



# Chapter 17: Database System Architectures

## Database System Concepts, 6<sup>th</sup> Ed.

- Chapter 1: Introduction
- **Part 1: Relational databases**
  - Chapter 2: Introduction to the Relational Model
  - Chapter 3: Introduction to SQL
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  - Chapter 6: Formal Relational Query Languages
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  - Appendix D: Network Model
  - Appendix E: Hierarchical Model



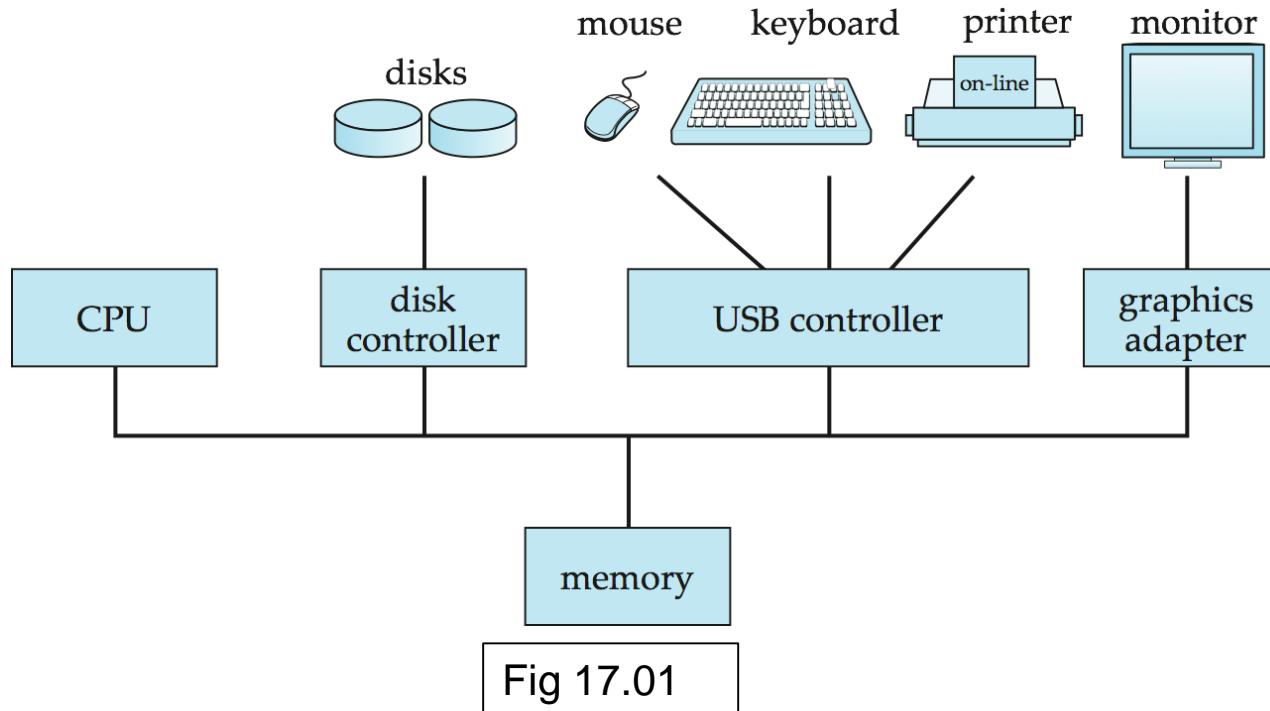
# Chapter 17: Database System Architectures

- 17.1 Centralized and Client-Server Systems
- 17.2 Server System Architectures
- 17.3 Parallel Systems
- 17.4 Distributed Systems
- 17.5 Network Types



# Centralized Systems

- Run on a single computer system and do not interact with other computer systems.
- **General-purpose computer system:** one to a few CPUs and a number of device controllers that are connected through a common bus that provides access to shared memory.
- **Single-user system (e.g., personal computer or workstation):** desk-top unit, single user, usually has only one CPU and one or two hard disks; the OS may support only one user.
- **Multi-user system:** more disks, more memory, multiple CPUs, and a multi-user OS. Serve a large number of users who are connected to the system via terminals. Often called server systems.

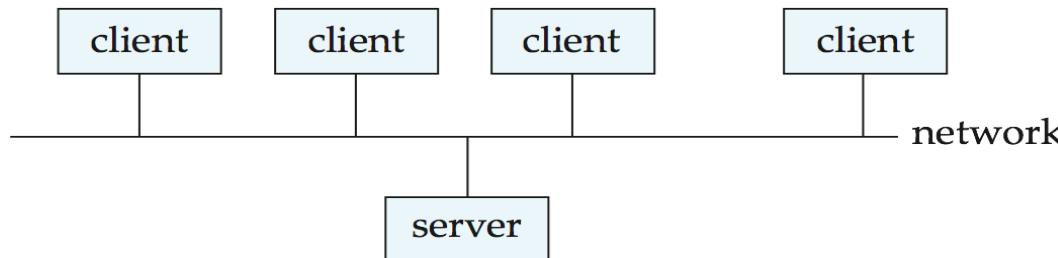




# Client-Server Systems [1/2]

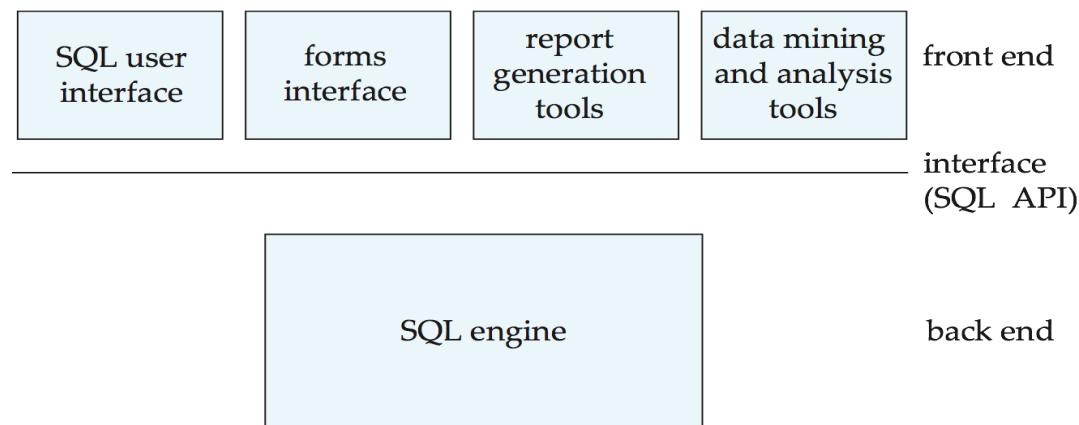
- Server systems satisfy requests generated at  $m$  client systems, whose general structure is shown below:

Fig 17.02



- Database functionality can be divided into:
  - **Back-end**: manages access structures, query evaluation & optimization, CC and recovery.
  - **Front-end**: consists of tools such as *forms*, *report-writers*, and graphical UI facilities.
- The interface between the front-end and the back-end is through **SQL** or through **an application program interface (ex. CLI)**

Fig 17.03





# Client-Server Systems [2/2]

- Client-Server System의 시작동기: Down Sizing
- Advantages of replacing mainframes with networks of workstations or personal computers connected to back-end server machines:
  - better functionality for the cost
  - flexibility in locating resources and expanding facilities
  - better user interfaces
  - easier maintenance
- Server systems can be broadly categorized into two kinds:
  - **transaction servers** which are widely used in relational database systems
  - **data servers**, used in object-oriented database systems

