Chapter 20: Database System Architectures

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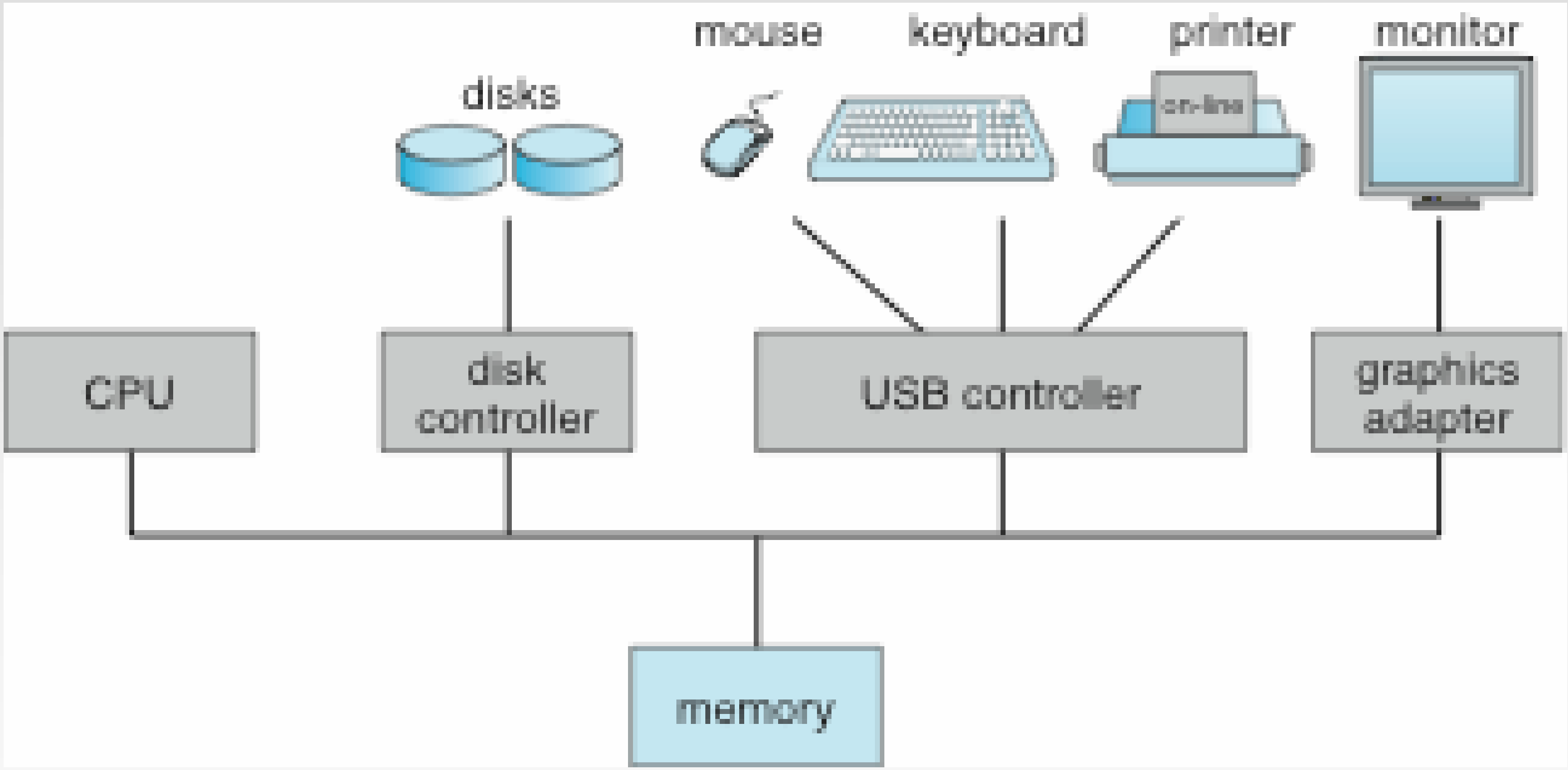
- Centralized and Client-Server Systems
- Server System Architectures
- Parallel Systems
- Distributed Systems
- Network Types

