CSE 5306
Distributed Systems

Architectures

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Architecture

- Software architecture
  - How software components are organized,
  - And how they interact with each other
- System architecture
  - The instantiation of software architecture
    - Centralized architecture, client-server system
    - Decentralized architecture, peer-to-peer system
    - Hybrid architecture, edge computing

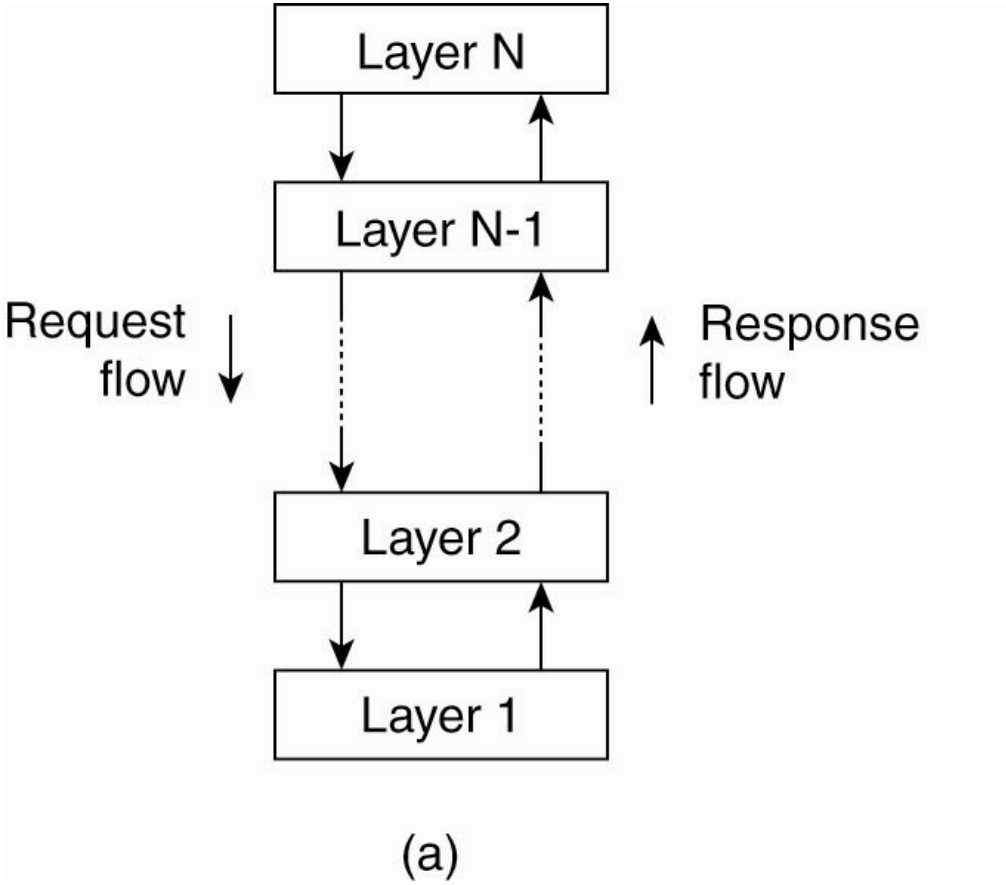
Architectural Style

- Component
  - A modular unit with well-defined interfaces
  - It is replaceable
- Connector
  - Mediates communication, coordination, and cooperation among components
  - Remote procedure calls, message passing, streaming data

