Distributed Data Management

Big Data Management

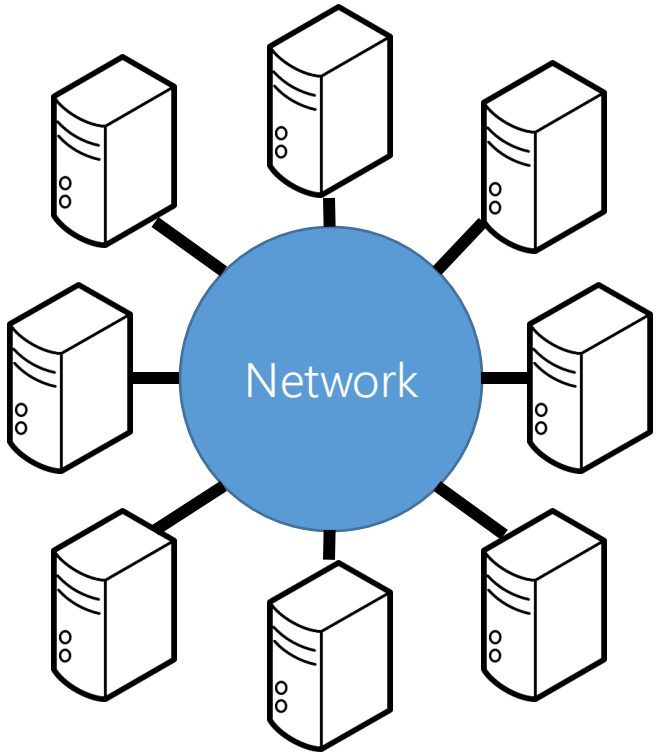
Distributed Systems

Distributed system

"One in which components located at networked computers communicate and coordinate their actions only by passing messages."

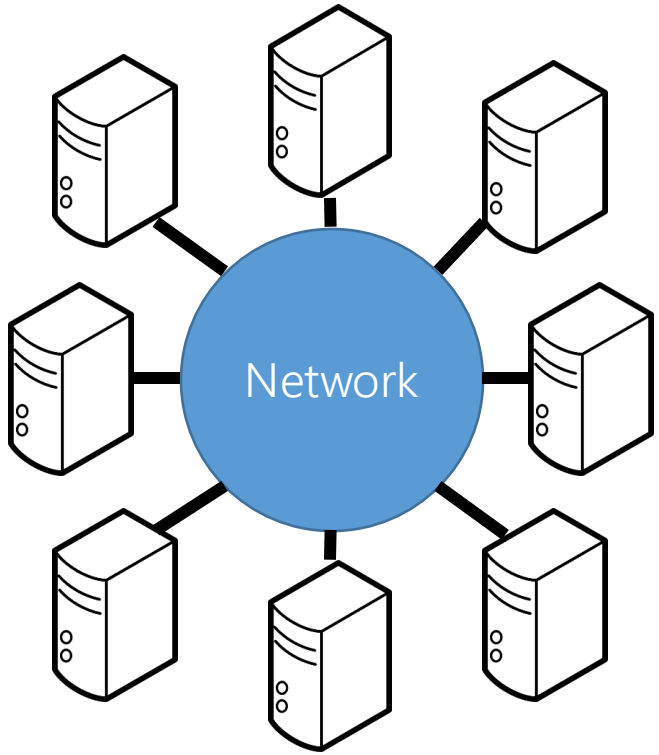
G. Coulouris et al.

- Characteristics:
  - Concurrency of components
  - Independent failures of components
  - Lack of a global clock



Challenges of distributed systems

- ~~Openness~~
- Scalability
- Quality of service
  - Performance/Efficiency
  - Reliability/Availability
  - ~~Confidentiality~~
- Concurrency
- Transparency
- ~~Heterogeneity of components~~