Centralized Systems

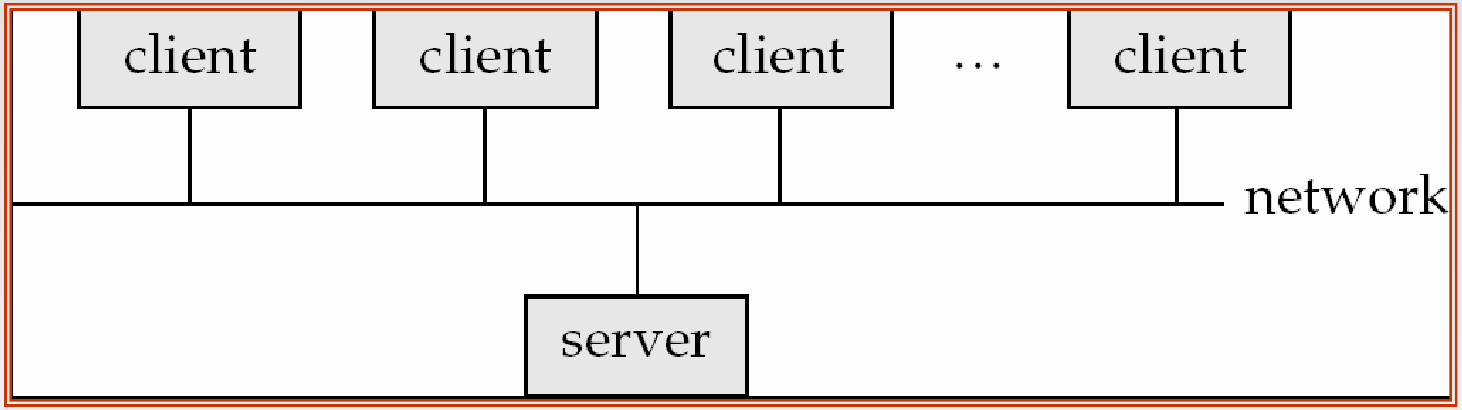
- Run on a single computer system and do not interact with other computer systems.
- General-purpose computer system: one to a few CPUs and a number of device controllers that are connected through a common bus that provides access to shared memory.
- Single-user system (e.g., personal computer or workstation): 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 vie terminals. Often called *server* systems.

A Centralized Computer System



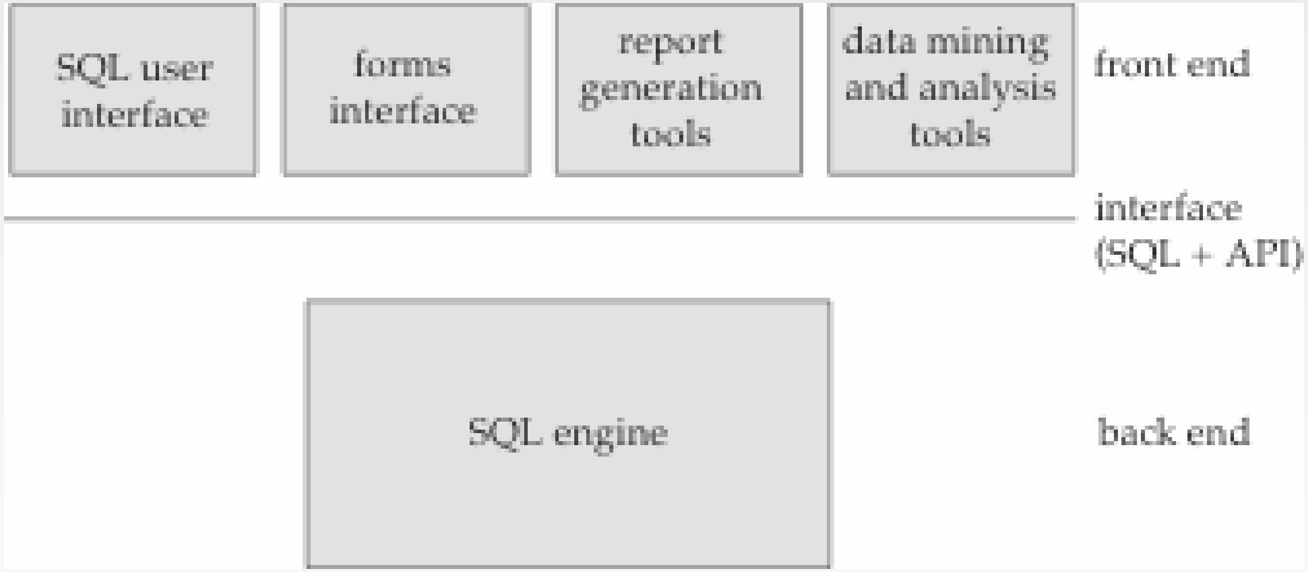
Client-Server Systems

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



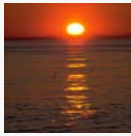
Client-Server Systems (Cont.)

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



Client-Server Systems (Cont.)

