CMSC724: Anatomy of a Database System

Amol Deshpande

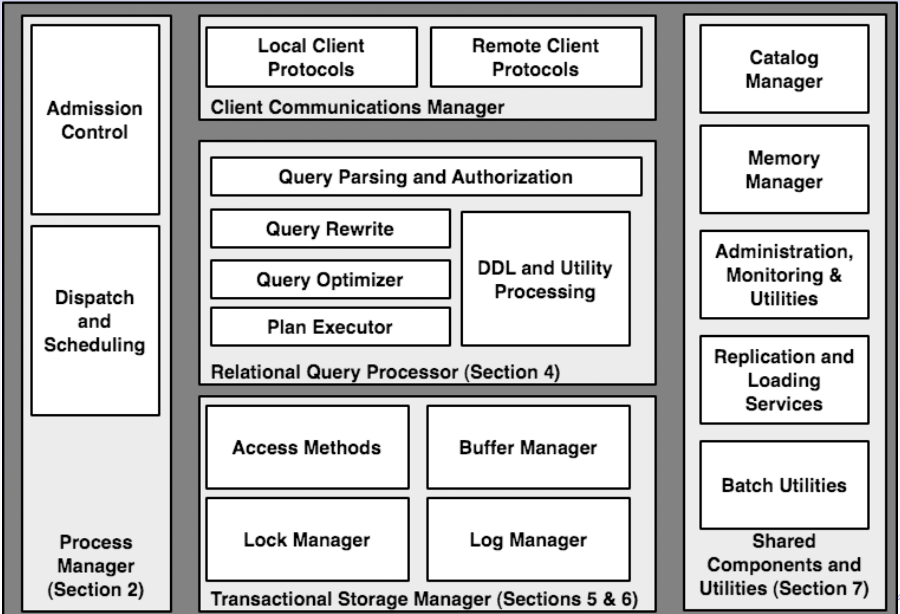
University of Maryland, College Park

February 8, 2011

Anatomy of a Database System

- How is it implemented ?
- Issues:
  - Process models
  - Parallelism
  - Storage models
  - Buffer manager
  - Query processing architecture
  - Transaction processing
  - Etc...

Overview


Admission Control
Dispatch and Scheduling
Process Manager (Section 2)
Local Client Protocols
Remote Client Protocols
Client Communications Manager
Query Parsing and Authorization
Query Rewrite
Query Optimizer
Plan Executor
DDL and Utility Processing
Relational Query Processor (Section 4)
Access Methods
Buffer Manager
Lock Manager
Log Manager
Transactional Storage Manager (Sections 5 & 6)
Catalog Manager
Memory Manager
Administration, Monitoring & Utilities
Replication and Loading Services
Batch Utilities
Shared Components and Utilities (Section 7)

Process Models

- Processes
  - Heavyweight, context switch expensive
  - Costly to create, limits on how many
  - Large address space, OS support from the beginning

Process Models

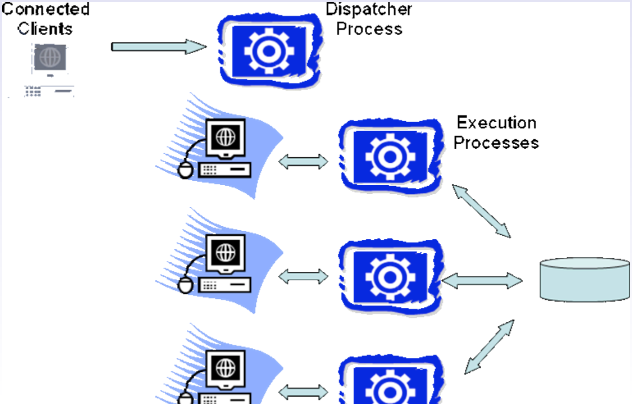
- Processes
  - Heavyweight, context switch expensive
  - Costly to create, limits on how many
  - Large address space, OS support from the beginning
- Threads
  - lightweight, more complicated to program
  - no OS support till recently
  - In theory, can have very large numbers, in practice, not lightweight enough

Process Models

- Processes
  - Heavyweight, context switch expensive
  - Costly to create, limits on how many
  - Large address space, OS support from the beginning
- Threads
  - lightweight, more complicated to program
  - no OS support till recently
  - In theory, can have very large numbers, in practice, not lightweight enough
- Huge implications on performance
  - Many DBMS wrote their own operating systems, their own thread packages etc...

