Non-Standard Database Systems

Database System Architectures

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Outline

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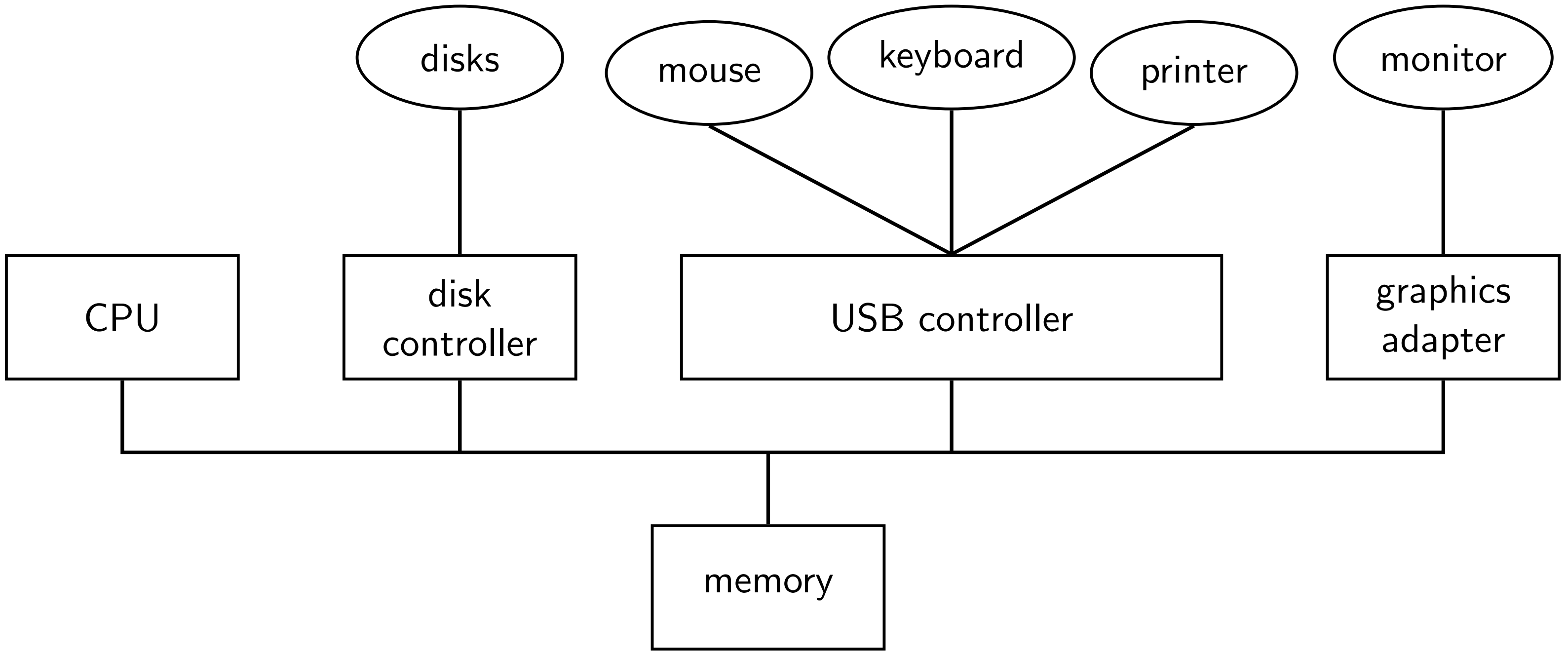
Centralized Systems