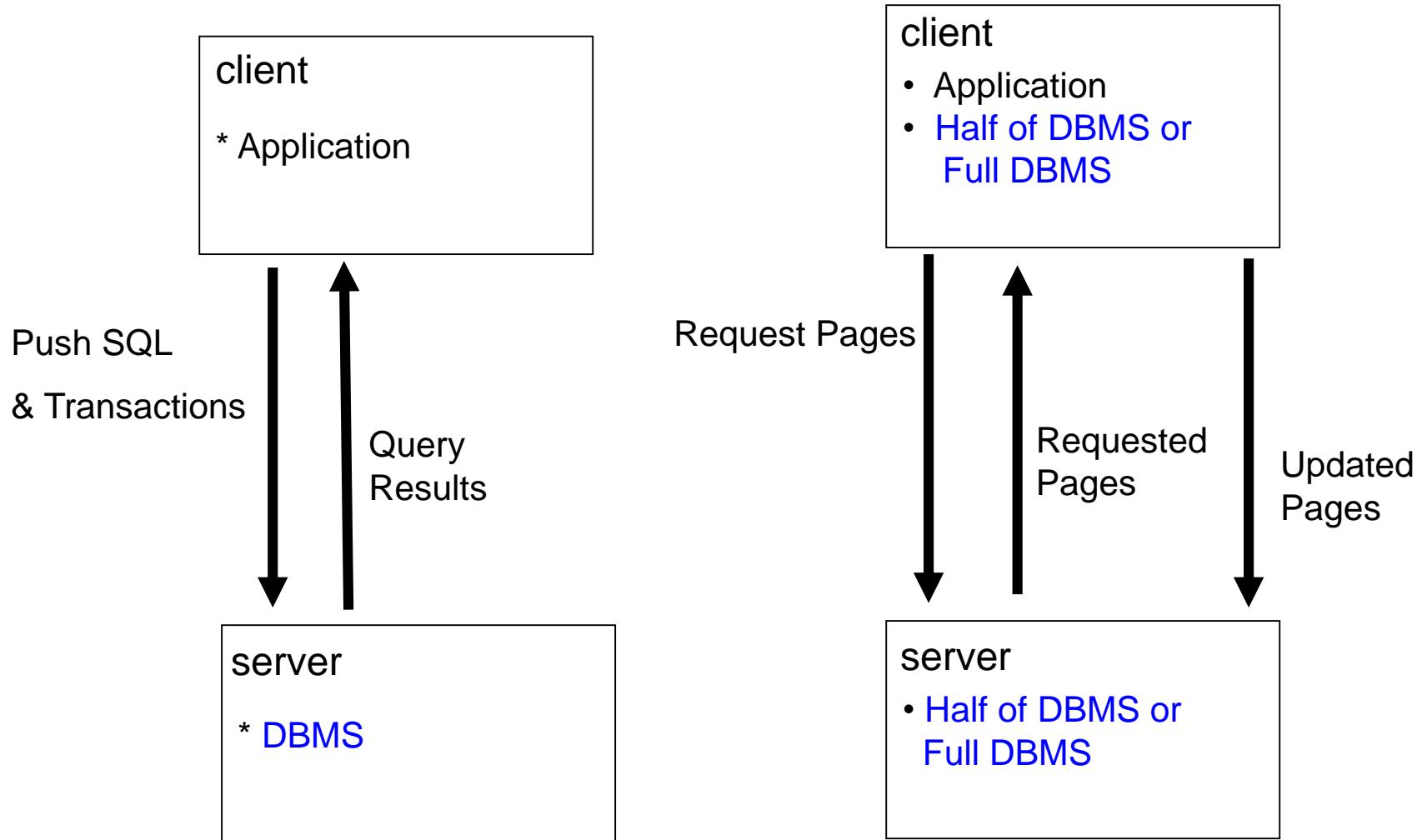


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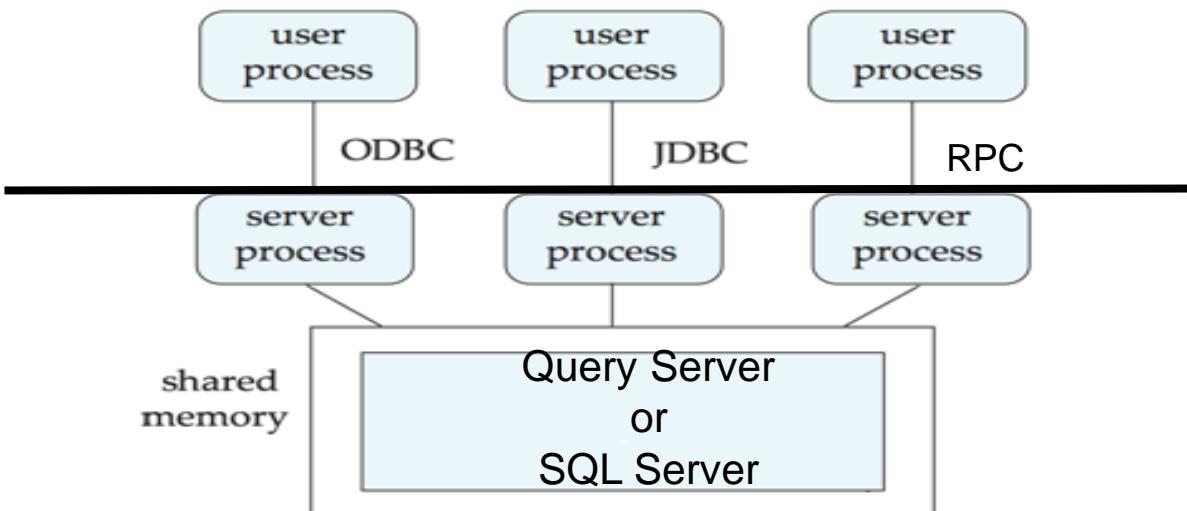
# Transaction Server vs Data Server





# Transaction Servers

- Also called **query server** systems or **SQL server** systems
  - clients send requests to the server system where the transactions are executed, and results are shipped back to the client
- Requests specified in SQL, and communicated to the server through a *remote procedure call (RPC)* mechanism
  - Transactional RPC allows many RPC calls to collectively form a transaction
  - *Open Database Connectivity (ODBC)* is a C API standard from Microsoft for connecting to a server, sending SQL requests, and receiving results
  - **JDBC standard** similar to ODBC, for Java





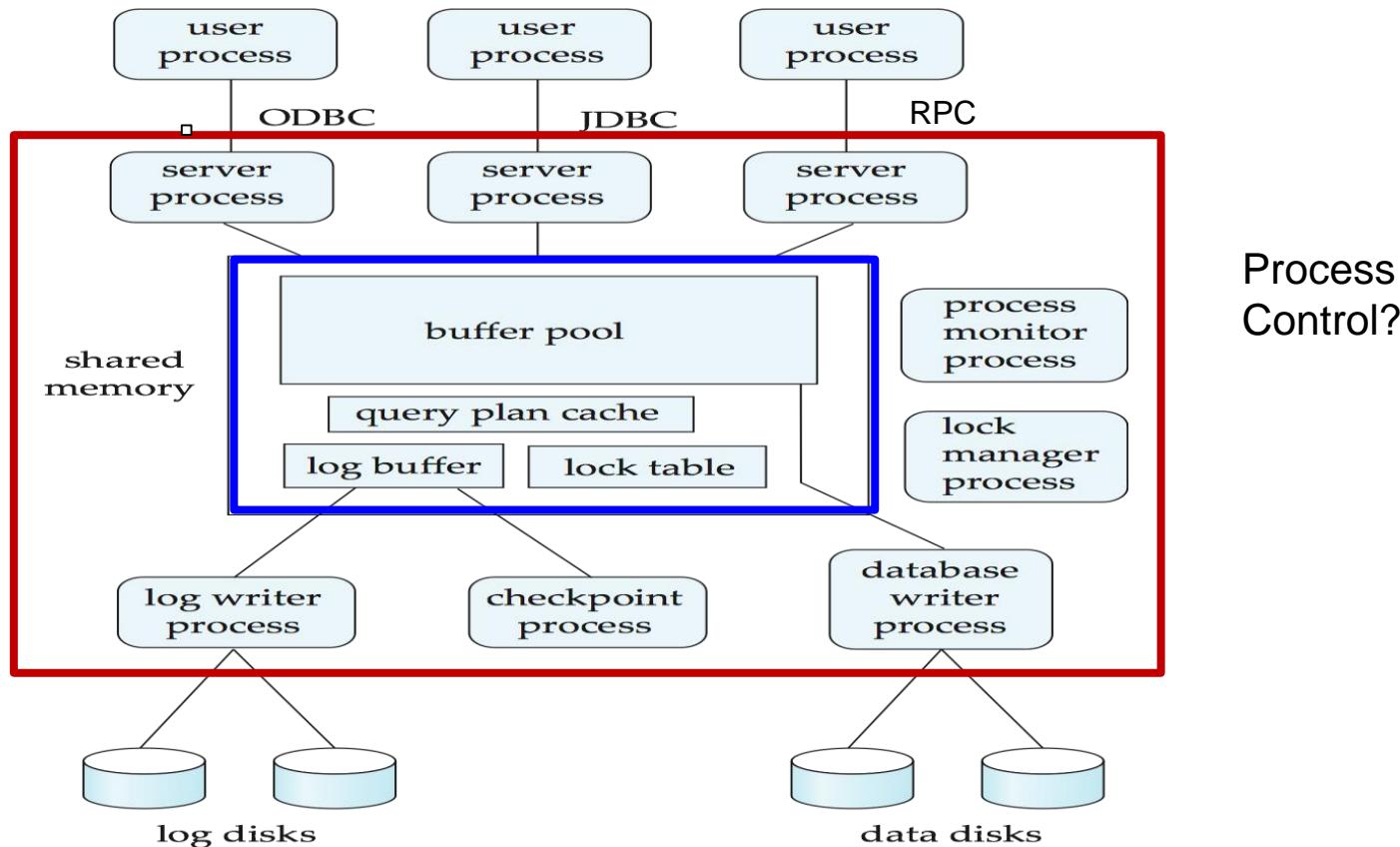
# Transaction Server Processes [1/3]