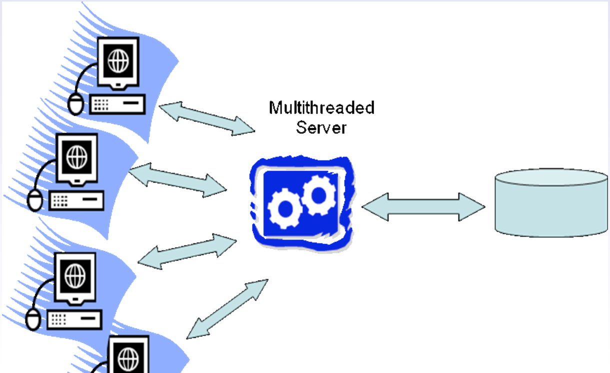
Process Models

- Assume: Uniprocessors + OS support for efficient threads
- Option 1: “Process per connection”
  - Not scalable (1000 Xion/s?), Shared data structures
  - OS manages time-sharing, easy to implement



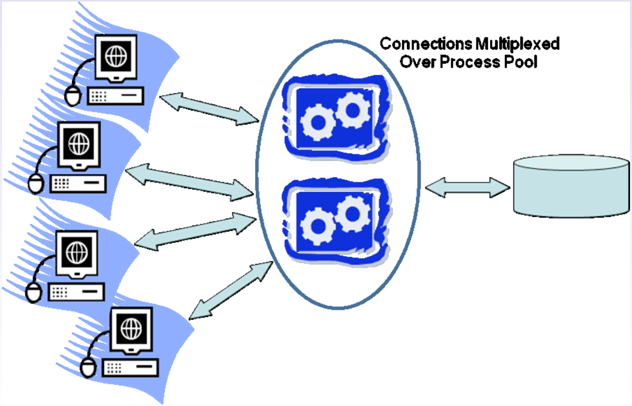
Process Models

- Assume: Uniprocessors + OS support for efficient threads
- Option 2: “Server Process Model”
  - Single multi-threaded server. Efficient.
  - Difficult to port/debug, no OS protection. Requires asynchronous I/O.



Process Models

- Assume: Uniprocessors + OS support for efficient threads
- Option 3: "Server Process + I/O processes"
  - Use I/O processes for handling disks. One process per device.



Process Models

- DBMS threads, OS processes, OS Threads etc...
  - Earlier OSs did not support:
    - Buffering control, asynchronous I/O, high-performance threads
  - Many DBMSs implemented their own thread packages
    - Much replication of functionality

Process Models

- DBMS threads, OS processes, OS Threads etc...
  - Earlier OSs did not support:
    - Buffering control, asynchronous I/O, high-performance threads
  - Many DBMSs implemented their own thread packages
    - Much replication of functionality
  - How to map DBMS threads on OS processes/threads ?
    - One or more processes/threads to host SQL processing threads
    - One or more “dispatcher processes/threads”
    - One process/thread per disk and one per log disk
    - One coordinator agent process/thread per session
    - Processes/threads for background tools/utilities

Storage Models

- Spatial control
  - Sequential vs random
    - Seeks not improving that fast
  - Controlling spatial locality
    - Directly access to the disk (if possible)
    - Allocate a large file, and address using the offsets

Storage Models

- Buffer management
  - DBMS need control – why ?
    - Correctness (WAL), performance (read-ahead)
    - Typical installations not I/O-bound
  - Allocate a large memory region
    - Maintain a page table with: disk location, dirty bit, replacement policy stats, pin count
  - Page replacement policy
    - LRU-2
  - “double buffering” issues
  - Memory-mapping: *mmap*

Transactions

- Monolithic (why?)
  - Lock manager, log manager, buffer pool, access methods
- ACID
  - Typically:
    - “I” – locking, “D” – logging
    - “A” – locking + logging, “C” – runtime checks
  - BASE ? (Eric Brewer)
    - Basically Available Soft-state Eventually consistent