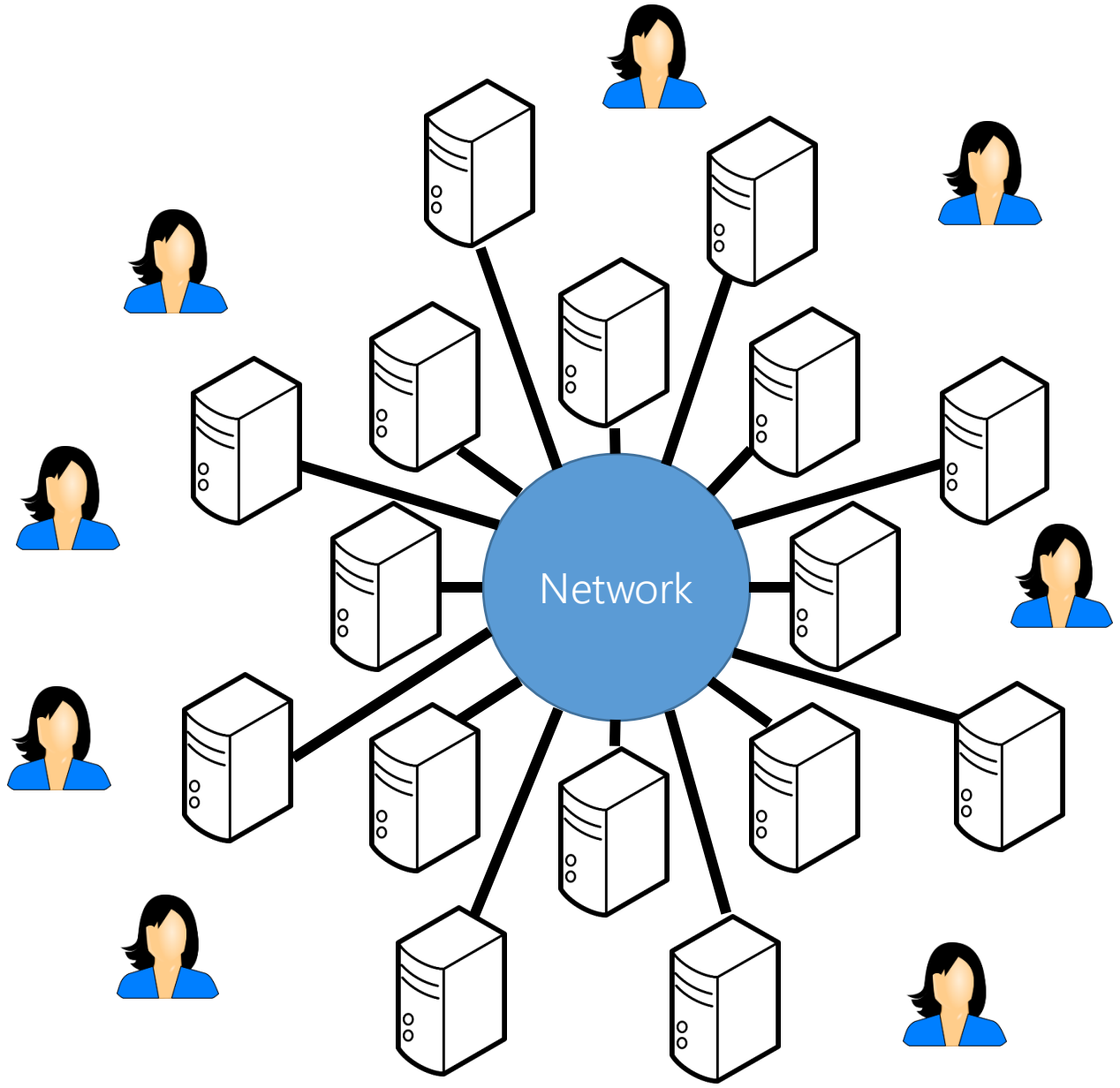
Scalability

Cope with large workloads

- Scale out

- Use:
  - Automatic load-balancing

- Avoid:
  - Bottlenecks
  - Unnecessary communication
    - Peer-to-peer

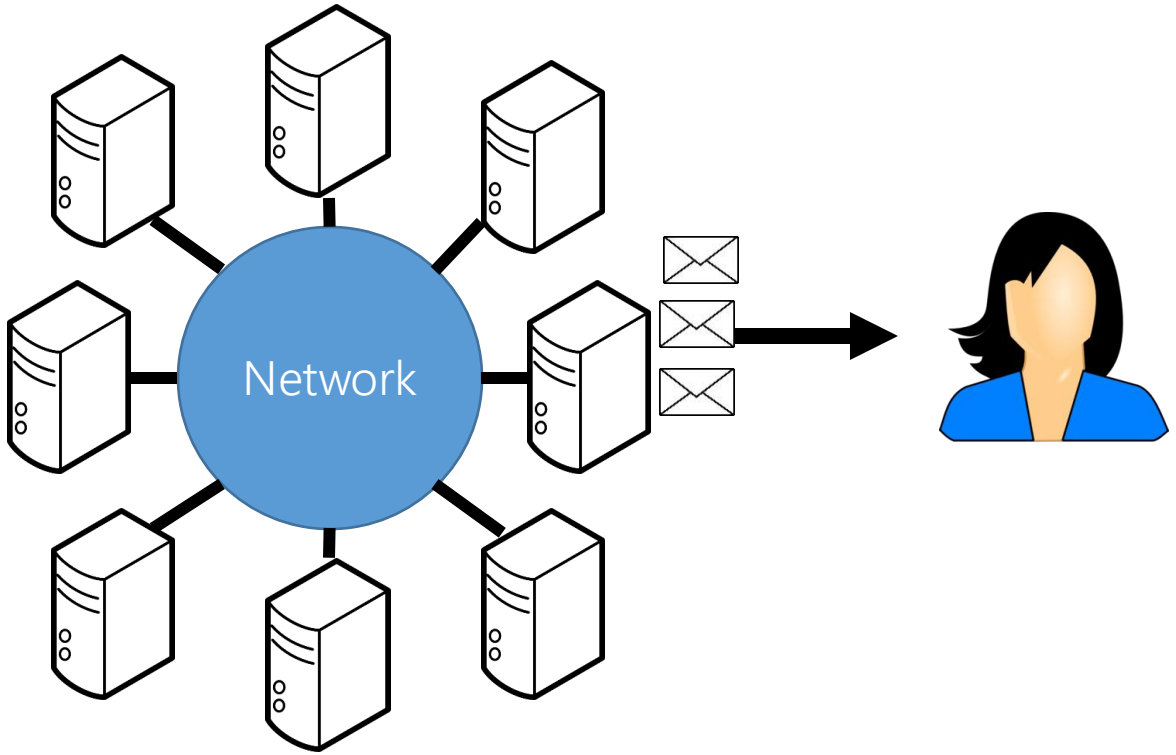