- 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 System Architecture

- Server systems can be broadly categorized into two kinds:
  - **transaction servers** which are widely used in relational database systems, and
  - **data servers**, used in object-oriented database systems

Transaction Servers

- Also called **query server** systems or SQL *server* systems
  - Clients send requests to the server
  - Transactions are executed at the server
  - Results are shipped back to the client.
- Requests are specified in SQL, and communicated to the server through a *remote procedure call* (RPC) mechanism.
- Transactional RPC allows many RPC calls to form a transaction.
- *Open Database Connectivity* (ODBC) is a C language application program interface standard from Microsoft for connecting to a server, sending SQL requests, and receiving results.
- JDBC standard is similar to ODBC, for Java

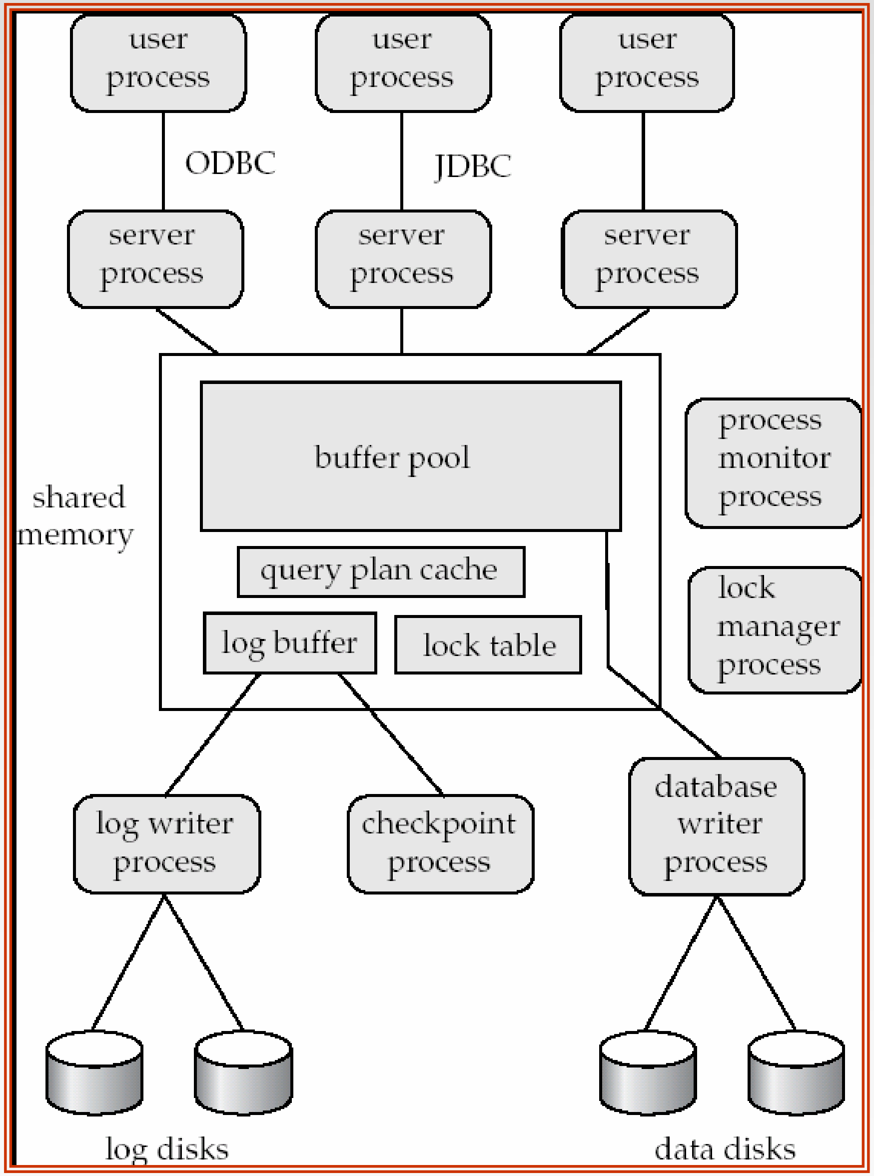
Transaction Server Process Structure

- A typical transaction server consists of multiple processes accessing data in shared memory.
- Server processes
  - These receive user queries (transactions), execute them and send results back
  - Processes may be **multithreaded**, allowing a single process to execute several user queries concurrently
  - Typically multiple multithreaded server processes
- Lock manager process
  - More on this later
- Database writer process
  - Output modified buffer blocks to disks continually

Transaction Server Processes (Cont.)