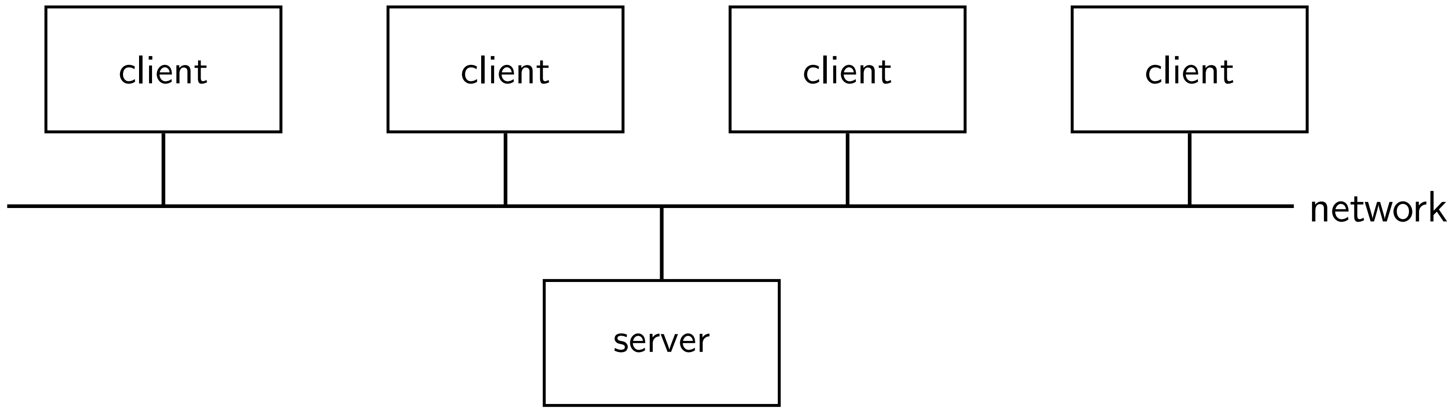
- Run on a single computer system and do not interact with other computer systems.
- General-purpose computer system: one to a few CPUs and a number of device controllers that are connected through a common bus that provides access to shared memory.
- Single-user system (e.g., personal computer or workstation):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

A Centralized Computer System



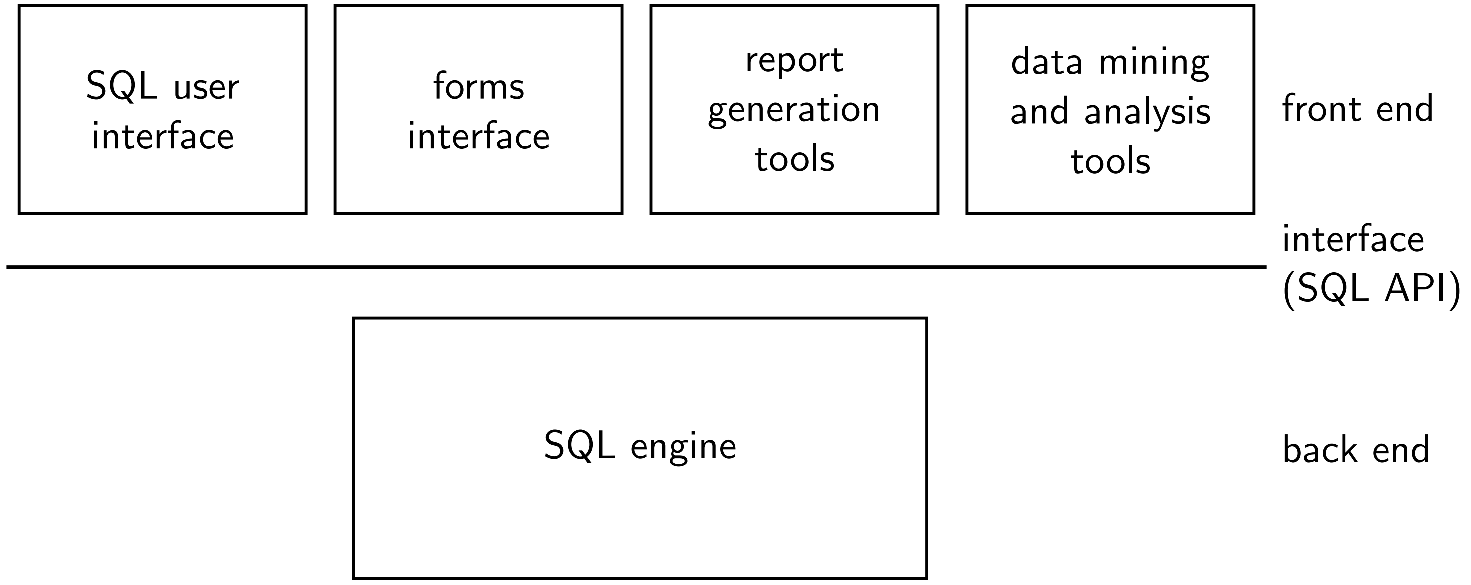
Client-Server Systems/1

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



Client-Server Systems/2

- 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/3

- 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

Outline

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.