Performance/Efficiency

Efficient processing

- Minimize latencies
- Maximize throughput

- Use
  - Parallelism
  - Network optimization
  - Specific techniques

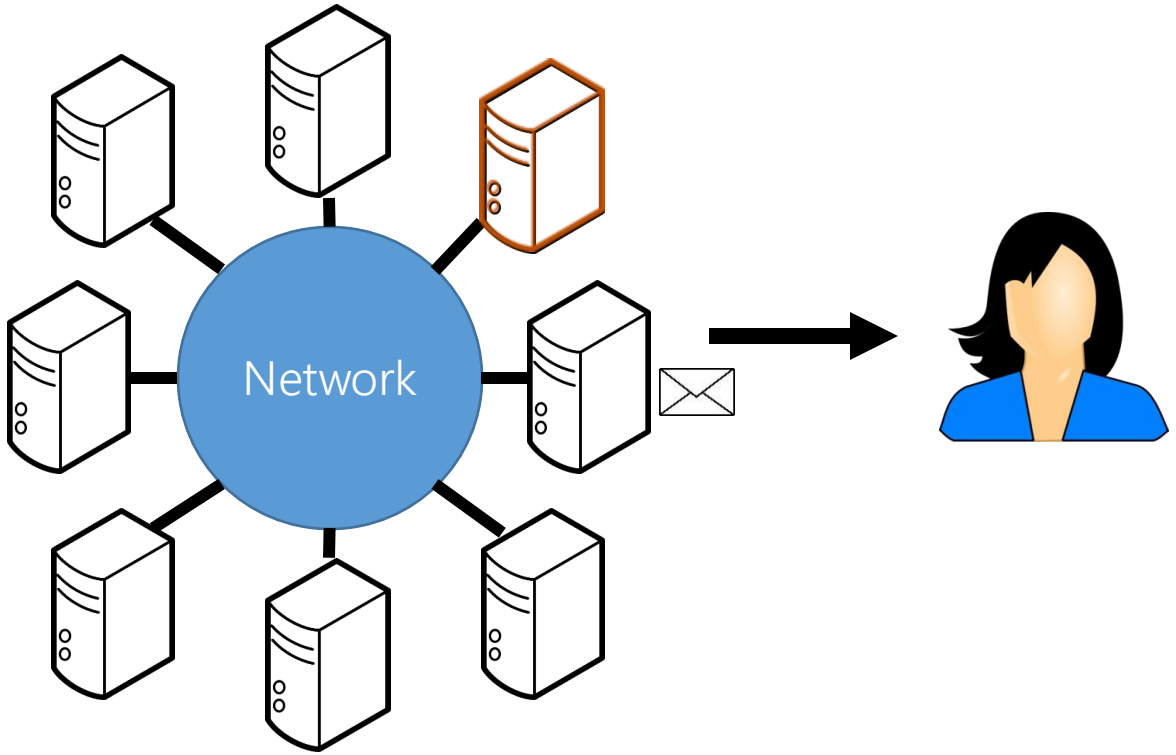