- A typical transaction server consists of **multiple processes** accessing data in shared memory
- **Server processes**
  - Receive user queries (transactions), execute them & send results back
  - Typically **multiple multithreaded** server processes allowing a single process to execute several user queries concurrently
- **Lock manager process:** More on this later
- **Database writer process:** Output modified buffer blocks to disks continually
- **Log writer process**
  - Server processes simply add log records to log record buffer
  - Log writer process outputs log records to stable storage.
- **Checkpoint process:** Performs periodic checkpoints
- **Process monitor process**
  - Monitors other processes, and takes recovery actions if any of the other processes fail
    - ▶ E.g. aborting any transactions being executed by a server process and restarting it



# Transaction Server Processes [2/3]

Fig 17.04



Process  
Control?

- Shared memory contains shared data
  - Buffer pool // Lock table // Log buffer // Cached query plans
  - All database processes can access shared memory
- To ensure that no two processes are accessing the same data structure at the same time, databases systems implement mutual exclusion
  - OS semaphores or Atomic instructions such as test-and-set



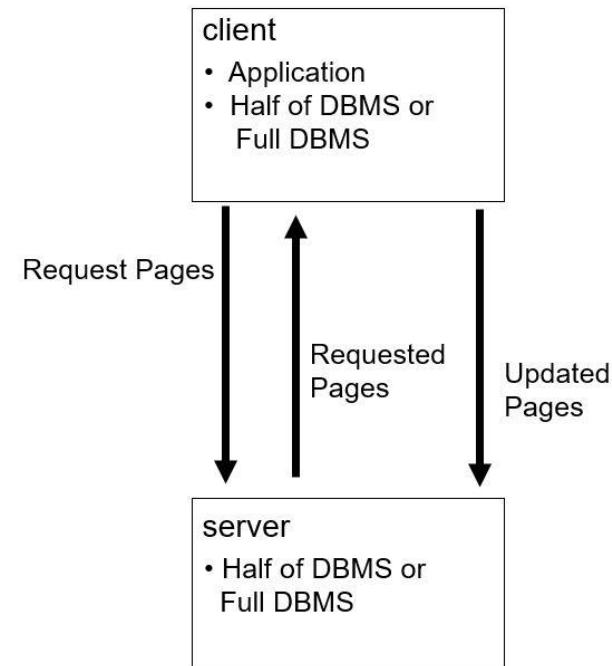
# Transaction Server Processes [3/3]

- Lock Manager의 역할: Lock의 허가, Deadlock의 해결
- Sending requests to lock manager process creates **severe overhead** of interprocess communication for lock request/grant (Lock manager에 message passing는 큰부담)
- Instead **each DB server process operates directly on the lock table** (Section 15.1)
  - Mutual exclusion ensured on the lock table using semaphores, or more commonly, atomic instructions
    - ▶ If a lock can be obtained, the lock table is updated directly in shared memory
    - ▶ If a lock cannot be immediately obtained, a lock request is noted in the lock table and the process (or thread) then waits for lock to be granted
    - ▶ When a lock is released, releasing process updates lock table to record release of lock, as well as grant of lock to waiting requests (if any)
  - Process/Thread waiting for lock may either:
    - ▶ Continually scan lock table to check for lock grant, or
    - ▶ Use OS semaphore mechanism to wait on a semaphore
      - Semaphore identifier is recorded in the lock table
      - When a lock is granted, the releasing process signals the semaphore to tell the waiting process/thread to proceed
- Lock manager process still used for deadlock detection



# Data Servers [1/3]

- Used in high-speed LANs, in cases where
  - The client machines are comparable in processing power to the server machine
  - The tasks to be executed in the client machines are **compute intensive**
- **Data** are shipped to **client machines where processing is performed**, and then shipped **results** back to the server machine.
- This architecture requires **full back-end functionality at the clients**
- Used in **many object-oriented database systems**
- Issues:
  - Page-Shipping versus Item-Shipping
  - Locking
  - Data Caching
  - Lock Caching





# Data Servers [2/3]

## ■ Page-Shipping versus Item-Shipping

- Smaller unit of shipping ⇒ more messages
- Worth **prefetching** related items along with requested item
- Page shipping can be thought of as a form of prefetching

## ■ Locking

- **Overhead** of requesting and getting locks from server is high due to message delays
  - ▶ With item shipping, locks are granted on **requested and prefetched items**
  - ▶ With page shipping, locks are granted on **whole page**
- **Locks on a prefetched item** can be **called back** by the server, and returned by client transaction if the prefetched item has not been used
- **Locks on the page** can be **deescalated** to locks on items in the page when there are lock conflicts
  - ▶ Locks on unused items can then be returned to server



# Data Servers [3/3]

## ■ Data Caching

- Data can be cached at client even in between transactions
- But need to check that data is up-to-date before it is used (**cache coherency**)
- Check can be done when requesting lock on data item