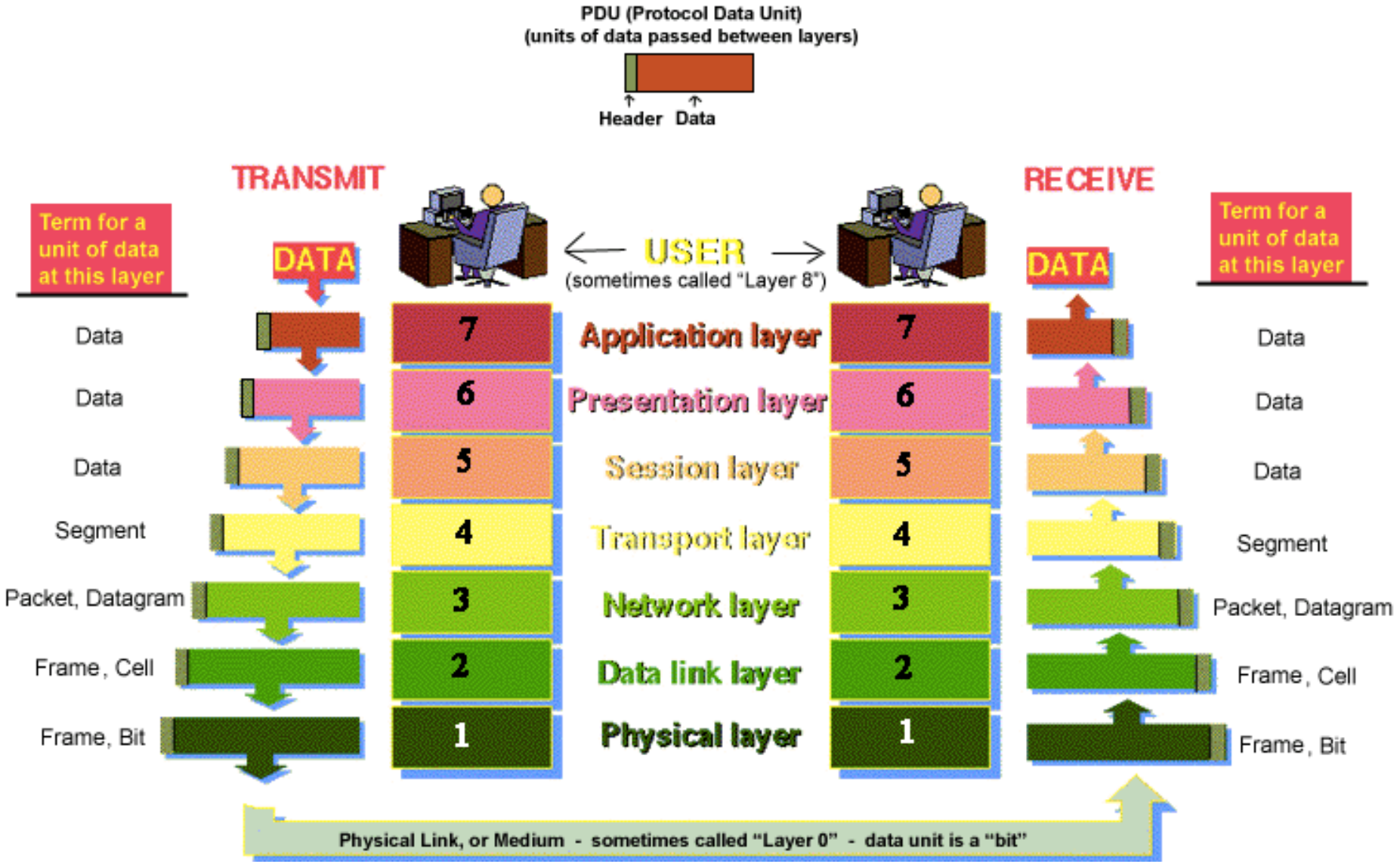
Software architecture

- Layered architectures
  - Widely adopted by the networking community
- Object-oriented architectures
  - Each object corresponds to a component; interactions are through (remote) procedure calls
- Data-centered architectures
  - Components communicate through a shared repository
- Event-based architectures
  - Processes communicate through the propagation of events, which can also carry data