Reliability/Availability

a) Keep consistency

b) Keep the system running
   - Even in the case of failures

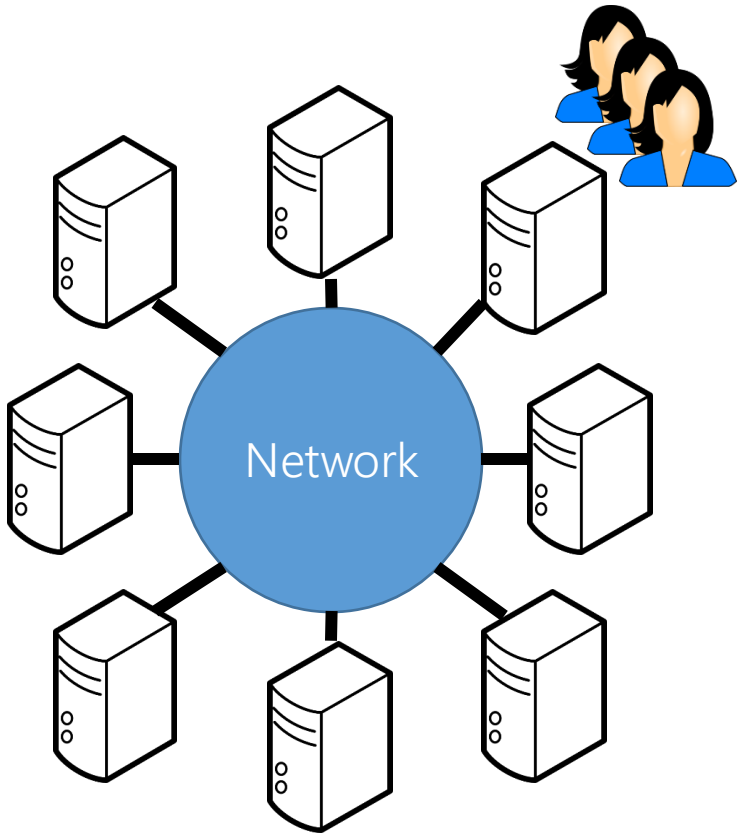
- Use
  - Replication
  - Flexible routing
  - Heartbeats
  - Automatic recovery