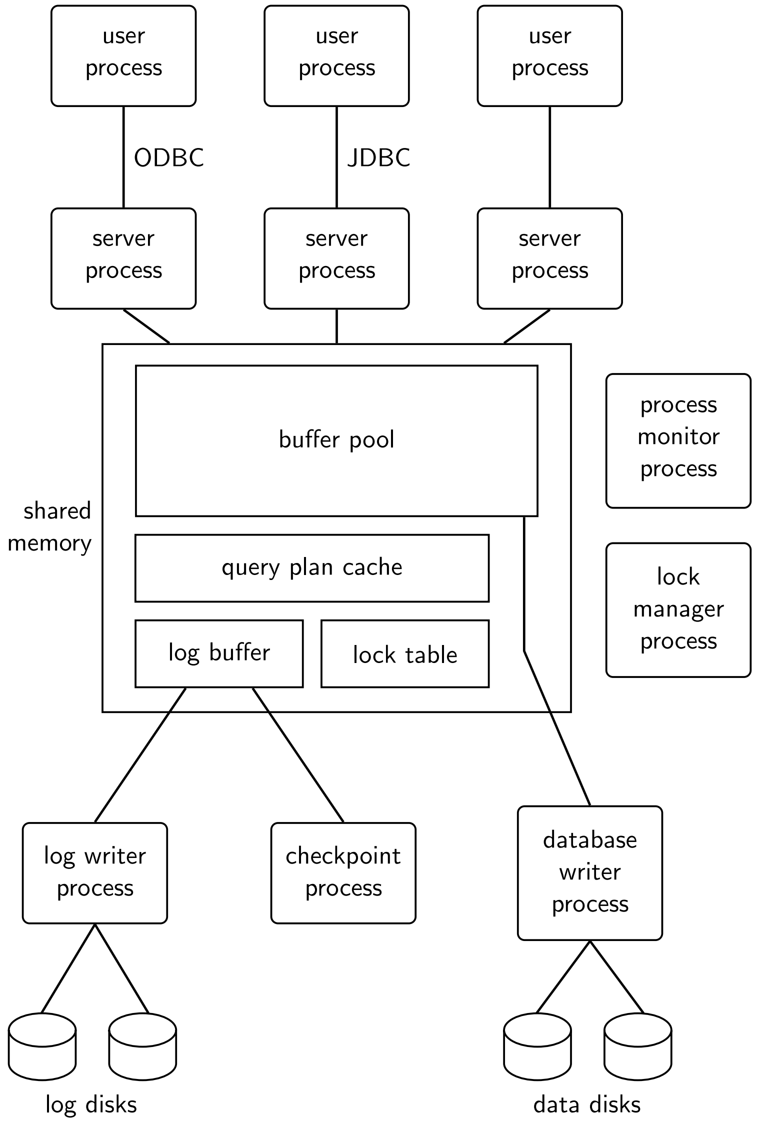
Transaction Server Process Structure/1

- A typical transaction server consists of multiple processes accessing data in shared memory.
- Server processes
  - 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 Process Structure/2

- 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 fails
    - E.g., aborting any transactions being executed by a server process and restarting it

Transaction Server Process Structure/3



Transaction Server Process Structure/4

- 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/1

- 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, clients ship 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/2

- 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 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

- 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.