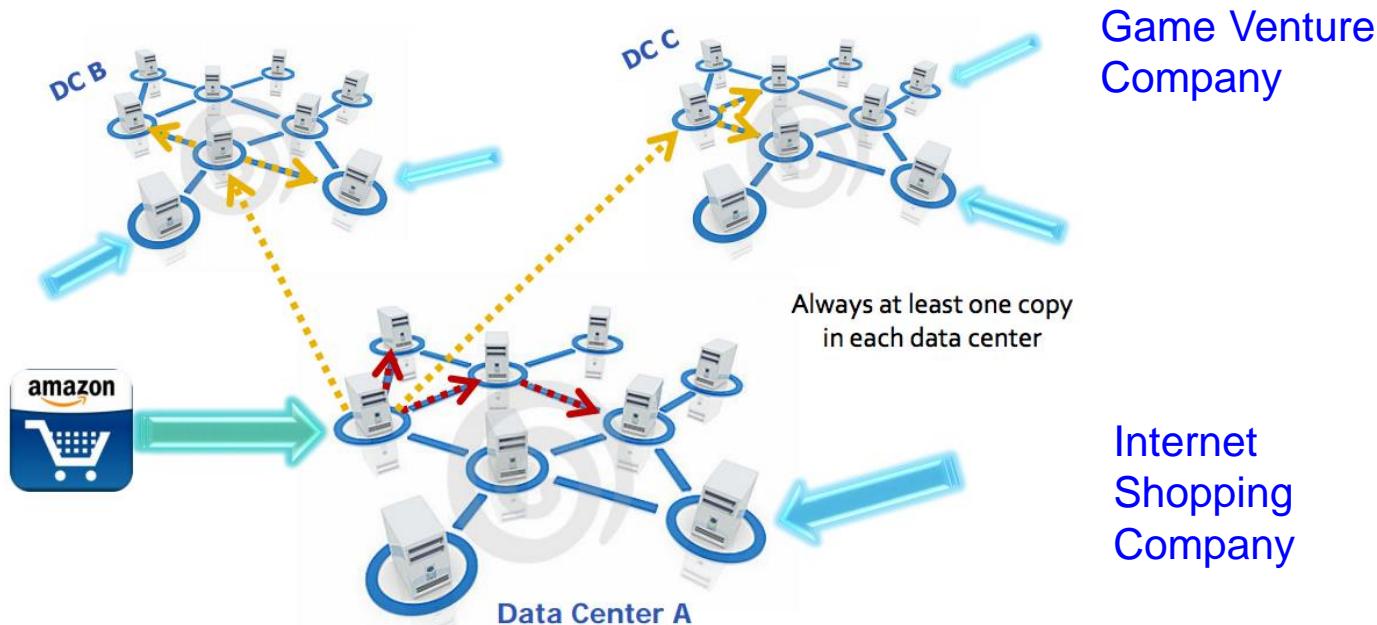
## ■ Lock Caching

- Locks can be retained by client system even in between transactions
- Transactions can acquire cached locks locally, without contacting server
  - ▶ Reduce communication overhead
- Server **calls back** locks from clients when it receives conflicting lock request
  - ▶ Client returns lock once no local transaction is using it
- Similar to deescalation, but across transactions



# Cloud-based Servers

- Third party cloud vendors provide a collection of machines
- Not real machines, but software simulated machines (called virtual machines)
  - Add/Release machines as needed
  - Software define architecture (SDA)
  - Software defined storage (SDS)
- Various degree of cloud services
  - Providing Just raw storage and virtual machines
  - Providing varying degree of control over data placement and replication
  - Providing even DBMS service





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# Parallel Systems

- Parallel database systems consist of multiple processors and multiple disks connected by a fast interconnection network
  - A **coarse-grain parallel** machine consists of a small number of powerful processors
  - A **fine grain parallel** or **massively parallel** machine utilizes thousands of smaller processors
- Two main performance measures:
  - **throughput** --- the number of tasks that can be completed in a given time interval
  - **response time** --- the amount of time it takes to complete a single task from the time it is submitted



# Speed-Up and Scale-Up

- **Speedup:** a fixed-sized problem executing on a small system is given to a  $N$ -times larger system

$\text{speedup} = \text{small system elapsed time} / \text{large system elapsed time}$

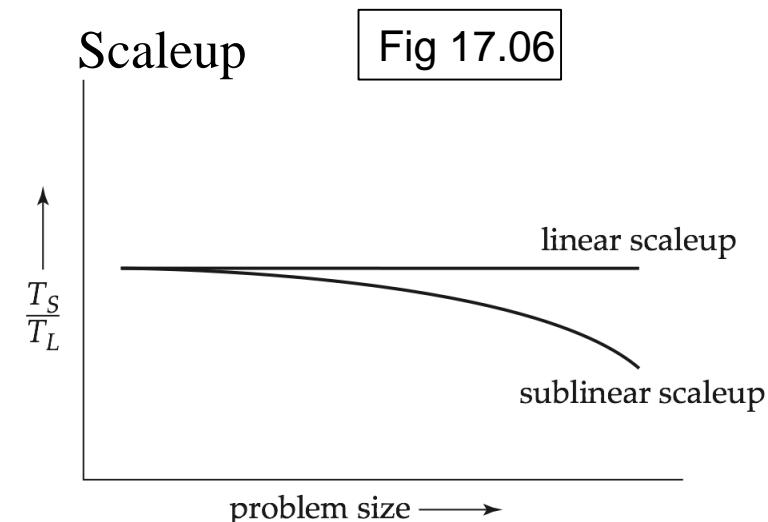
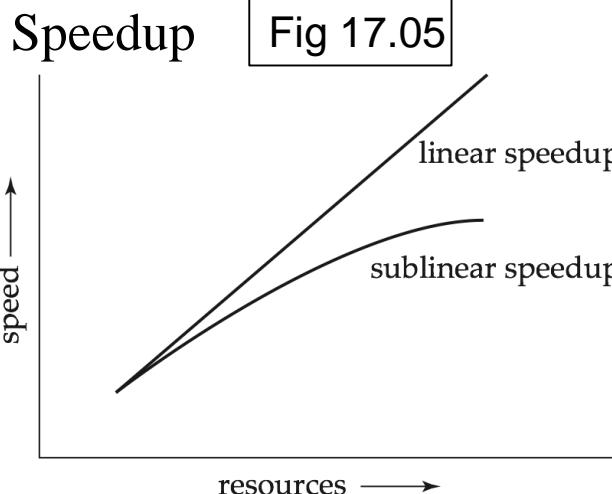
- Speedup is **linear** if equation equals  $N$

- **Scaleup:** increase the size of both the problem and the system

- $N$ -times larger system used to perform  $N$ -times larger job

$\text{scaleup} = \text{small system small problem elapsed time } (T_S) / \text{big system big problem elapsed time } (T_L)$

- Scale up is **linear** if equation equals 1





# Batch and Transaction Scaleup

## ■ Batch scaleup:

- A single large job
  - ▶ typical of most database queries and scientific simulation
- Use an  $N$ -times larger computer on  $N$ -times larger problem

## ■ Transaction scaleup:

- Numerous small queries submitted by independent users to a shared database
  - ▶ typical transaction processing and timesharing systems
- $N$ -times as many users submitting requests (hence,  $N$ -times as many requests) to an  $N$ -times larger database, on an  $N$ -times larger computer
- Well-suited to parallel execution



# Factors Limiting Speedup and Scaleup

Speedup and scaleup of parallel processing are often **sublinear** due to:

## ■ **Startup costs**

- Cost of starting up multiple processes may dominate computation time, if the degree of parallelism is high

## ■ **Interference**

- Processes accessing shared resources (e.g., system bus, disks, or locks) compete with each other, thus spending time waiting on other processes, rather than performing useful work

## ■ **Skew**

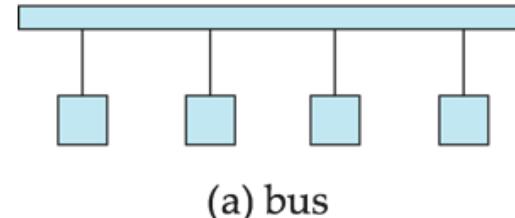
- Increasing the degree of parallelism increases the variance in service times of parallelly executing tasks
- Overall execution time determined by **slowest** of parallelly executing tasks



# Interconnection Network Architectures

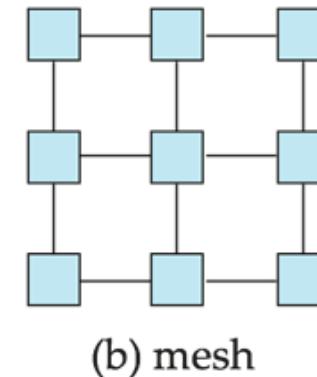
## ■ Bus

- System components send data on and receive data from a single bus
- Does not scale well with increasing parallelism



## ■ Mesh

- Components are arranged as nodes in a grid, and each component is connected to all adjacent components
- Communication links grow with growing number of components, and so scales better
- But may require  $2\sqrt{n}$  hops to send message to a node (or  $\sqrt{n}$  with wraparound connections at edge of grid)



## ■ Hypercube

- Components are numbered in binary
- Components are connected to one another if their binary representations differ in exactly one bit
- $N$  components are connected to  $\log(n)$  other components and can reach each other via at most  $\log(n)$  links; reduces communication delays