Layered architecture

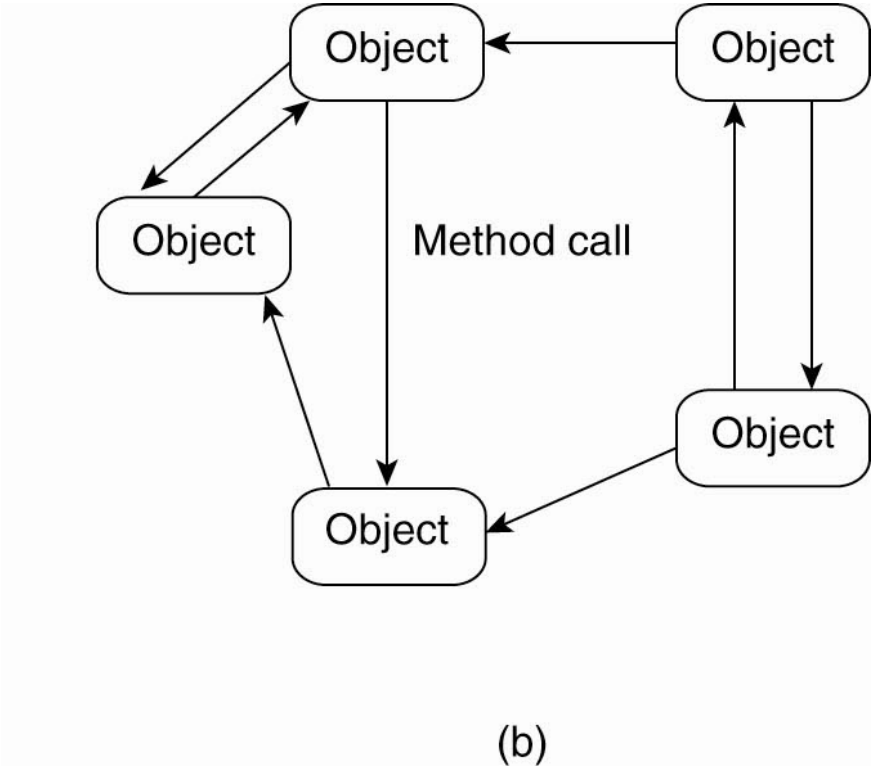


THE 7 LAYERS OF OSI



--From http://www.infocellar.com/networks/osi-model.htm

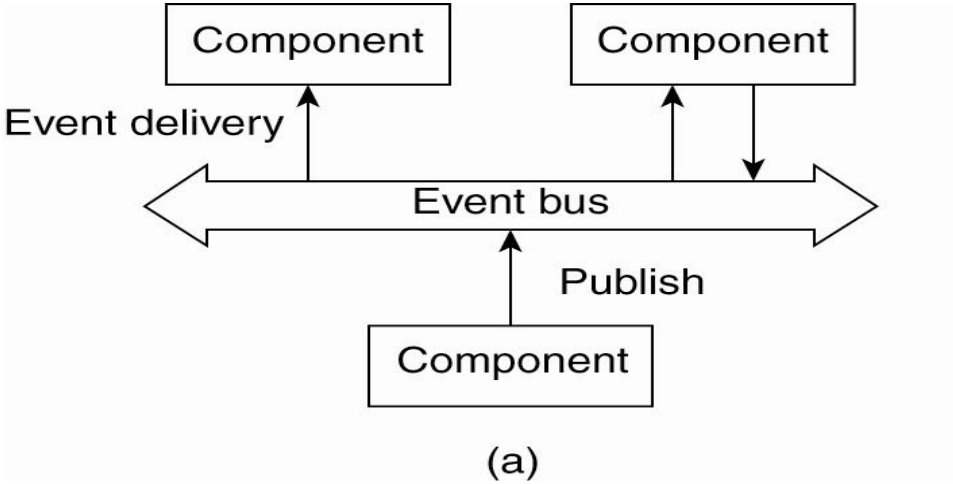
Object-oriented architecture



- Each object is an autonomous system that interacts with each other via RPC or RMI
- Example: client-server style

Event-based architecture

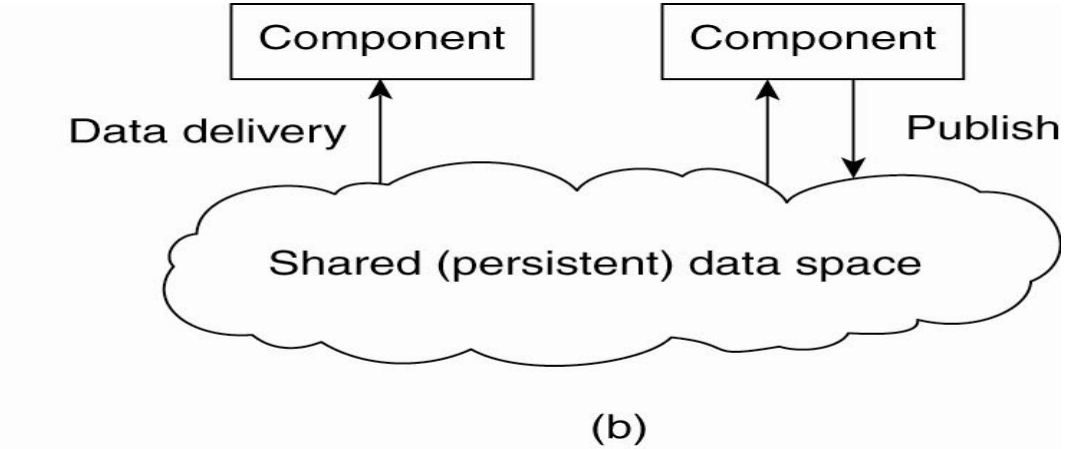
- Decoupled in space
  - Processes are loosely coupled, need not explicitly refer to each other
- Communication via propagation of events
  - Mostly publish/subscribe system



(a)

Shared data-space architecture

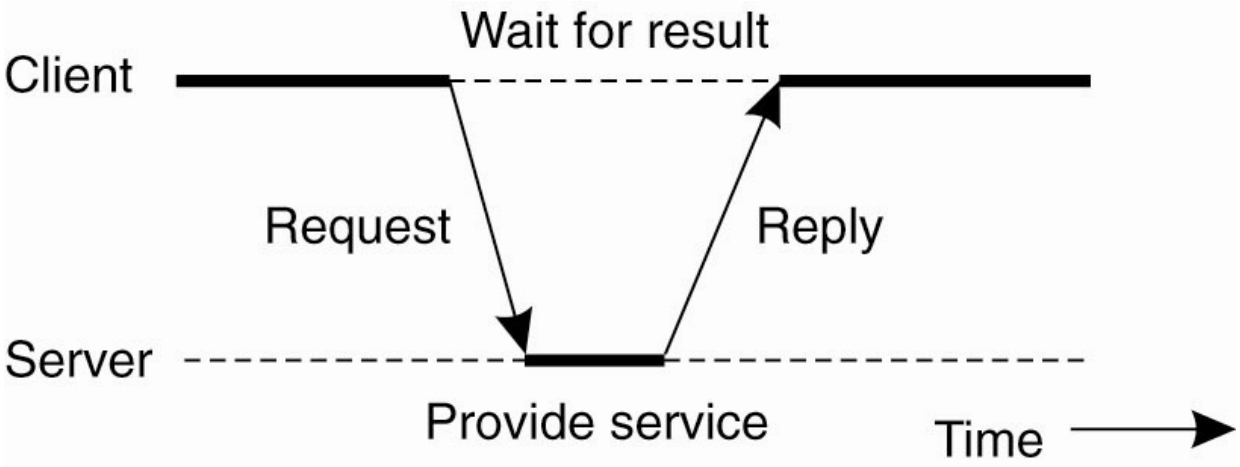
- Not only decoupled in space but also decouple in time
  - Processes need not both be active when communication takes place [More details in Chap 13]
- Examples of shared data-space architecture
  - Shared distributed file systems



System architecture

- Centralized architectures
  - Client-server model
  - Application layering
  - Multi-tiered architecture
- Decentralized architectures
  - Peer-to-peer architecture
  - Overlay networks
- Hybrid architectures
  - Edge-server systems
  - Collaborative distributed systems

The client-server model



General interaction between a client and a server.