- 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 System Processes (Cont.)



Transaction System Processes (Cont.)

- Shared memory contains shared data
  - Buffer pool
  - Lock table
  - Log buffer
  - Cached query plans (reused if same query submitted again)
- 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** using either
  - Operating system semaphores
  - Atomic instructions such as test-and-set
- To avoid overhead of interprocess communication for lock request/grant, each database process operates directly on the lock table
  - instead of sending requests to lock manager process
- Lock manager process still used for deadlock detection

Data Servers

- Used in high-speed LANs, in cases where
  - The clients are comparable in processing power to the server
  - The tasks to be executed are compute intensive.
- Data are shipped to clients where processing is performed, and then shipped results back to the server.
- 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 (Cont.)

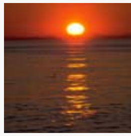
- **Page-shipping** versus **item-shipping**
  - Smaller unit of shipping $\Rightarrow$ more messages
  - Worth **prefetching** related items along with requested item
  - Page shipping can be thought of as a form of prefetching
- Locking
  - Overhead of requesting and getting locks from server is high due to message delays
  - Can grant locks on requested and prefetched items; with page shipping, transaction is granted lock on whole page.
  - Locks on a prefetched item can be P{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 (Cont.)

- **Data Caching**
  - Data can be cached at client even in between transactions
  - But 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
  - 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.

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 **massively parallel** or **fine grain 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 system which is *N*-times larger.
  - Measured by:

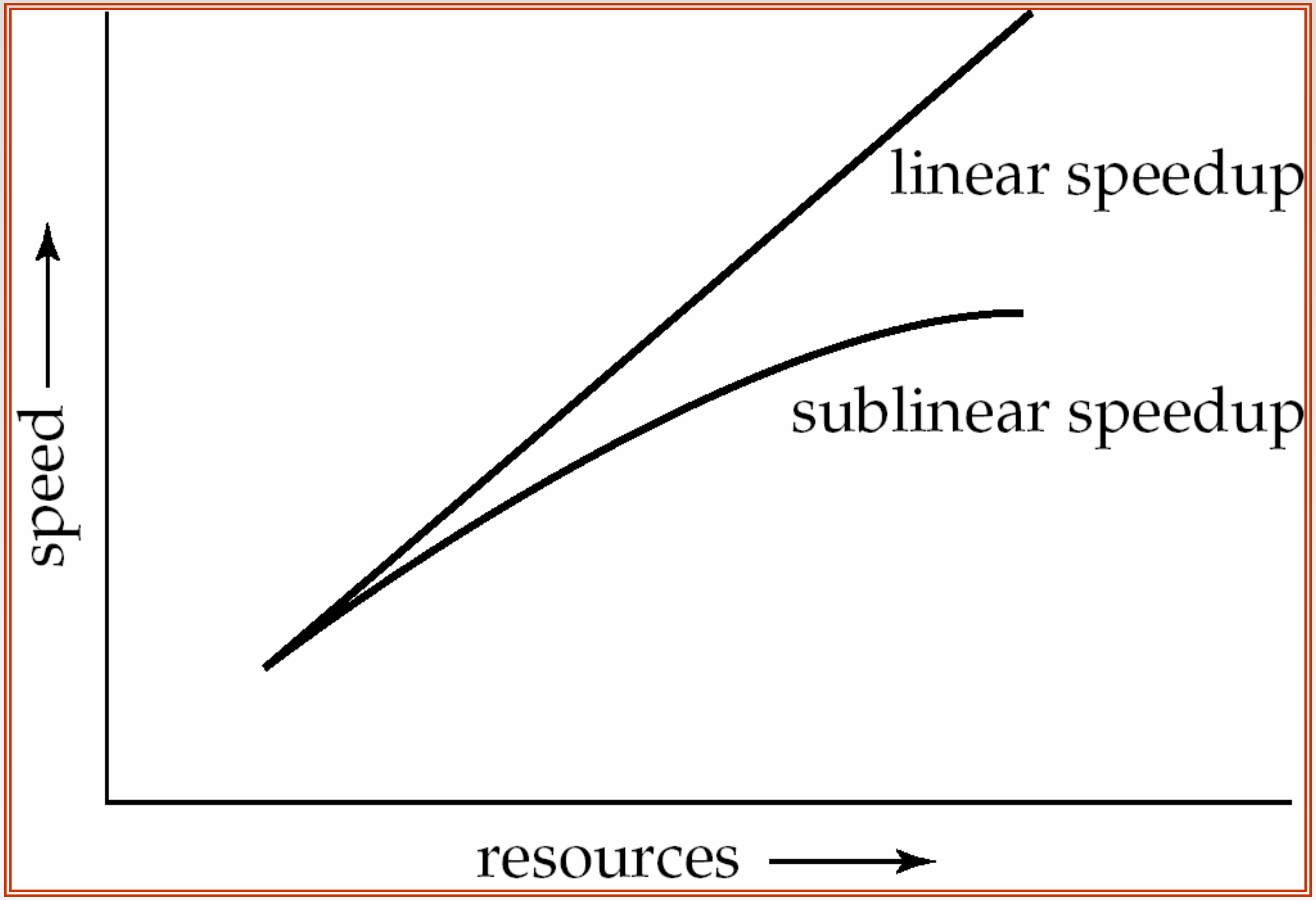
$$\textit{speedup} = \frac{\textit{small system elapsed time}}{\textit{large system elapsed time}}$$