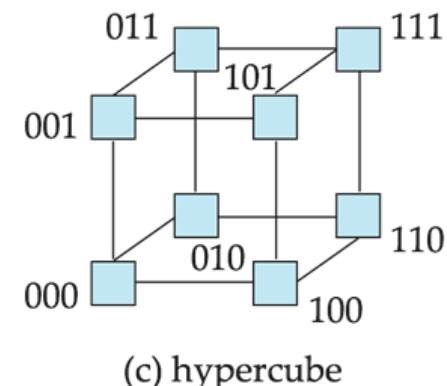
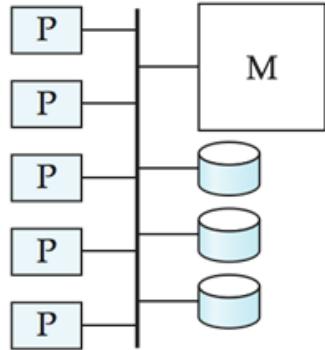


Fig 17.07

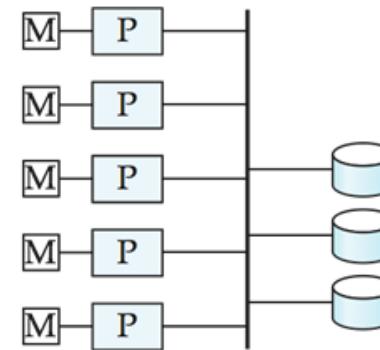


# Parallel Database Architectures

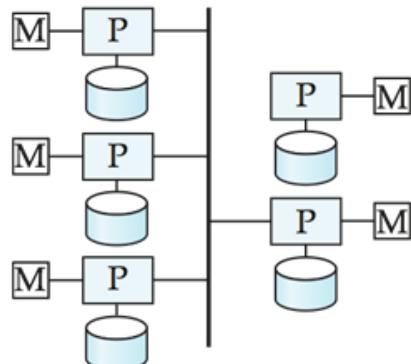
- **Shared memory** -- processors share a common memory
- **Shared disk** -- processors share a common disk, sometimes called **clusters**
- **Shared nothing** -- processors share **neither** a common memory **nor** common disk
- **Hierarchical** -- hybrid of the above architectures



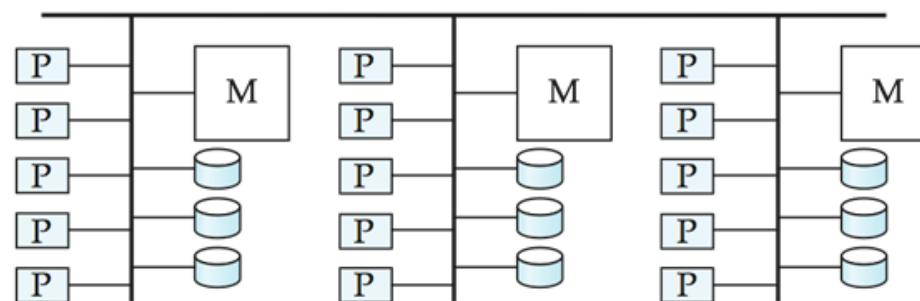
(a) shared memory



(b) shared disk



(c) shared nothing



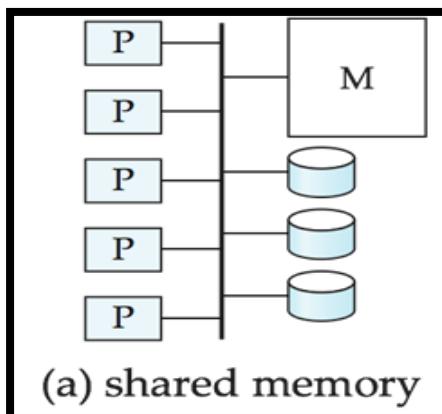
(d) hierarchical

Fig 17.08



# Shared-Memory Parallel DB

- Processors and disks have access to a **common memory**, typically via a bus or through an interconnection network
  - **SMP (Symmetric Multi Processing)** 방식
  - Each processor has its own cache → **cache coherence problem**
  - Widely used for **lower degrees of parallelism** (4 to 8)
- **Advantage**
  - Extremely efficient communication between processors
  - Data in shared memory can be accessed by any processor without having to move it using software
- **Downside**
  - Architecture is **not scalable beyond 32 or 64 processors** since the bus or the interconnection network becomes a bottleneck



Multi-processor Server Systems based on Intel® Xeon® processors

**MP SuperServer® Solution**

**TU 8-Way: SYS-7088B-TR4FT**

- Supports 8 Intel® Xeon® E7-8800 v4/v3 product families (up to 24 cores per CPU)
- Up to 24TB DDR4 in 192 DIMM slots
- Up to 15 PCI-E 3.0 slots, U.2 NVMe support option available
- Up to 12x 2.5" hot-swap SAS3/SATA3 HDD/SSD drive bays
- 4x 10GbE-T LAN ports (via SIO)
- 2 SATA3 SATA DOM + 2 SATA2 M.2 for internal storage device connection via C602J onboard, Onboard PMI 2.0
- 1600W Hot-swap (N+1) redundant Titanium Level power supplies

8-Way 4-Way

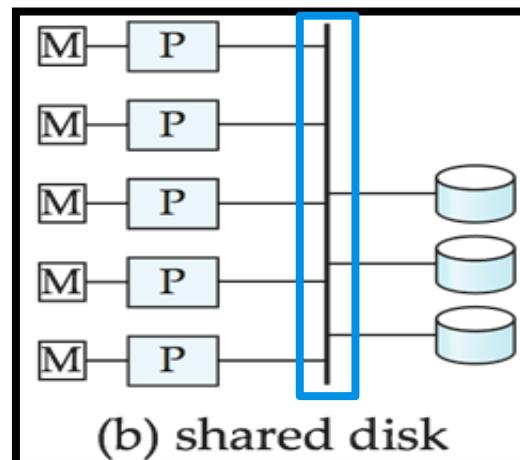
CPU1 CPU8  
8 CPU Modules: CPU1 to CPU8

For more detail >



# Shared-Disk Parallel DB

- All processors with private memories can directly access **all disks** via an interconnection network
  - The memory bus is not a bottleneck
  - Architecture provides a degree of **fault-tolerance** — if a processor fails, the other processors can take over its tasks since the database is resident on disks that are accessible from all processors
  - Mainframe 기반 parallel processor
    - IBM Sysplex with IBM DB2 and IMS
    - DEC clusters (now part of Compaq) running Oracle RDBMS
- **Downside:** bottleneck now occurs at **interconnection** to the disk subsystem
- Shared-disk systems can scale to **a somewhat larger number of processors**, but communication between processors is slower

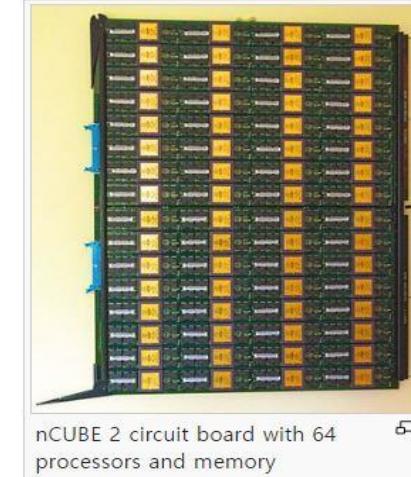
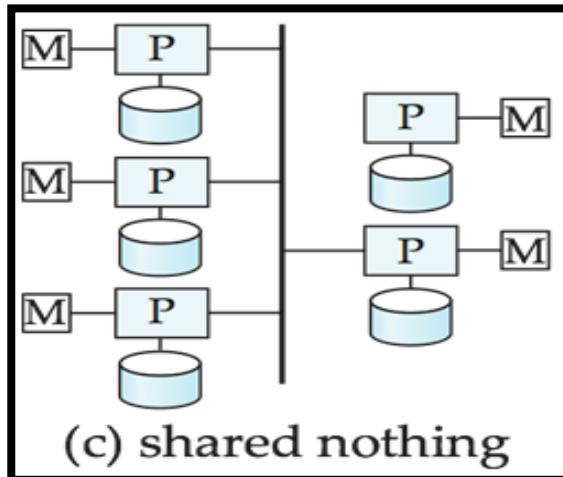


