- **Drawbacks**
  - Concurrent programming is hard to get right (race conditions, deadlocks)
  - Portability issues can arise when using OS threads
  - **Big problem**: entire process blocks on synchronous I/O calls
    - Solution 1: OS provides asynchronous I/O (true in modern OS)
    - Solution 2: Use separate process(es) for I/O tasks

DBMS Threads vs OS Threads

- **Why do DBMSs implement their own threads?**
  - Legacy: originally, there were no OS threads
  - Portability: OS thread packages are not completely portable
  - Performance: fast task switching

- **Drawbacks**
  - Replicating a good deal of OS logic
  - Need to manage thread state, scheduling, and task switching

- **How to map DBMS threads onto OS threads or processes?**
  - Rule of thumb: one OS-provided dispatchable unit per physical device
  - See page 9 and 10 of Hellerstein and Stonebraker's paper

Historical Perspective (1981)

- See paper: “OS Support for Database Management”

- No OS threads
- No shared memory between processes
  - Makes one process per user hard to program
- Some OSs did not support many to one communication
  - Thus forcing the one process per user model
- No asynchronous I/O
  - But inter-process communication expensive
  - Makes the use of I/O processes expensive

- Common original design: DBMS threads

Commercial Systems

- Oracle
  - Unix default: process-per-user mode
  - Unix: DBMS threads multiplexed across OS processes
  - Windows: DBMS threads multiplexed across OS threads
- DB2
  - Unix: process-per-user mode
  - Windows: OS thread-per-user
- SQL Server
  - Windows default: OS thread-per-user
  - Windows: DBMS threads multiplexed across OS threads

Admission Control

- Why does a DBMS need admission control?
- When does DBMS perform admission control?

Admission Control

- Why does a DBMS need admission control?
  - To avoid thrashing and provide “graceful degradation” under load
- When does DBMS perform admission control?
  - In the dispatcher process: want to drop clients as early as possible to avoid wasting resources on incomplete requests
  - Before query execution: delay queries to avoid thrashing

Outline

- **History of database management systems**
- **DBMS architecture**
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  - Process models
  - Storage models
  - Query processor

Storage Model

- **Problem**: DBMS needs spatial and temporal control over storage
  - Spatial control for performance
  - Temporal control for correctness and performance

Alternatives

- **Use “raw” disk device interface directly**
- **Use OS files**

Spatial Control
Using "Raw" Disk Device Interface

- **Overview**
  - DBMS issues low-level storage requests directly to disk device
- **Advantages**
  - DBMS can ensure that important queries access data sequentially
  - Can provide highest performance
- **Disadvantages**
  - Requires devoting entire disks to the DBMS
  - Reduces portability as low-level disk interfaces are OS specific
  - Many devices are in fact "virtual disk devices"

Spatial Control
Using OS Files

- **Overview**
  - DBMS creates one or more very large OS files

- **Advantages**
  - Allocating large file on empty disk can yield good physical locality

- **Disadvantages**
  - OS can limit file size to a single disk
  - OS can limit the number of open file descriptors
  - But these drawbacks have mostly been overcome by modern OSs

Historical Perspective (1981)

- Recognizes mismatch problem between OS files and DBMS needs
  - If DBMS uses OS files and OS files grow with time, blocks get scattered
  - OS uses tree structure for files but DBMS needs its own tree structure

- Other proposals at the time
  - Extent-based file systems
  - Record management inside OS

Commercial Systems

- Most commercial systems offer both alternatives
  - Raw device interface for peak performance
  - OS files more commonly used

- In both cases, we end-up with a DBMS file abstraction implemented on top of OS files or raw device interface

Temporal Control Buffer Manager

- Correctness problems
  - DBMS needs to control when data is written to disk in order to provide **transactional semantics** (we will study transactions later)
  - OS buffering can **delay writes**, causing problems when crashes occur

- Performance problems
  - OS optimizes buffer management for general workloads
  - DBMS understands its workload and can do better
  - Areas of possible optimizations
    - Page replacement policies
    - Read-ahead algorithms (physical vs logical)
    - Deciding when to flush tail of write-ahead log to disk

Historical Perspective (1981)

- Problems with OS buffer pool management long recognized
  - Accessing OS buffer pool involves an expensive system call
  - Faster to access a DBMS buffer pool in user space
  - LRU replacement does not match DBMS workload
  - DBMS can do better
  - OS can do only sequential prefetching, DBMS knows which page it needs next and that page may not be sequential
  - DBMS needs ability to control when data is written to disk