Outline

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:

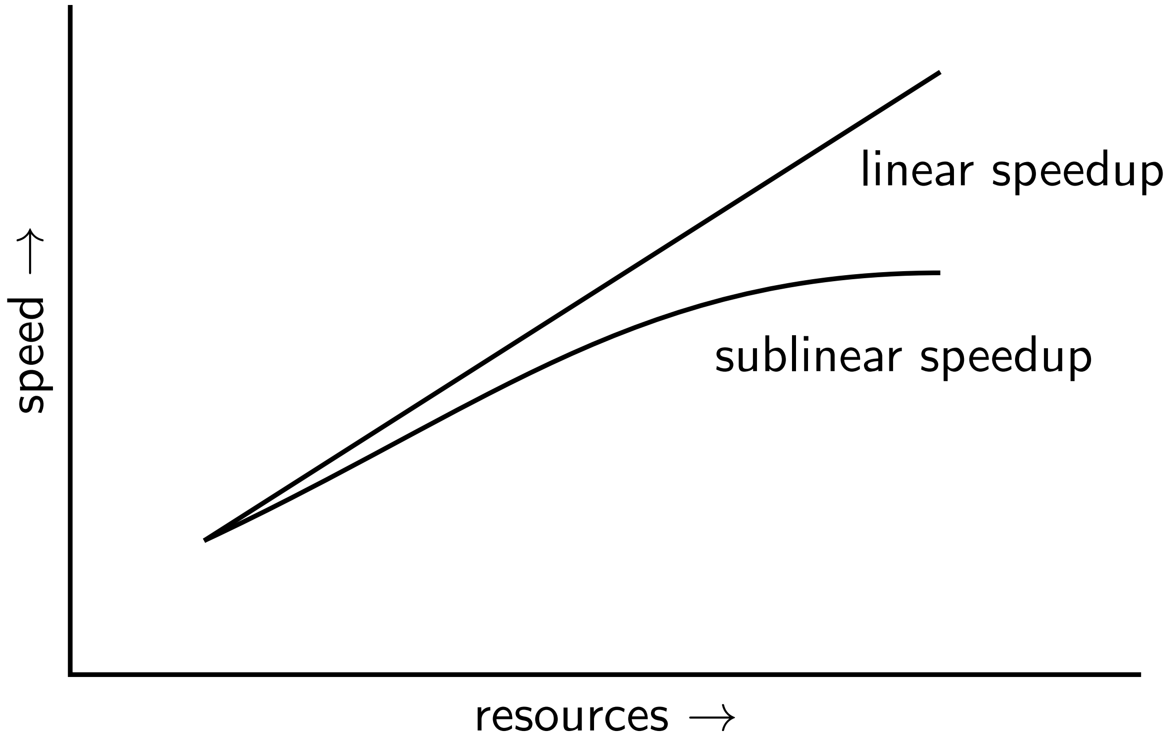
$$speedup = \frac{small\ system\ elapsed\ time}{large\ system\ elapsed\ time}$$

  - 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:

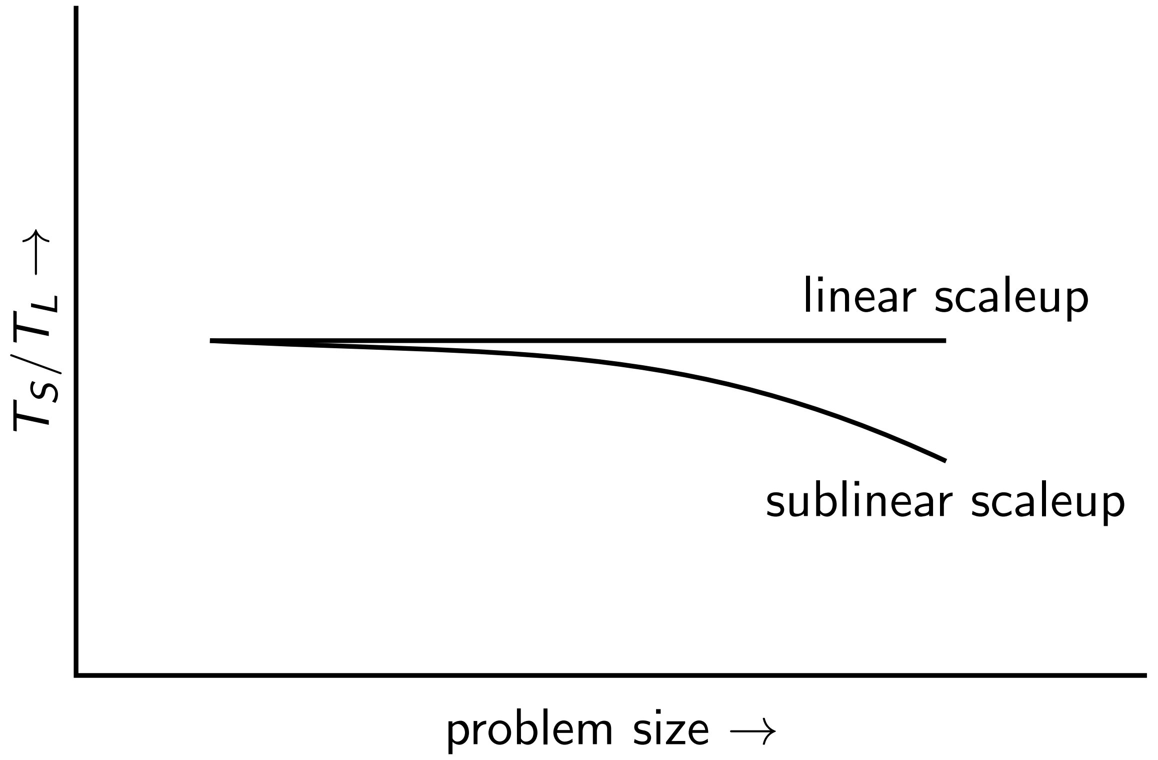
$$scaleup = \frac{small\ system\ smallproblem\ elapsed\ time}{big\ system\ big\ problem\ elapsed\ time}$$