(b) shared disk



# Shared-Nothing Parallel DB

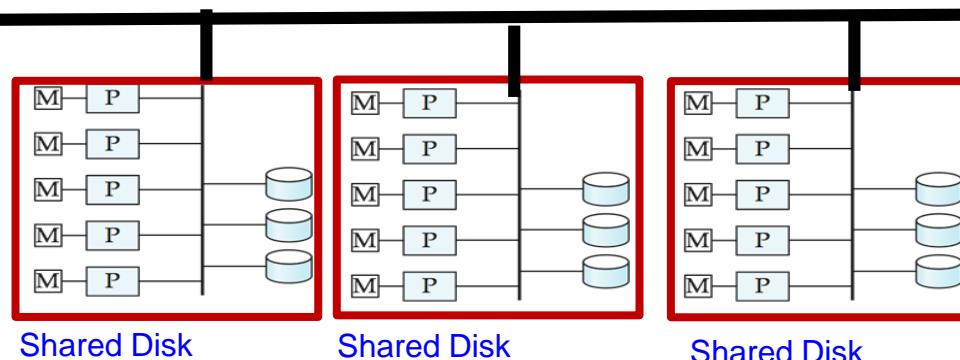
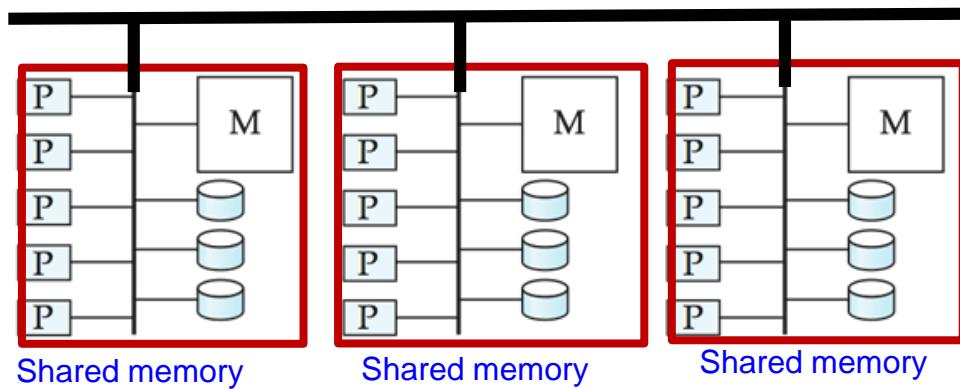
- Node consists of a processor, memory, and one or more disks
  - Processors at one node communicate with another processor at another node using an interconnection network
  - A node functions as **the server for the data on the disk the node owns**
- Examples: Teradata, Tandem, Oracle n-CUBE
- Data in local disks (and local memory) cannot be accessed through interconnection network, thereby minimizing the interference of resource sharing
- Shared-nothing multiprocessors can be scaled up to **thousands of processors without interference**
  - MPP (Massively Parallel Processing) 방식
- Main drawback: cost of communication and non-local disk access
  - Sending data involves software interaction at both ends





# Hierarchical Parallel DB

- Combines characteristics of shared-memory, shared-disk, and shared-nothing
  - Top level is a **shared-nothing architecture** – nodes connected by an interconnection network, and do not share disks or memory with each other
  - Each node could be a **shared-memory system** with a few processors
  - Alternatively, each node could be a **shared-disk system**, and each of the systems sharing a set of disks could be a shared-memory system



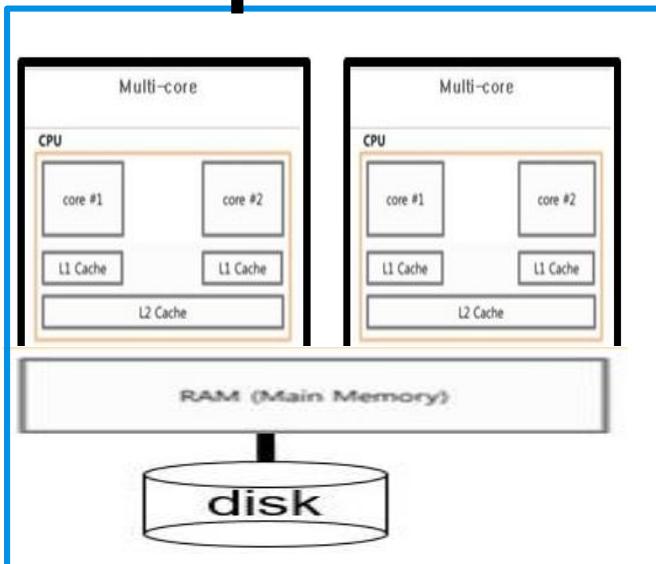


# 대세! PC Cluster and Server Cluster

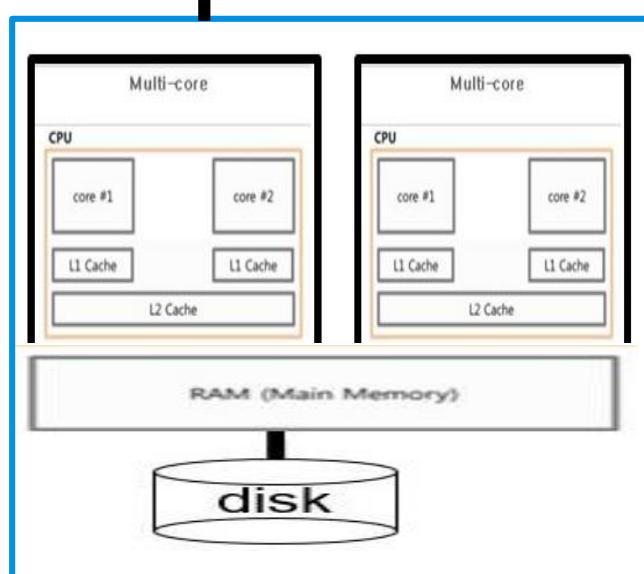
## ■ Multiprocessors vs. Multicores

- Multiprocessors have private cache hierarchy (on chip)
- Multicores have shared L2 (on chip)

- Total 12 node cluster
- Each node
  - Intel Core i5-2400 SandyBridge (3.1GHz, quad-core)
  - 4GB memory / 4TB HDD



Node



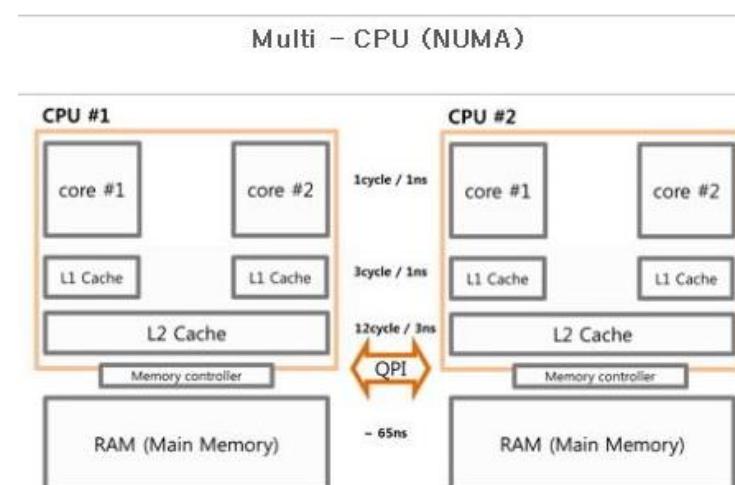
Node





# Difficult Parallel Programming!

- Shared Memory Parallel Architecture의 문제점 → Memory bottleneck
- Shared Nothing Parallel Architecture의 문제점 → Difficult Parallel Programming
- Parallel Programming with **distributed virtual-memory on NUMA Capable Architecture**
  - **Distributed Virtual Memory**
    - **Virtual memory-mapping HW + Special SW**
    - **To view multiple disjoint memories as a single virtual memory**
  - **Non-uniform memory architecture (NUMA)**
    - 몇 개의 core들이 중간단계의 L2 cache를 공유하므로 **Memory access**를 대폭줄일수 있다 → 성능향상, 시스템확장성증대
- **Hadoop**
- **Spark**