Concurrency

Share resources as much as possible

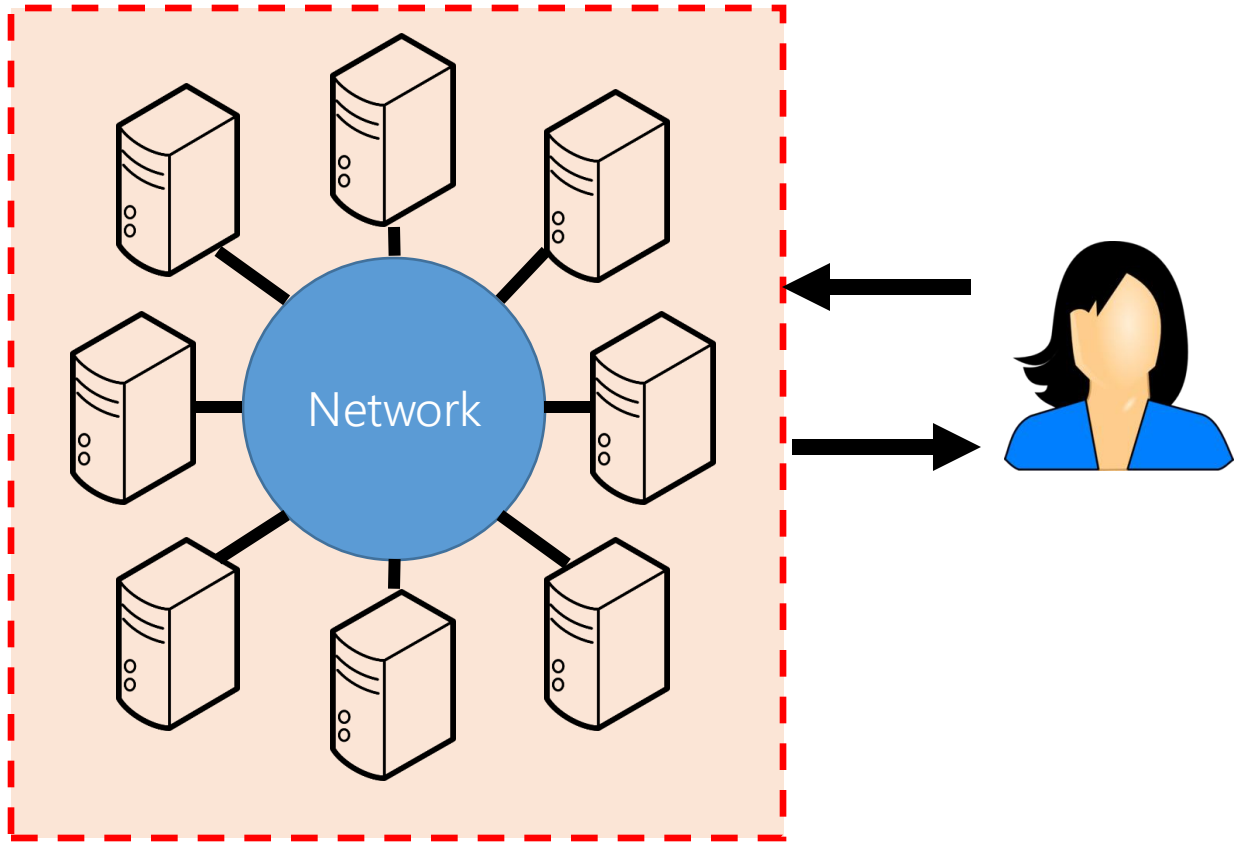
- Use
  - Consensus Protocols
- Avoid
  - Interferences
  - Deadlocks



Transparency

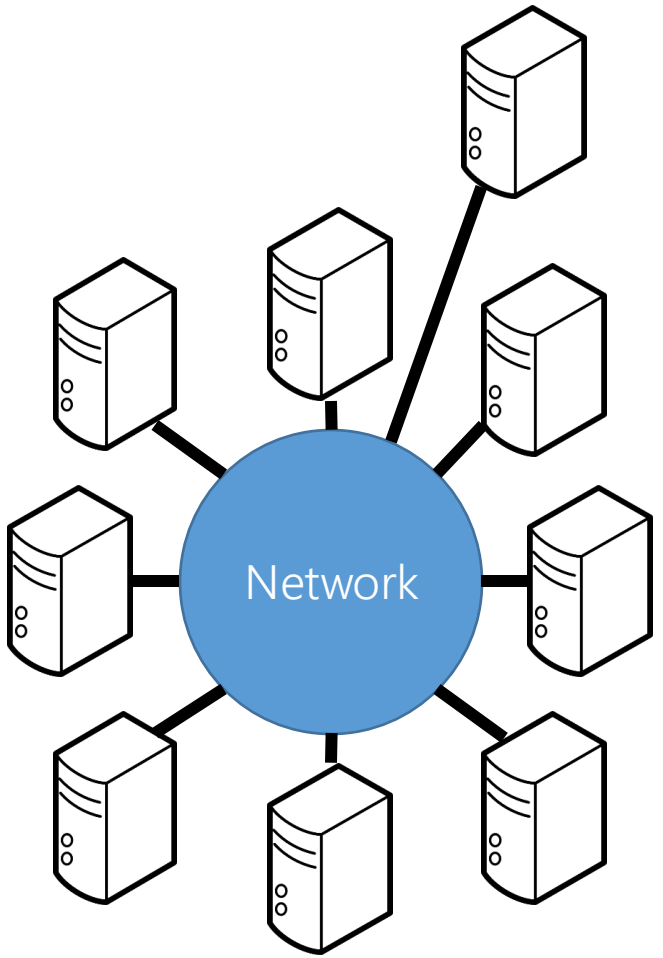
a) Hide implementation (i.e., physical) details to the users