Commercial Systems

- DBMSs implement their own buffer pool managers
- Modern filesystems provide good support for DBMSs
  - Using large files provides good spatial control
  - Using interfaces like the mmap suite
    - Provides good temporal control
    - Helps avoid double-buffering at DBMS and OS levels

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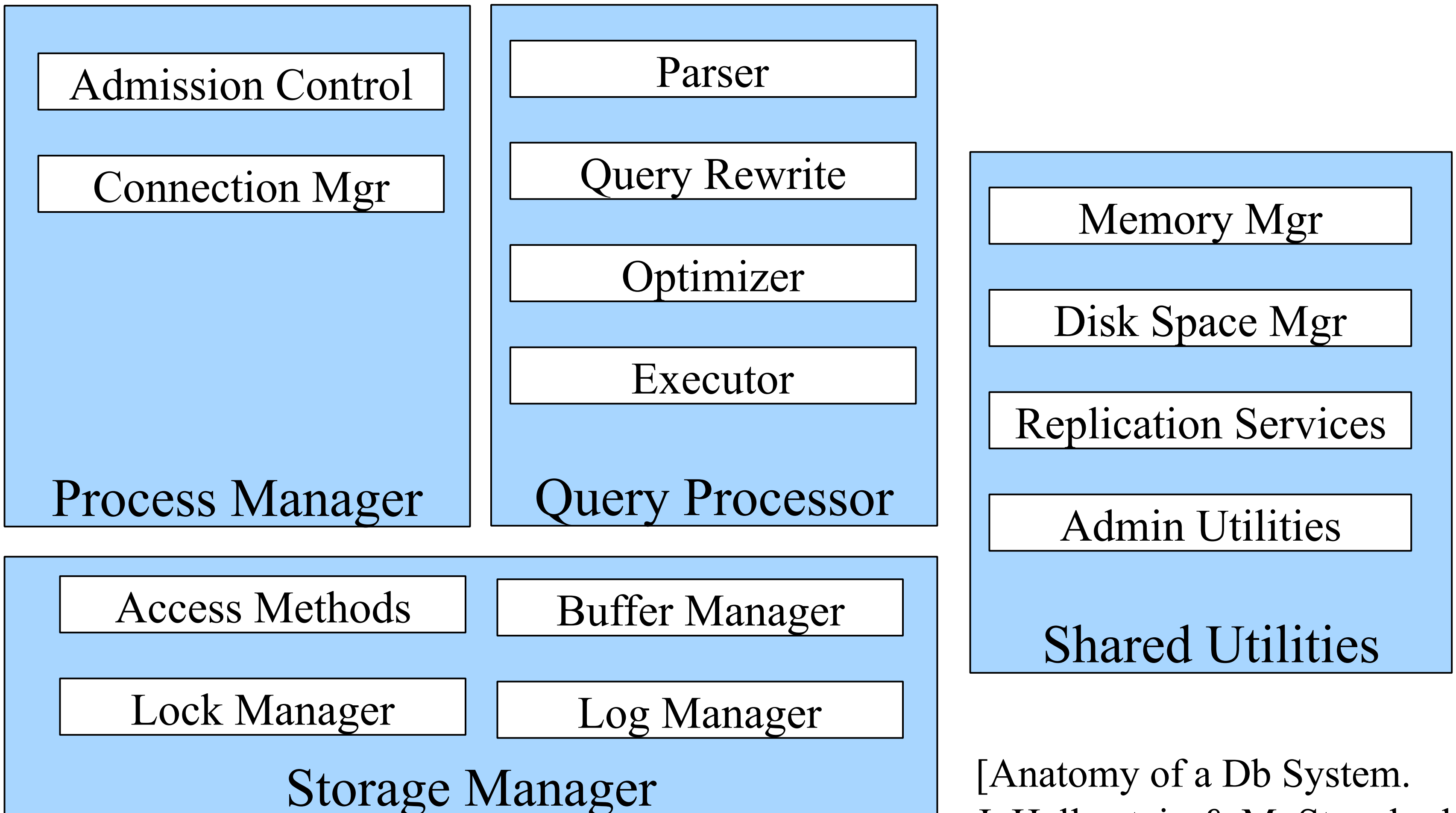
DBMS Architecture



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Summary

- Past few weeks: transactions
- Today: overview of architecture of a DBMS
- Next few weeks
  - Storage and indexing
  - Query execution
  - Query optimization
  - Distribution
  - Parallel processing