An example client and server

```
void *worker(void *arg) // worker thread
{
        unsigned int socket;
        socket = *(unsigned in *)arg;
        process (socket);
        pthread_exit(0);
}
int main (void) // main thread, or dispatcher thread
{
        unsigned int server_s, client_s, i=0;
        pthread_t threads[200];
        server_s = socket(AF_INET, SOCK_STREAM, 0);
        ……
        listen(server_s, PEND_CONNECTIONS);
        while(1){
                client_s = accept(server_s, …);
                pthread_create(&threads[i++], &attr, worker, &client_s);
        }
}
```

Client-server communication

- Connectionless protocol
  - Hard for a sender to detect if the message is successfully received
    - Retransmission may cause problems
  - OK for idempotent operations
    - Operations that can be repeated many times without harm [More details in Chap 8]
- Connection-oriented protocol
  - Often used for non-idempotent operations
  - Problem: low performance and high cost (e.g., TCP/IP)

Application layering

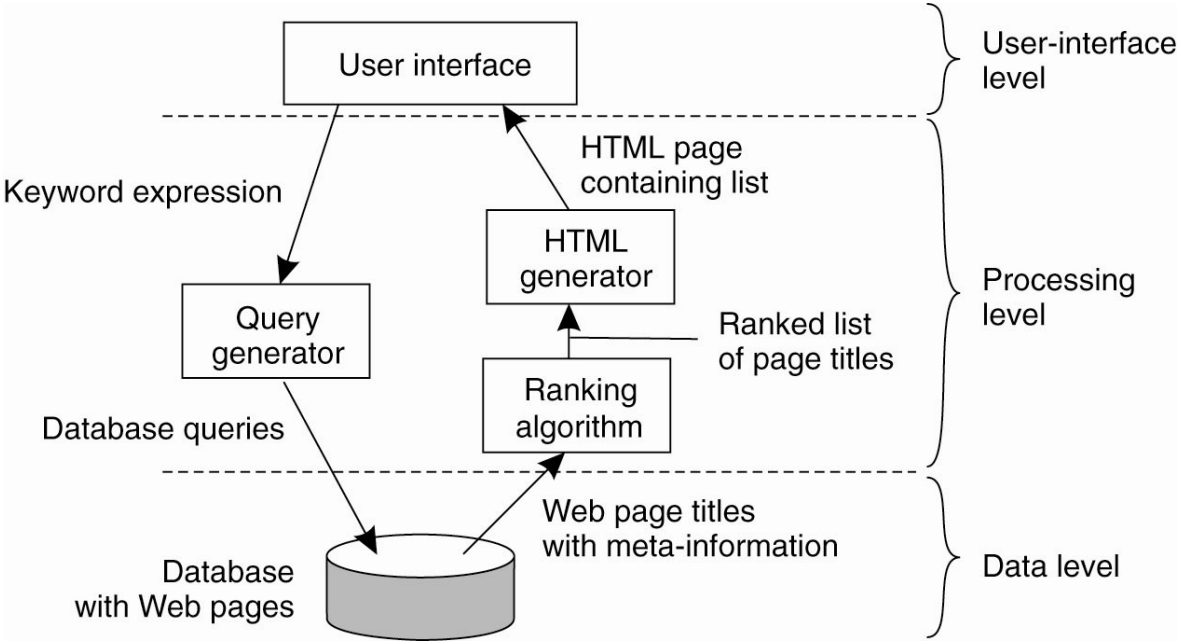
- Many client-server system can be divided into three levels
  - The user-interface level: display management
  - The processing level: core functionality of applications
  - The data level: actual data being acted on (database or file systems)

User-interface level

- Clients implement the user-interface level allowing end users to interact with applications.
  - A character-based screen: mainframe environment
  - A graphical display: X-Windows, Windows, Apple Mac
  - A graphical window: exchange data through user actions