  - 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
  - Measured by:

$$\textit{scaleup} = \frac{\textit{small system small problem elapsed time}}{\textit{big system big problem elapsed time}}$$

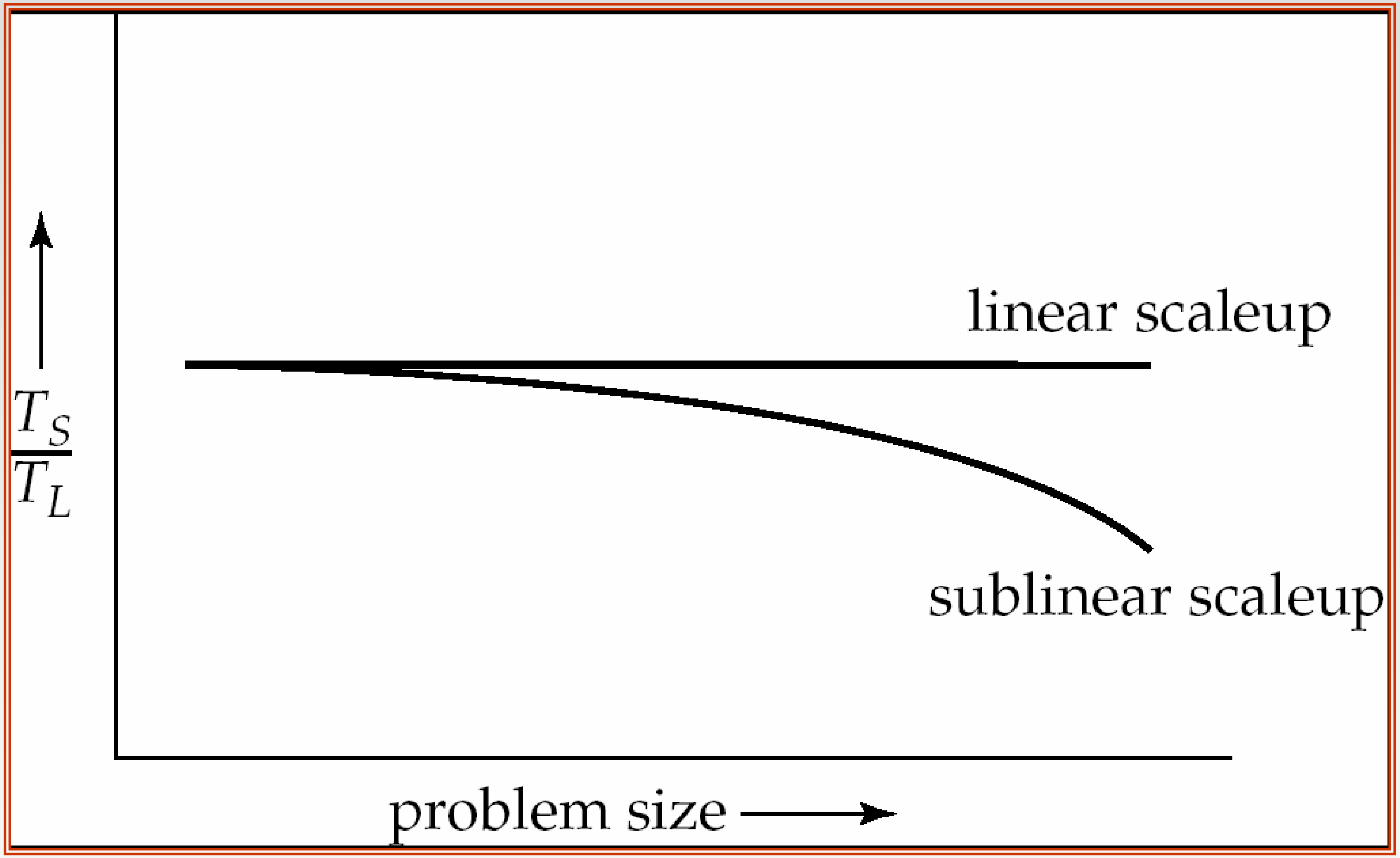
  - Scale up is **linear** if equation equals 1.