b) Make transparent to the user all the mechanisms to solve the other challenges



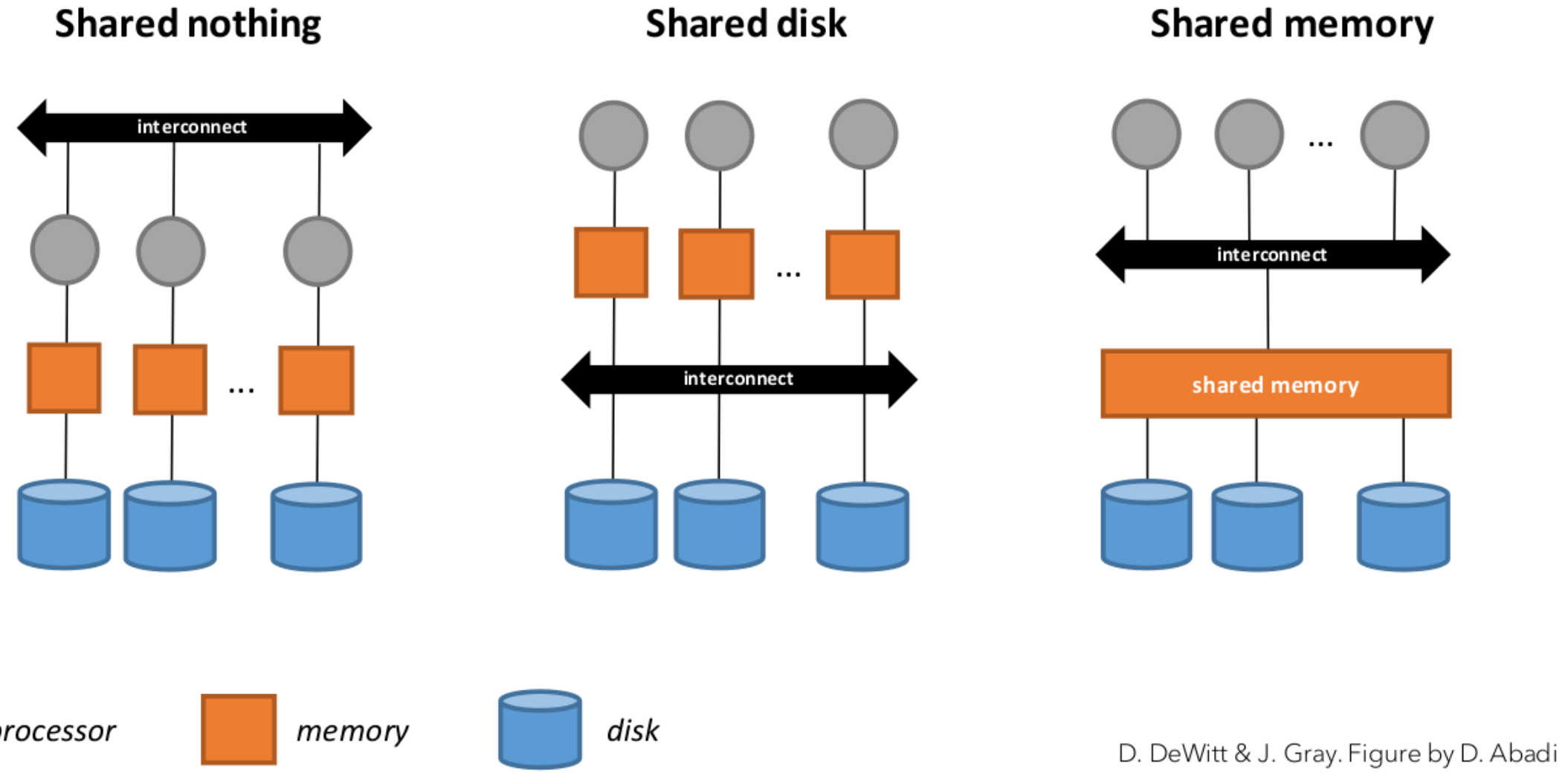
Further objectives

- Use
  - Platform-independent software
- Avoid
  - Complex configurations
  - Specific hardware/software