Processing level

- Example: Internet search engine

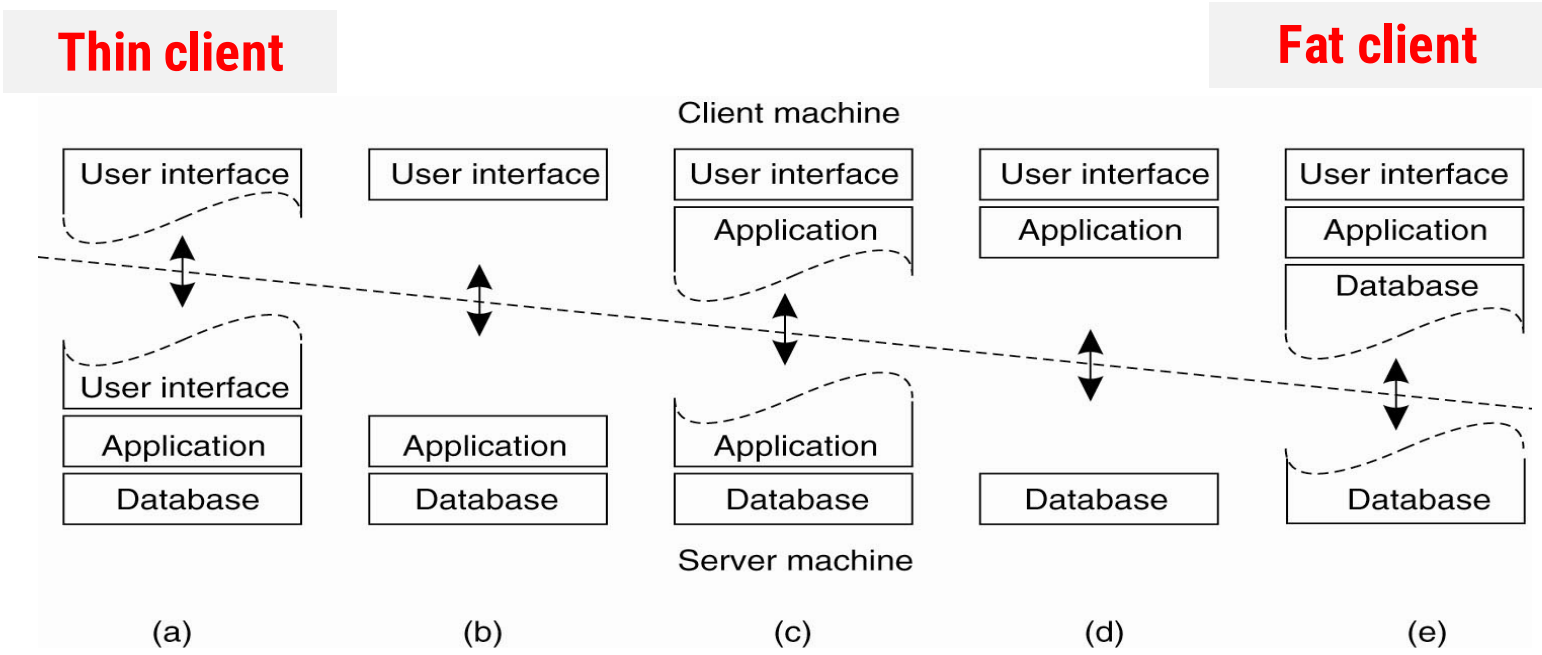


Data level

- Data level contains the programs that maintain the actual data on which the application operate.
  - Data are often persistent.
    - Even if no application is running, data will be stored somewhere for next use.
  - Keeping data consistent across different applications.

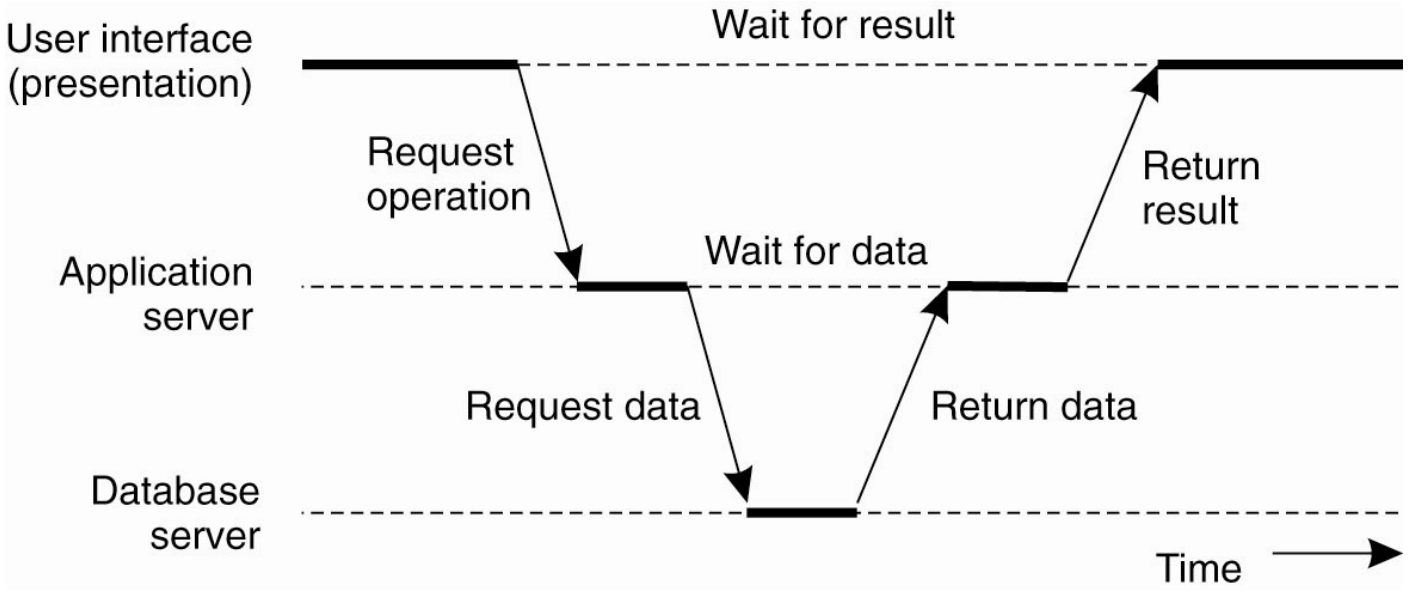
Two-tiered architecture

- The simplest organization is to have only two types of machines:
  - A client that only containing (part of) the user-interface level
  - A server containing the rest (processing level and data level)