Speedup



Speedup

Scaleup



Scaleup

Batch and Transaction Scaleup

- **Batch scaleup**:
  - A single large job; typical of most decision support 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

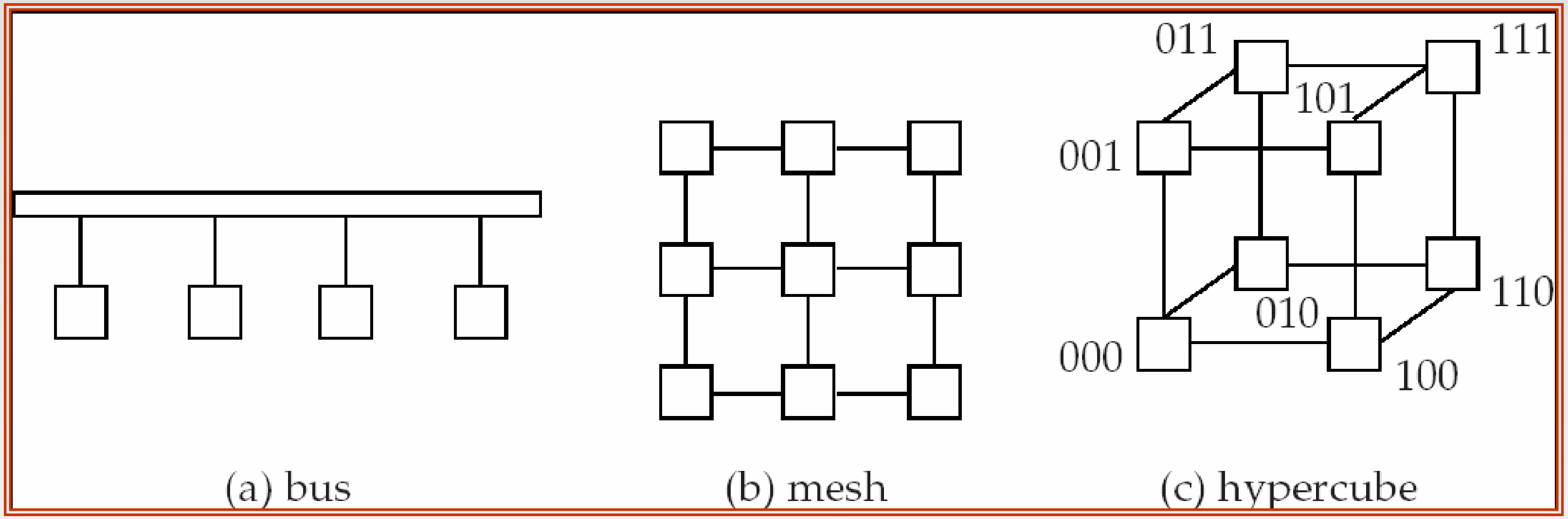
Speedup and scaleup are often sublinear due to:

- **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 parallely executing tasks. Overall execution time determined by **slowest** of parallely executing tasks.

Interconnection Network Architectures

- **Bus**. System components send data on and receive data from a single communication 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.