  - Scale up is linear if equation equals 1.

Speedup



Scaleup



$T_S/T_L \rightarrow$
linear scaleup
sublinear scaleup
problem size $\rightarrow$

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

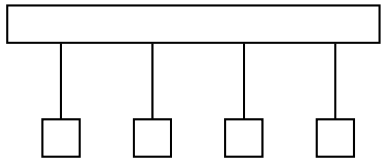
Speedup and scaleup are often sublinear due to:

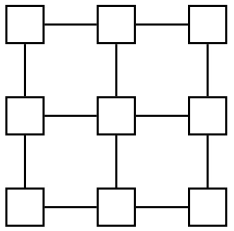
- Startup costs: Cost of starting up multiple processes may dominate computation time, if the degree of parallelism is high.
- Interference: Processes accessing shared resources (e.g., system bus, disks, or locks) compete with each other, thus spending time waiting on other processes, rather than performing 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.

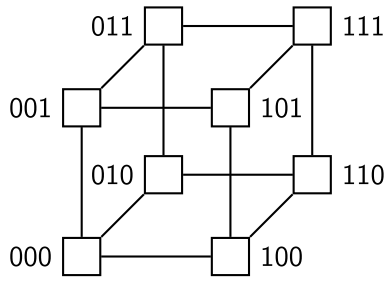
Interconnection Network Architectures

- 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


Bus


Mesh

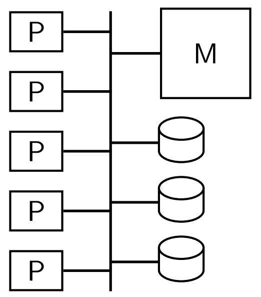