Three-tiered architecture

- The server tier in two-tiered architecture becomes more and more distributed
  - A single server is no longer adequate for modern information systems
- The three-tiered architecture



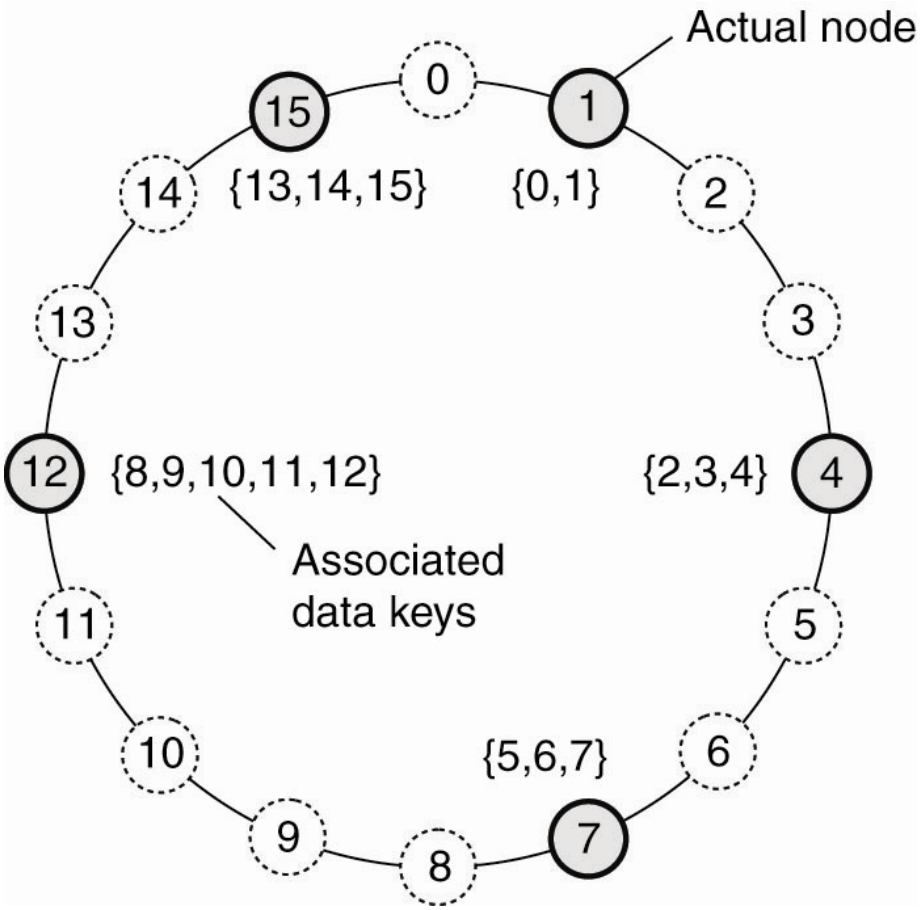
Decentralized architecture

- Multi-tiered architecture is vertical distribution
  - Placing logically different components on different machines
- An alternative is horizontal distribution (P2P systems)
  - A collection of logically equivalent parts
  - Each part operates on its own share of the complete data set, thus balancing the load
- The main question for peer-to-peer system is
  - How to organize the processes in an overlay network
    - A network in which the nodes are formed by the processes and the links represent the possible communication channels.
  - Two types: structured and unstructured

Structured P2P architectures

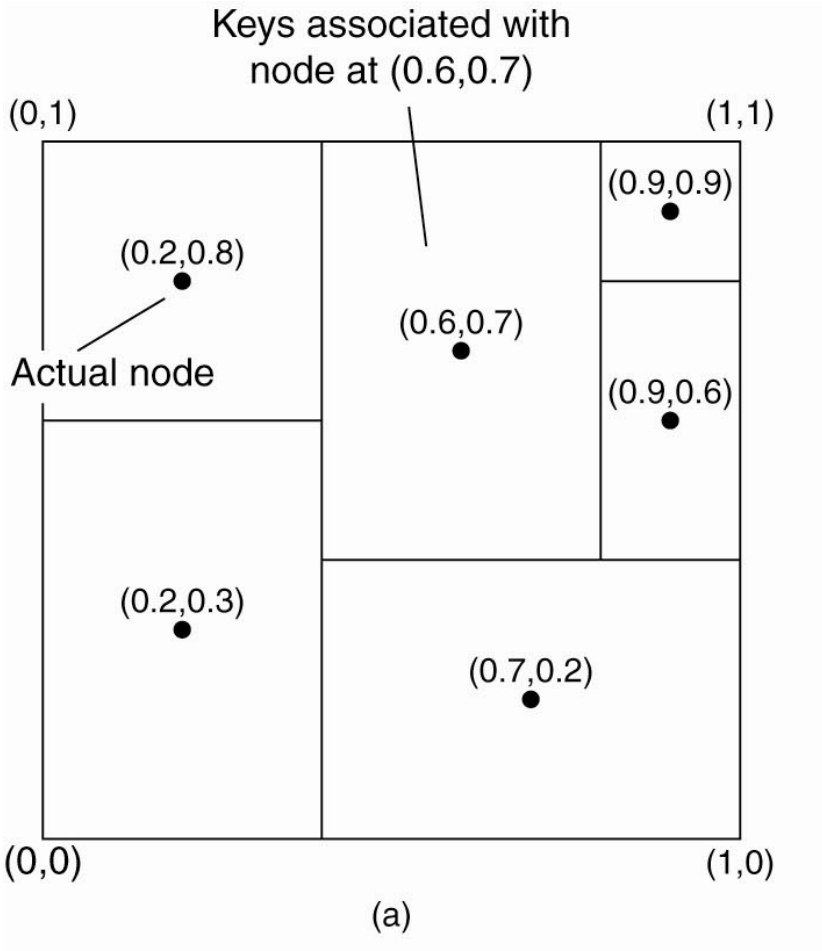
- Structured: the overlay network is constructed in a deterministic procedure
  - Most popular: distributed hash table (DHT)
- Key questions
  - How to map data item to nodes
  - How to find the network address of the node responsible for the needed data item
- Two examples
  - Chord and content addressable network (CAN) [More details in Chap. 5]