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# Distributed Systems

- Data spread over multiple machines (also referred to as **sites** or **nodes**)
- Network interconnects the machines
- Data shared by users on multiple machines

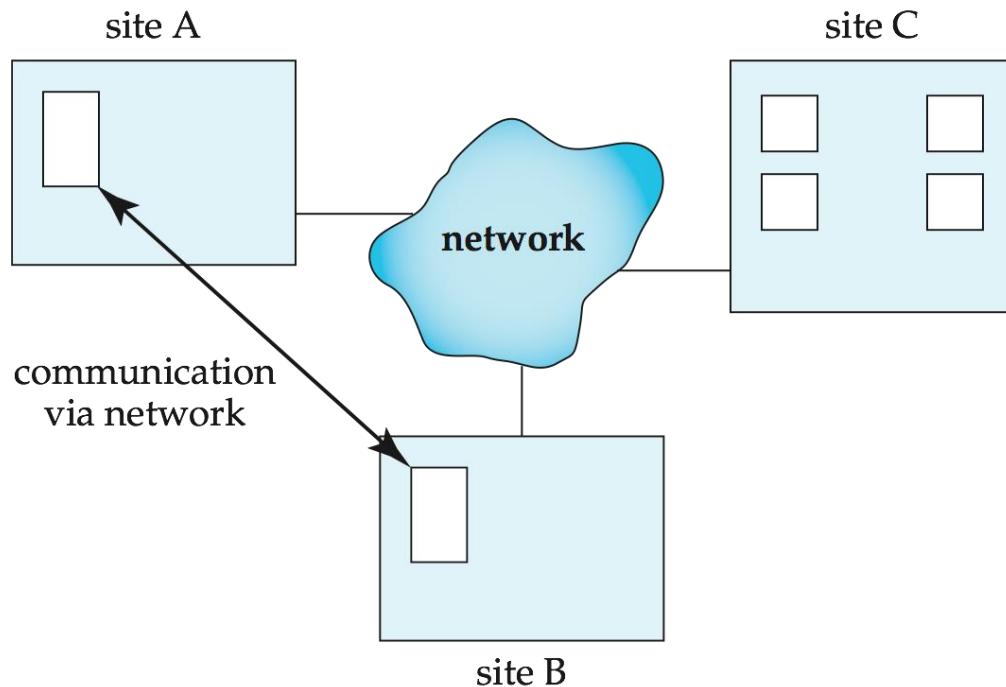


Fig 17.09



# Distributed Databases

- Homogeneous distributed databases
  - Same software/schema on all sites, data may be partitioned among sites
  - Goal: provide a view of a single database, hiding details of distribution
- Heterogeneous distributed databases
  - Different software/schema on different sites
  - Goal: integrate existing databases to provide useful functionality
- Differentiate between *local* and *global* transactions
  - A local transaction accesses data in the *single* site at which the transaction was initiated
  - A global transaction either accesses data in a site different from the one at which the transaction was initiated or accesses data in several different sites



# Trade-offs in Distributed Systems

## ■ Advantages

- Sharing data
  - ▶ Users at one site able to access the data residing at some other sites
- Autonomy
  - ▶ Each site is able to retain a degree of control over data stored locally
- Higher system availability through redundancy
  - ▶ Data can be replicated at remote sites, and system can function even if a site fails
  - ▶ Primary site vs Back-up site

## ■ Disadvantages: added complexity for proper coordination among sites

- Software development cost
- Greater potential for bugs
- Increased processing overhead



# Implementation Issues for Distributed Databases

- Atomicity needed even for transactions that update data at multiple sites
- The two-phase commit protocol (2PC) used to ensure atomicity (Section 19.4.1)
  - Basic idea: each site executes transaction till just before commit, and then leaves final decision to a coordinator
  - Each site must follow decision of coordinator: even if there is a failure while waiting for coordinator's decision
  - 2PC is not always appropriate
    - ▶ Other transaction models (persistent messaging, workflows), may be used
- Distributed concurrency control (and deadlock detection) required
- Distributed query processing: reducing communication overhead
- Replication of data items required for improving data availability
- Details of above in Chapter 19



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# Local-Area Network

- Local-area networks (LANs) – composed of processors that are distributed over small geographical areas, such as a single building or a few adjacent buildings

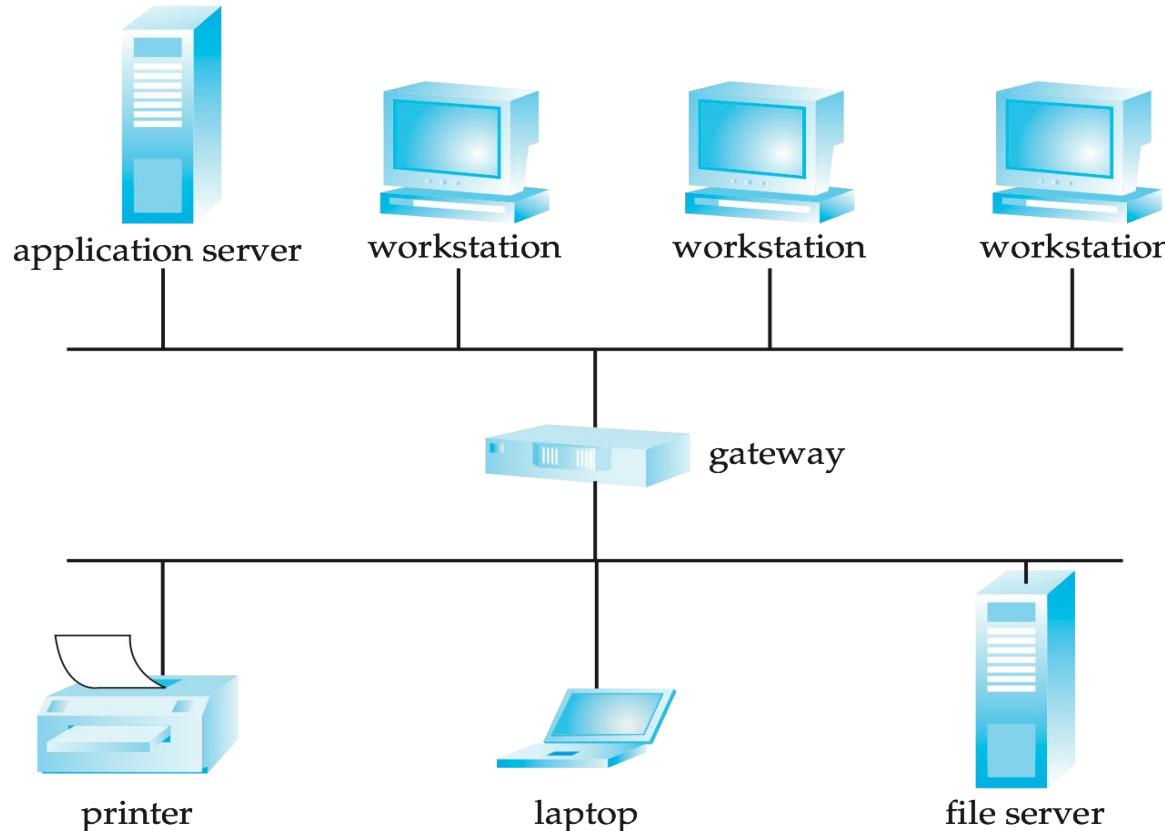
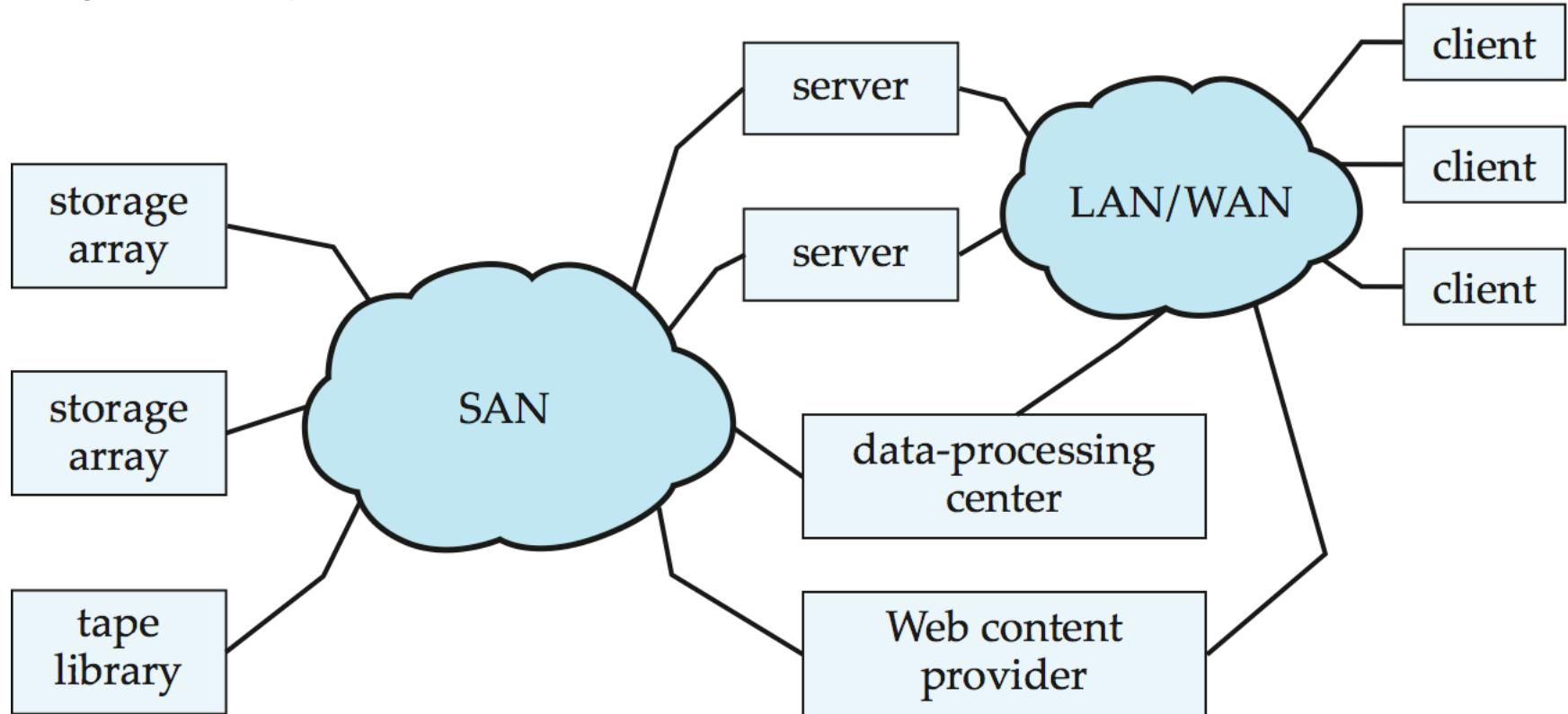