Cloud Databases

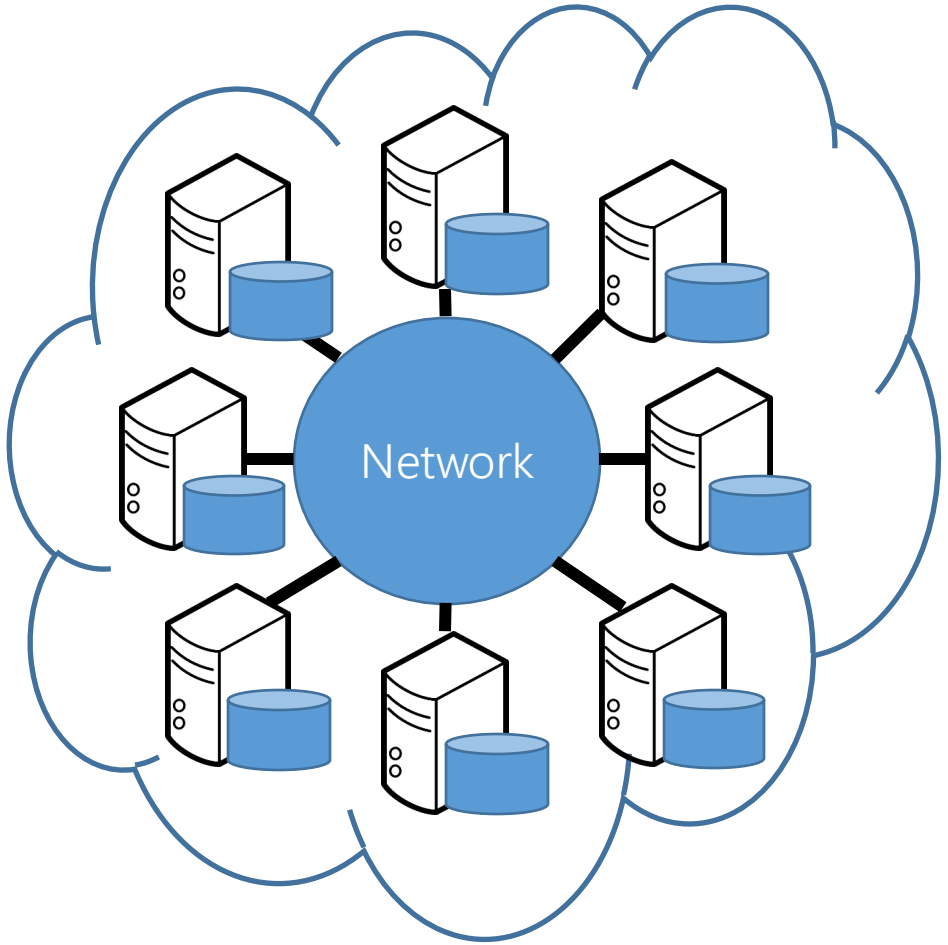
Parallel database architectures



D. DeWitt & J. Gray. Figure by D. Abadi

Key Features of Cloud Databases

- Scalability
  a) Ability to horizontally scale
- Quality of service
  - Performance/Efficiency
    b) Fragmentation: Replication & Distribution
    c) Indexing: Distributed indexes and RAM
  - Reliability/Availability
- Concurrency
  d) Weaker concurrency model than ACID
- Transparency
  e) Simple call level interface or protocol
    - No declarative query language
- Further objectives
  f) Quick/Cheap set up
  g) Multi-tenancy
  h) Flexible schema
    - Ability to dynamically add new attributes



Multi-tenancy platform problems (provider side)

- Difficulty: Unpredictable load characteristics
  - Variable popularity
  - Flash crowds
  - Variable resource requirements
- Requirement: Support thousands of tenants
  a) Maintain metadata about tenants (e.g., activated features)
  b) Self-managing
  c) Tolerating failures
  d) Scale-out is necessary (sooner or later)
     - Rolling upgrades one server at a time
  e) Elastic load balancing
     - Dynamic partitioning of databases

Data management problems (tenant side)

I. (Distributed) data design
- Data fragmentation
- Data allocation
- Data replication

II. (Distributed) catalog management
- Metadata fragmentation
- Metadata allocation
- Metadata replication

III. (Distributed) transaction management
- Enforcement of ACID properties
  - Distributed recovery system
  - Distributed concurrency control system
  - Replica consistency
    - Latency&Availability vs. Update performance