Chord System



Content addressable network

- 2-dim space [0,1] * [0,1] is divided among 6 nodes
- Each node has an associated region
- Every data item in CAN is assigned a unique point in space
- The node owning the region is responsible for the data item



Unstructured P2P architectures

- Largely relying on randomized algorithm to construct the overlay network
  - Each node has a list of neighbors, which is more or less constructed in a random way
- One challenge is how to efficiently locate a needed data item
  - Flood the network
- Many systems try to construct an overlay network that resembles a random graph [More details in Chap. 5]
- Each node maintains a partial view, i.e., a set of live nodes randomly chosen from the current set of nodes

Super-peers

- In unstructured peer-to-peer systems, locating relevant data items can become problematic as the network grows.
  - Super-peers: Make use of special nodes that maintain indexes of data items.
- How to select the nodes that are eligible to as the super-peer ?
  - Leader-election problem [More details in Chap 6]

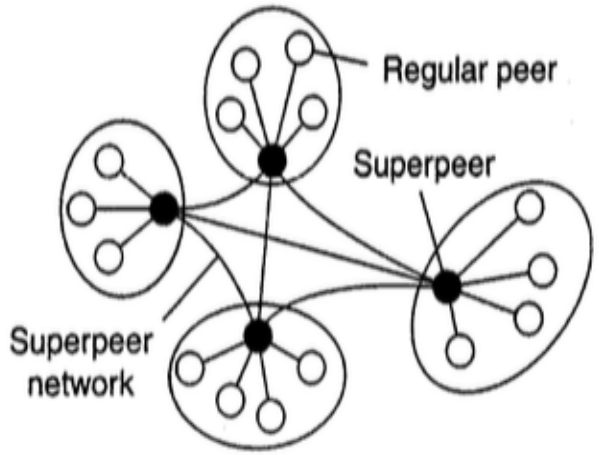


Figure 2-12. A hierarchical organization of nodes into a superpeer network.

Hybrid Forms: Edge-Server System

- Servers are placed “at the edge” of the network.
  - The edge is formed by the boundary between enterprise networks and the actual Internet.
- Edge server’s main purpose is to serve content
  - Web-based solutions [More details in Chap 12]