Hypercube

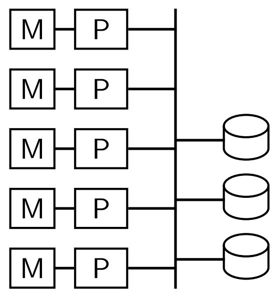
Parallel Database Architectures

- 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

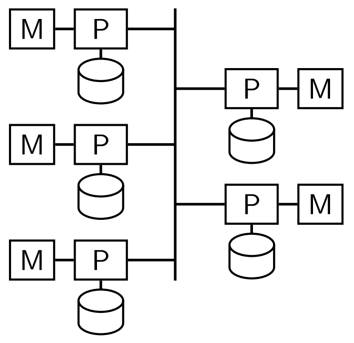
Parallel Database Architectures



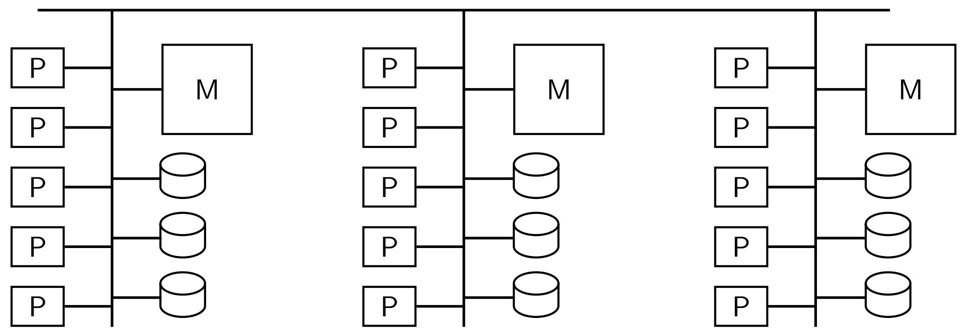
shared memory



shared disk



shared nothing



hierarchical

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 ($< 1\mu s$) — data in shared memory can be accessed by any processor.
- Downside: architecture is not scalable beyond about 64 processors since the bus or the interconnection network becomes a bottleneck
- Widely used for lower degrees of parallelism (4 to 8).

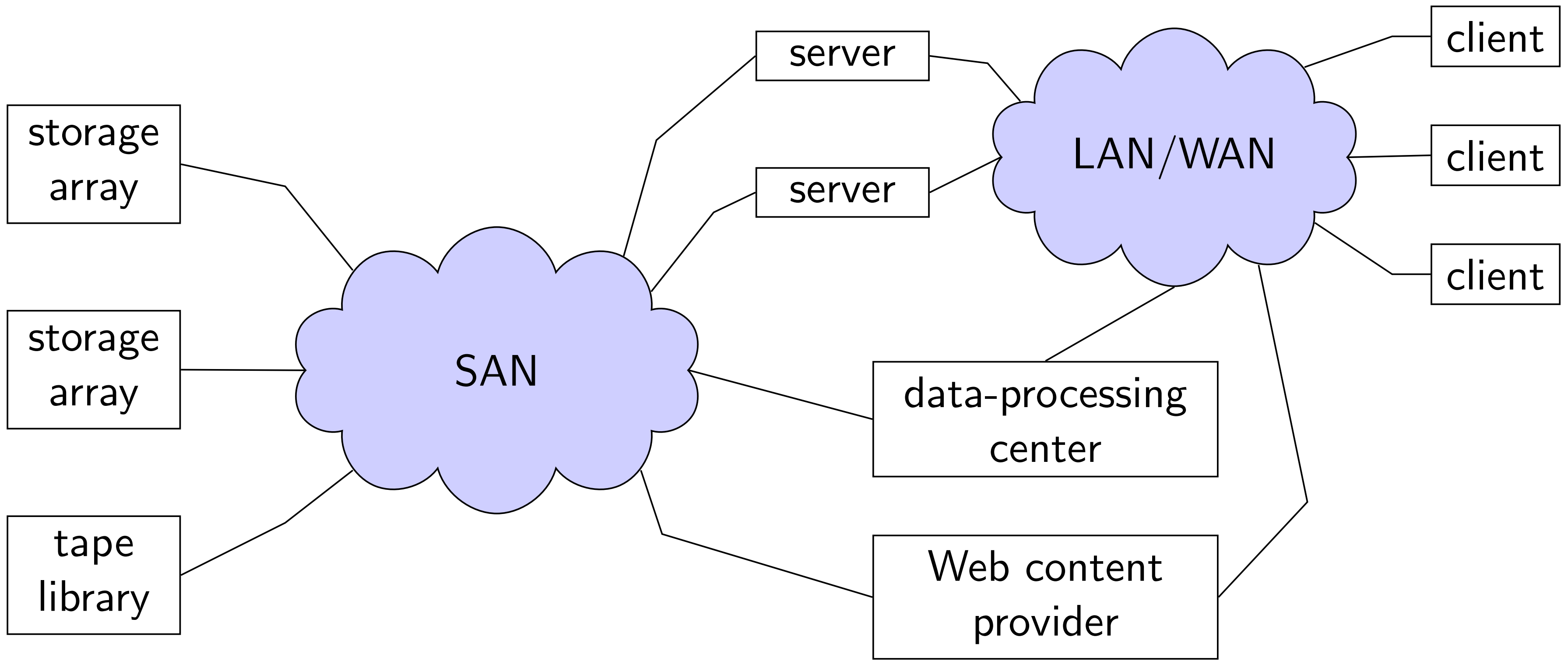
Shared Disk/1

- 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 scale to a larger number of processors, but communication between processors is slower (some *ms*).