Fig 17.10



# Storage-Area Network

- To build large-scale shared-disk systems
  - Scalability by adding more computer
  - High availability



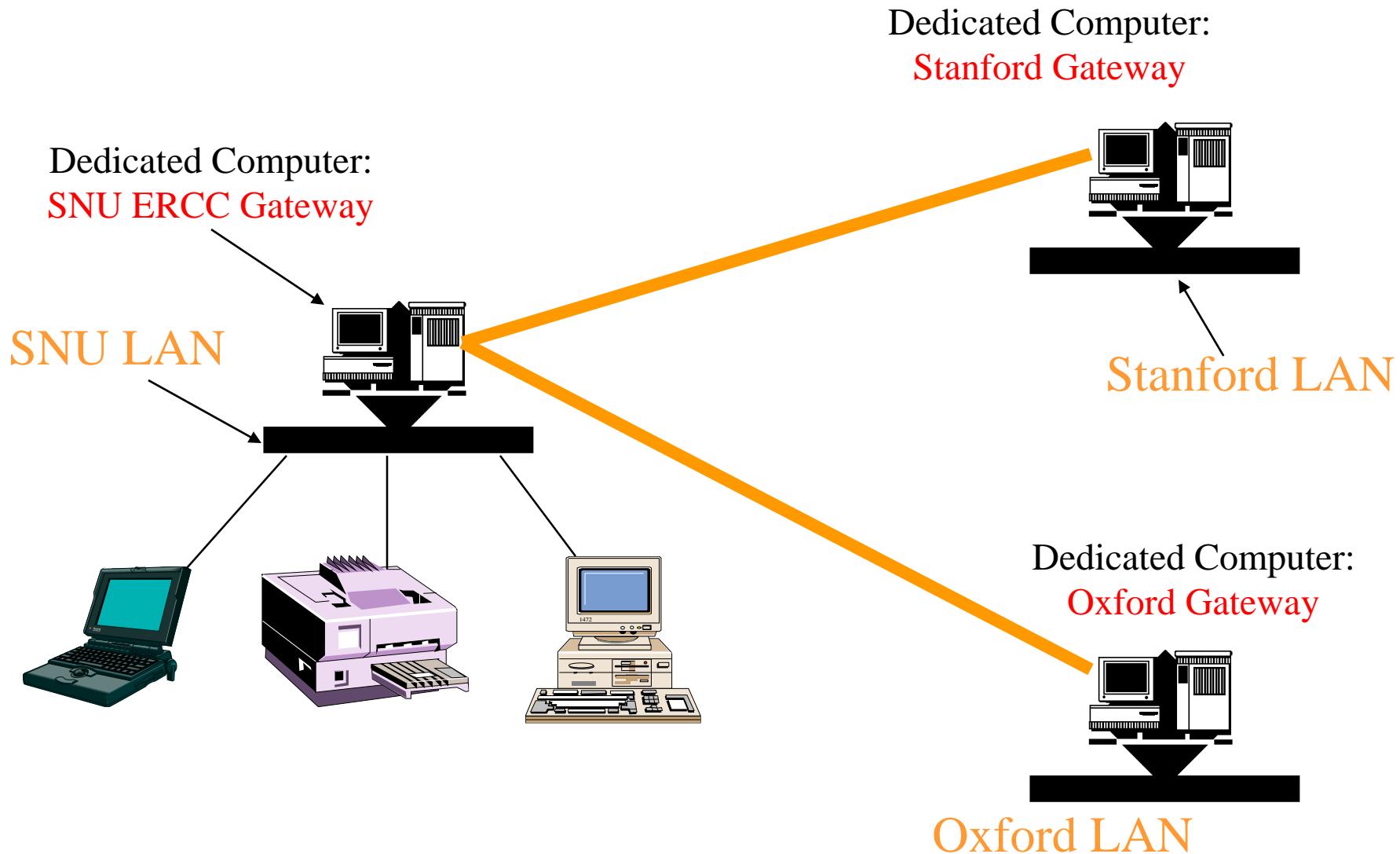


# Wide Area Networks

- **Wide-area networks (WANs)** – composed of processors distributed over a large geographical area
  - *Discontinuous Connection WANs*, such as those based on periodic dial-up (e.g. using UUCP), that are connected only for part of the time
  - *Continuous Connection WANs*, such as the Internet, where hosts are connected to the network at all times
- **WANs with continuous connection** are needed for distributed database systems
- **WANs with discontinuous connection**
  - **Mobile wireless connection**
  - Earlier groupware applications such as Lotus Notes can work on this
  - Data is replicated, so updates are propagated to replicas periodically
  - No global locking is possible, and copies of data may be independently updated
  - Non-serializable executions can thus result
    - ▶ Conflicting updates may have to be detected, and resolved in an application dependent manner



# WAN (Wide Area Network): Example





# So What?

- Client-Server System 특징
- Transactional Server, Data Server, Cloud Server의 특징
- Parallel HW의 성질, Distributed Computing 환경의 성질
  
- Parallel HW의 성질의 이용해서 DBMS 내부에서 어떻게 이용할것인가?
  - Chapter 18
  
- Distributed Computing 환경을 고려하여 DBMS는 무엇을 지원해야 하나?
  - Chapter 19