Transactions

- Locks
  - Strict 2PL most common
  - Uses a dynamic hash table-based “lock table”
    - Contains: lock mode, holding Xion, waiting Xions etc
    - Also, a way to start the Xion when a lock is obtained
- Latches
  - Quick-duration
  - Mostly for internal data structures, internal logic
    - Can’t have deadlocks or other consistency issues

Isolation Levels

- Degrees of consistency (Gray et al.)
  - Read uncommitted, read committed, repeatable read, serializable
  - “Phantom” tuples
  - ANSI SQL Isolation levels
    - Not fully well-defined

Log manager

- Required for atomicity and durability
  - Allows recovery and transaction aborts
  - Why a problem ?
    - "STEAL" and "NO FORCE"
  - Concepts:
    - Write-ahead logging, in-order flushes etc
    - Undo/redo, checkpoints
  - ARIES

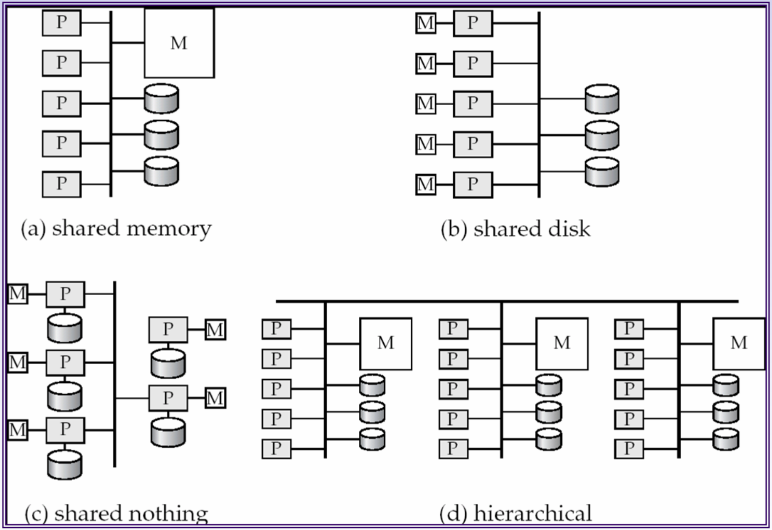
Locking/Logging and Indexes

- Locking:
  - Can't use 2PL on indexes
  - Solutions: "Crabbing", Right-link schemes
- Logging:
  - No need to "undo" a index page split
- Phantom problem:
  - 1. Use predicate locking
  - 2. "next-key" locking

Shared Components

- Memory allocations
  - Usually “context”-based
    - Allocate a large context, and do everything within it
  - Why ?
- Disk management subsystems
  - Dealing with RAID etc
- Replication services
  - Copy, trigger-based or replay-log
- Statistics gathering, reorganization/index construction, backup/export

Parallelism



Parallelism

- Shared memory
  - Direct mapping from uni-processor
- Shared nothing
  - Horizontal data partitioning, partial failure
  - Query processing, optimization challenging
- Shared disk
  - Distributed lock managers, cache-coherency etc...

Query Processing

- Assume single-user, single-threaded
  - Concurrency managed by lower layers
- Steps:
  - Parsing: attritube references, syntax etc...
    - Catalog stored as “denormalized” tables
  - Rewriting:
    - Views, constants, logical rewrites (transitive predicates, true/false predicates), semantic (using constraints), subquery flattening

Query Processing

- Steps: Optimizer
  - Block-by-block
  - Machine code vs interpretable
  - Compile-time vs run-time
  - Selinger ++:
    - Larger plan space, selectivity estimation
    - Top-down (SQLServer), auto-tuning, expensive fns
- "Hints"

Query Processing

- Steps: Executor
  - "get_next()" iterator model
    - Narrow interface between iterators
    - Can be implemented independently
    - Assumes no-blocking-I/O
  - Some low-level details
    - Tuple-descriptors
    - Very carefully allocated memory slots
    - "avoid in-memory copies"
  - Pin and unpin

Query Processing

- SQL Update/Delete
  - “Halloween” problem
- Access Methods
  - B+-Tree and heap files
    - Multi-dimensional indexes not common
  - init(SARG)
    - “avoid too many back-and-forth function calls”
  - Allow access by RID