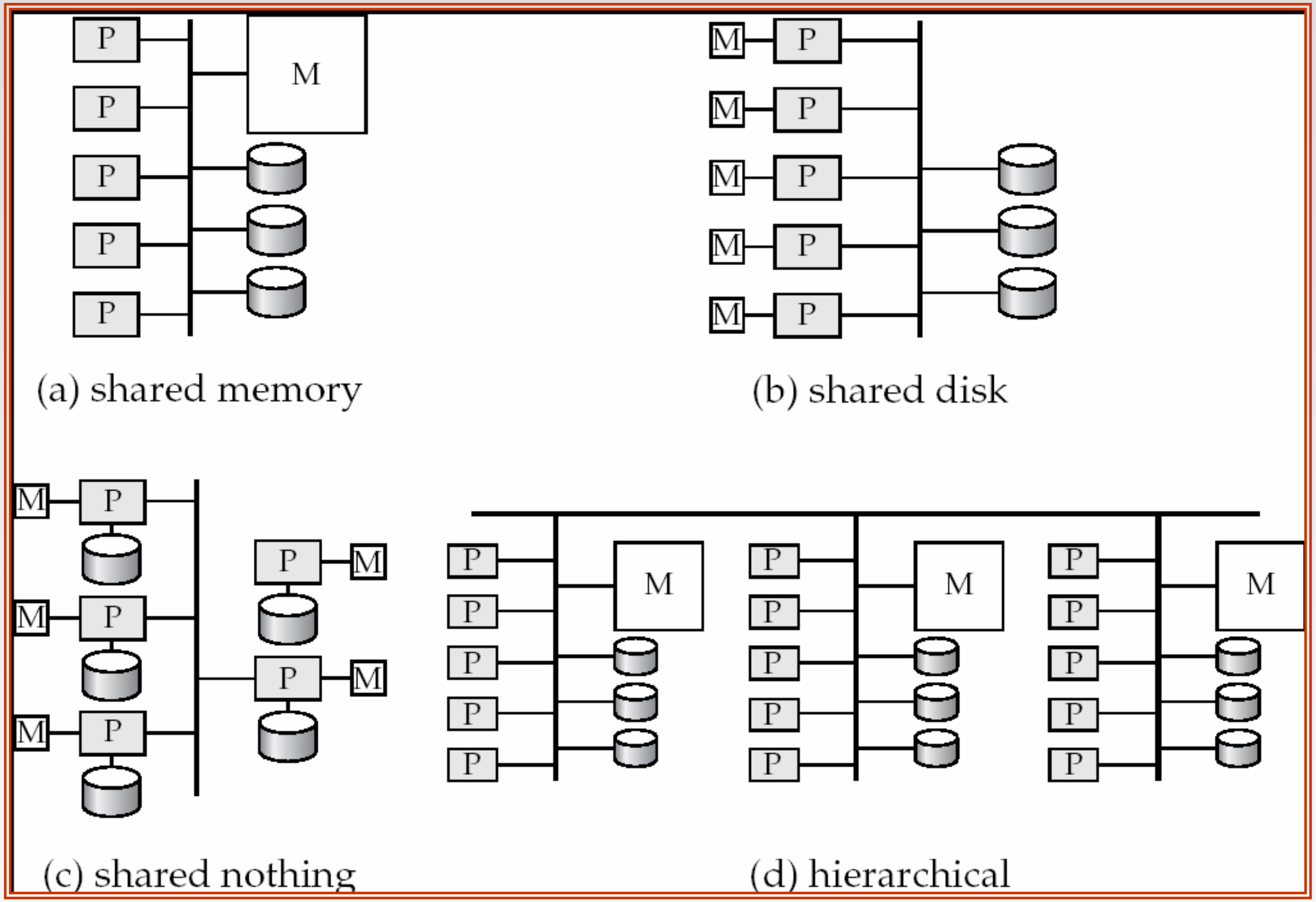
Interconnection Architectures



Parallel Database Architectures

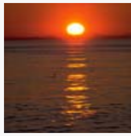
- **Shared memory** -- processors share a common memory
- **Shared disk** -- processors share a common disk
- **Shared nothing** -- processors share neither a common memory nor common disk
- **Hierarchical** -- hybrid of the above architectures

Parallel Database Architectures



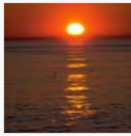
Shared Memory

- Processors and disks have access to a common memory, typically via a bus or through an interconnection network.
- 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
- Widely used for lower degrees of parallelism (4 to 8).



Shared Disk

- All processors can directly access all disks via an interconnection network, but the processors have private memories.
  - 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.
- Examples: IBM Sysplex and DEC clusters (now part of Compaq) running Rdb (now Oracle Rdb) were early commercial users
- 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.