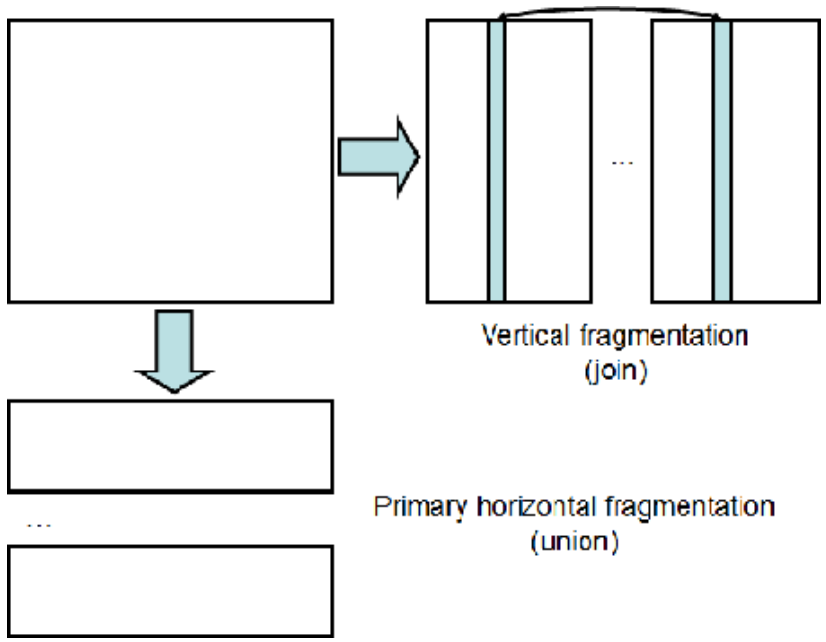
IV. (Distributed) query processing
- Optimization considering
  - Distribution/Parallelism
    - Communication overhead
  - Replication

(Distributed) Data Design

DDB Design

- Given a DB and its workload, how should the DB be split and allocated to sites as to optimize certain objective functions
  - Minimize resource consumption for query processing

- Two main issues:
  - Data fragmentation
  - Data allocation
    - Data replication



Data Fragmentation

- Usefulness
  - An application typically accesses only a subset of data
  - Different subsets are (naturally) needed at different sites
  - The degree of concurrency is enhanced
    - Facilitates parallelism
      - Fragments can be even defined dynamicaly (i.e., at query time, not at design time)
- Difficulties
  - Complicates the catalog management
  - May lead to poorer performance when multiple fragments need to be joined
    - Fragments likely to be used jointly can be colocated to minimize communication overhead
  - Costly to enforce the dependency between attributes in different fragments

Fragmentation Correctness

- Completeness
  - Every tuple in the relation must be assigned to a fragment
- Disjointness
  - There is no redundancy and every datum is assigned to only one fragment
    - The decision to replicate data is in the allocation phase
- Reconstruction
  - The original relation can be reconstructed from the fragments
    - Union for horizontal fragmentation
    - Join for vertical fragmentation

Data Allocation

- Given a set of fragments, a set of sites on which a number of applications are running, **allocate** each fragment such that some optimization criterion is met (subject to certain constraints)
- It is known to be an NP-hard problem
  - The optimal solution depends on many factors
    - Location in which the query originates
    - The query processing strategies (e.g., join methods)
  - Furthermore, in a dynamic environment the workload and access patterns may change
- The problem is typically simplified with certain assumptions (e.g., only communication cost considered)
- Typical approaches build *cost models* and any optimization algorithm can be adapted to solve it
  - Sub-optimal solutions
  - Heuristics are also available (e.g., best-fit for non-replicated fragments)

Data Replication

- Generalization of Allocation (for more than one location)
- Provides execution alternatives
- Improves availability
- Generates consistency problems
  - Specially useful for read-only workloads
    - No synchronization required

Closing

Summary

- Distributed Systems
- Distributed Database Systems
  - Distributed Database Systems Architectures
- Cloud Databases
- Distributed Database Design
  - Fragmentation
    - Kinds
    - Characteristics
  - Allocation
    - Replication
- Distributed Catalog

References

- D. DeWitt & J. Gray. *Parallel Database Systems: The future of High Performance Database Processing*. Communications of the ACM, June 1992
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