Shared Disk/2

- File server / NAS (Network Attached Storage)
  - disks connected via RAID controller
  - mounted as directory in file system
    - Samba
    - NFS - Network File System
- SAN - Storage Array Network
  - block level access
  - appears to be locally attached block device
  - shared disk file system runs on top of SAN
    - IBM GPFS (General Parallel FS)
    - Oracle Cluster FS
    - Lustre (mainly super computing/Linux)

Storage Area Network



Shared Nothing

- Node consists of a processor, memory and one or more disks.
- Node function as servers for the data on the disks they own.
- Communication between processors through interconnection network.
- Examples: Teradata, Tandem, Oracle-n CUBE
- Minimize interference of resource sharing: data accessed from local disks (and local memory accesses) do not pass through interconnection network
- Can be scaled up to thousands of processors without interference.
- Main drawbacks:
    - cost of communication
    - cost of non-local disk access
    - sending data involves software interaction at both ends

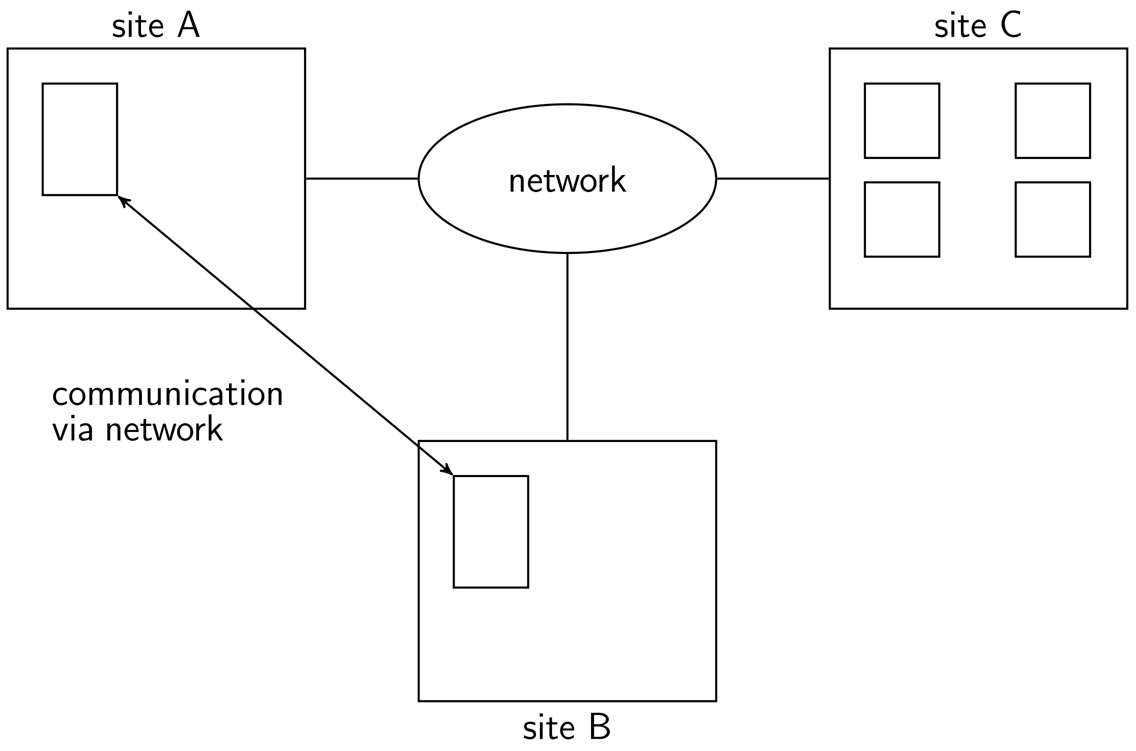
Hierarchical

- 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)

Outline

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.