Shared Nothing

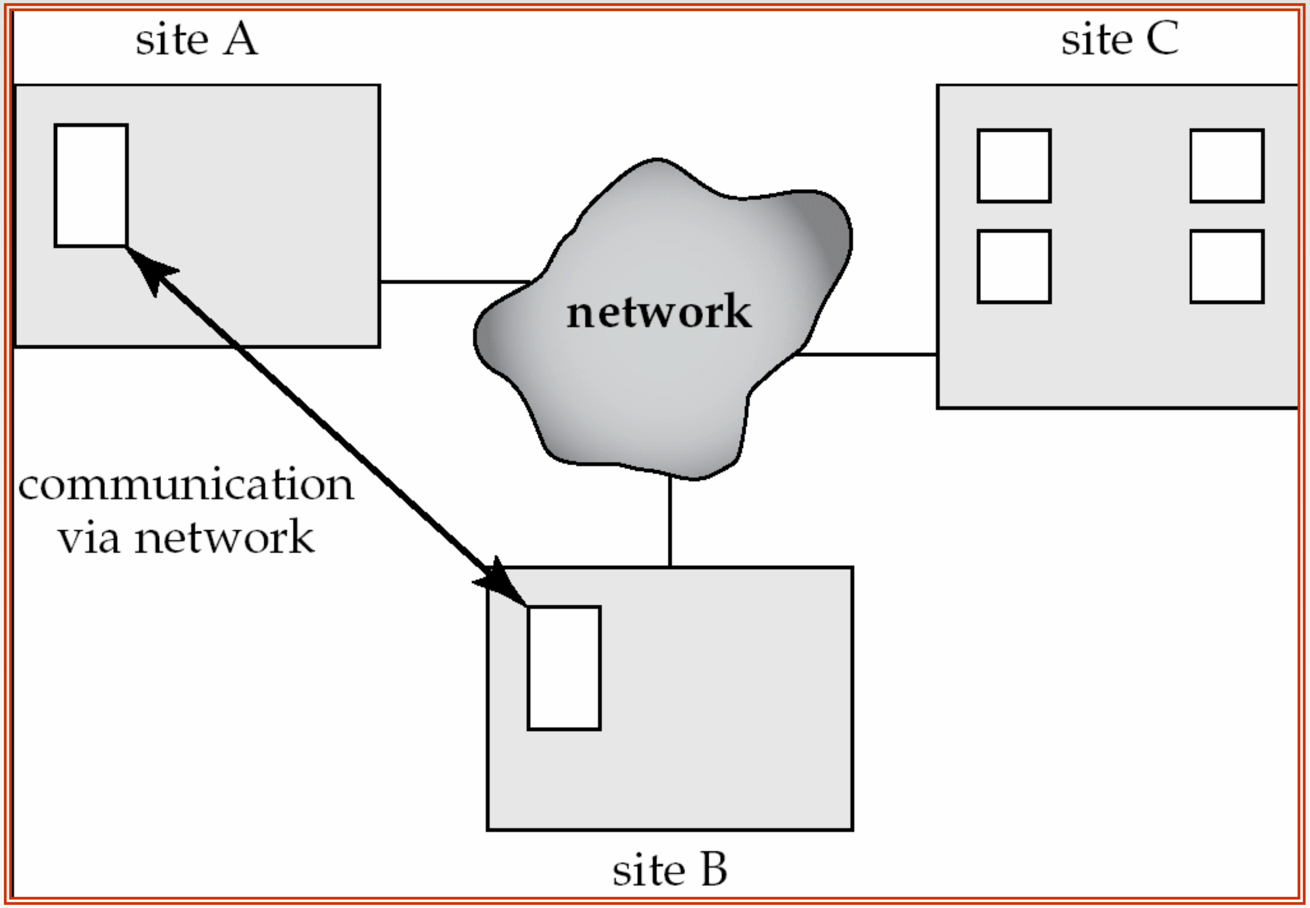
- Node consists of a processor, memory, and one or more disks. Processors at one node communicate with another processor at another node using an interconnection network. A node functions as the server for the data on the disk or disks the node owns.
- Examples: Teradata, Tandem, Oracle-n CUBE
- Data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

Hierarchical

- Combines characteristics of shared-memory, shared-disk, and shared-nothing architectures.
- 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 of the system 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.
- Reduce the complexity of programming such systems by **distributed virtual-memory** architectures
  - Also called **non-uniform memory architecture (NUMA)**

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



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

- 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.
- Disadvantage: added complexity required to ensure 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) is used to ensure atomicity
  - Basic idea: each site executes transaction until just before commit, and the leaves final decision to a coordinator
  - Each site must follow decision of coordinator, even if there is a failure while waiting for coordinators decision
- 2PC is not always appropriate: other transaction models based on persistent messaging, and workflows, are also used
- Distributed concurrency control (and deadlock detection) required
- Data items may be replicated to improve data availability
- Details of above in Chapter 22

Network Types

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

Networks Types (Cont.)

- WANs with continuous connection (e.g. the Internet) are needed for implementing distributed database systems
- Groupware applications such as Lotus notes can work on WANs with discontinuous connection:
  - Data is replicated.
  - Updates are propagated to replicas periodically.
  - Copies of data may be updated independently.
  - Non-serializable executions can thus result. Resolution is application dependent.

End of Chapter