Differences to Shared-Nothing Parallel Systems

- sites geographically separated
- sites separately administrated
- slower interconnection between sites
- differentiation between local and global transactions

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

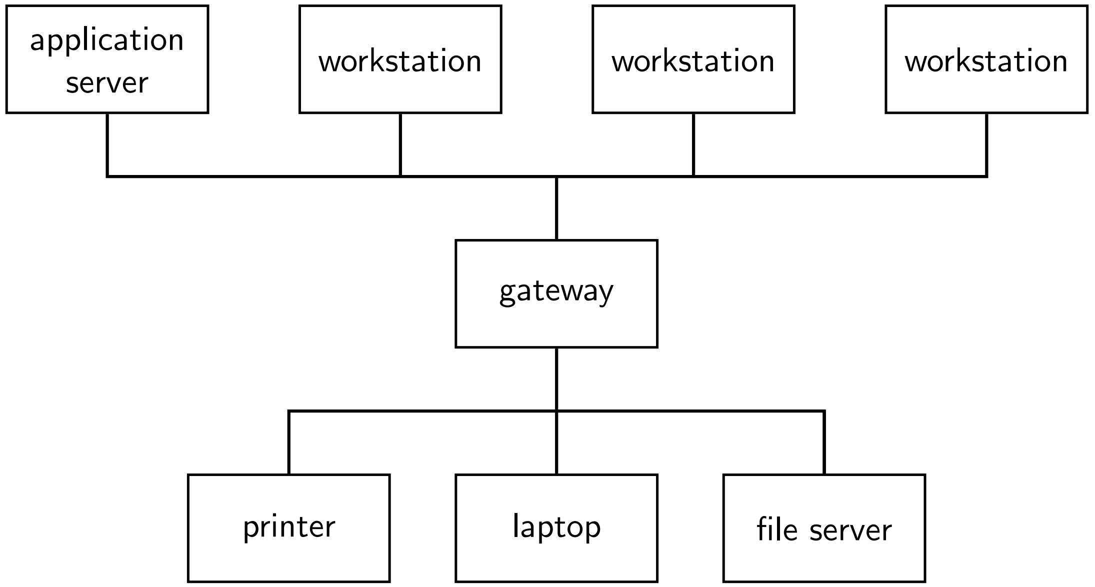
- Atomicity needed even for transactions that update data at multiple sites
- The two-phase commit protocol (2PC) is used to ensure atomicity
  - Basic idea: each site executes transaction until just before commit, and then leaves final decision to a coordinator
  - Each site must follow decision of 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

Outline

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.

Local-Area Network/1



Local-Area Network/2

- Link technology: twisted pair, coaxial cable, fiber optics, wireless connection
- Ethernet: Specification for computer networks
  - Software (e.g., protocols)
  - Hardware (e.g., cables, network cards, switches)
- Transfer rates
  - Fast Ethernet: 1, 10, 100 Mb/s (1 Mb/s $= 10^6$ bits / second)
  - Gigabit Ethernet: 1 Gb/s
  - Widely used: 10 Gb/s, highest transfer rate: 400 Gb/s
  - Higher transfer rates (1 Tb/s) require new technologies
- Distances:
  - usually single building or neighboring buildings
  - up to 70km with fiber optics

Wide-Area Network

- Fast wide-area links (fiber optics, satellite channel): hundreds of gigabits
- Last link typically slower (e.g., cable modem, wireless connection): some megabits
- Latency higher than in LAN
  - speed of light delay
  - queuing delay at routers
- WANs with continuous connection (e.g., the Internet) are needed for implementing distributed database systems.

Example: Network Latency

- What are the number of routers and the network latency for
  - localhost (i.e., network connection to the local machine)
  - in the LAN (e.g., ssh.cosy.sbg.ac.at)
  - in the WAN (e.g., www.tum.de, sidney.edu.au)
- Use ping to measure latency and traceroute to learn how the network packets are routed