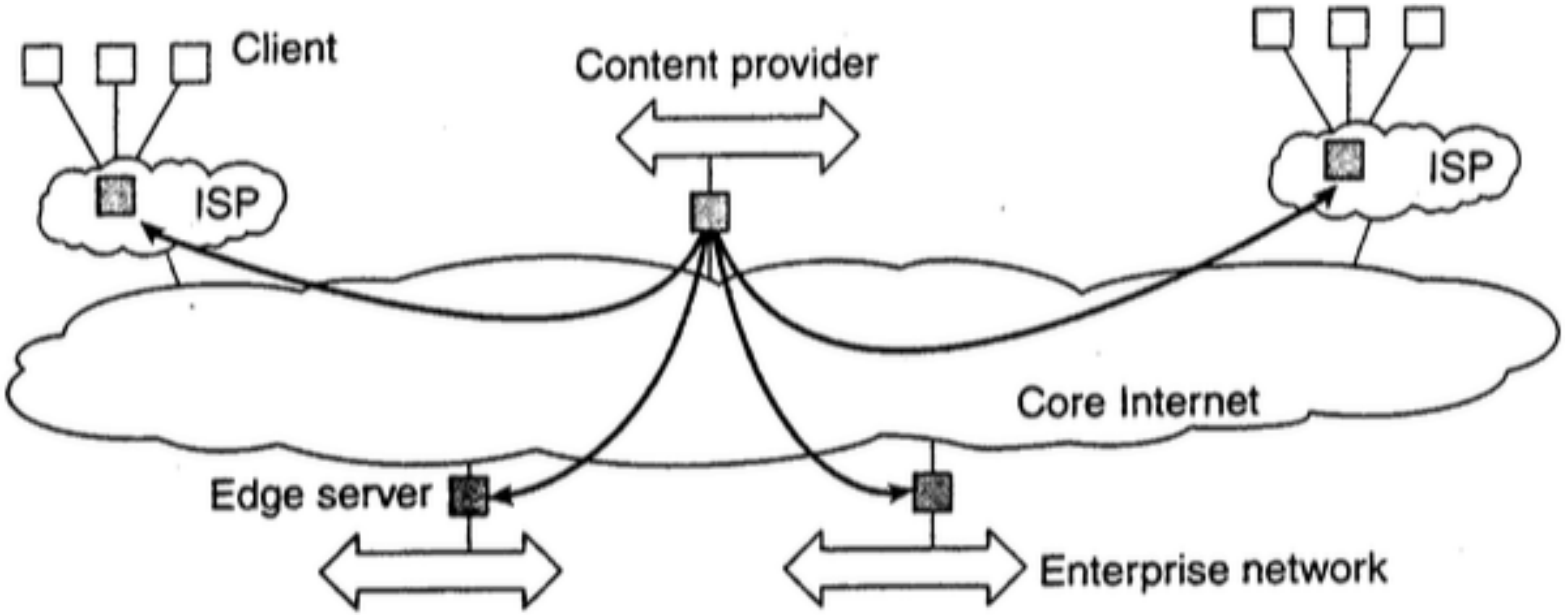


Figure 2-13. Viewing the Internet as consisting of a collection of edge servers.

Collaborative Distributed Systems

- BitTorrent file-sharing system.
  - The basic idea is when an end user is looking for a file, he downloads chunks of the file from other active users.
- The design goal is to ensure collaboration.

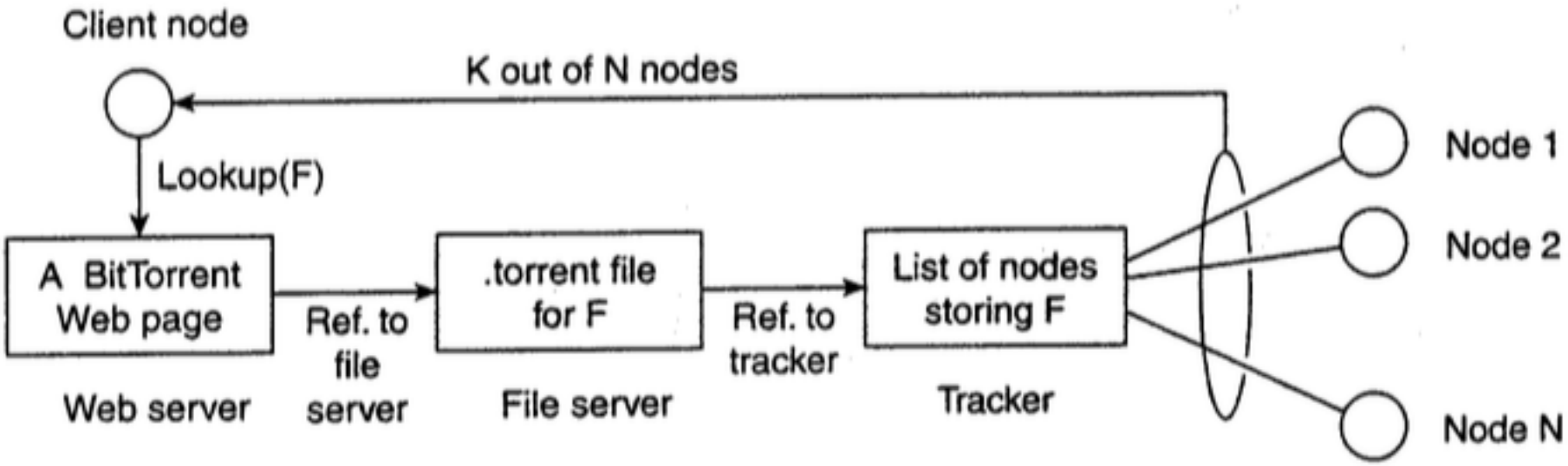


Figure 2-14. The principal working of BitTorrent [adapted with permission from Pouwelse et al. (2004)].

Collaborative Content Distributed Systems

- End users provide enhanced web servers that are capable of collaborating in the replication of Web pages.
- Each server has the following components:
  - A component that can redirect client requests to other servers
  - A component for analyzing access patterns
  - A component for managing the replication of web pages

Architectures Versus Middleware

- Middleware forms a layer between applications and distributed platforms, the purpose is to provide a degree of distribution of transparency.
- Middleware systems usually follow a specific architecture style.
  - Object-based architecture style: CORBA、OMG, and 2004a
  - Event-base architecture style: TIB/Rendezvous
    - Benefits: designing applications become simpler
    - Drawbacks: Adding other interaction patterns is difficult
- Solutions should be adaptable to applications requirements
  - Make several versions of a middleware system
  - Configure, adapt, and customize the middleware as needed by applications

Interceptors: adapt the middleware

- Environment in which distributed applications are executed changes continuously.
  - Mobility, variance in the quality-of-service of networks
  - Failing hardware, battery drainage
- An interceptor is nothing but a software construct that will break the usual flow of control and allow other application specific code to be executed.

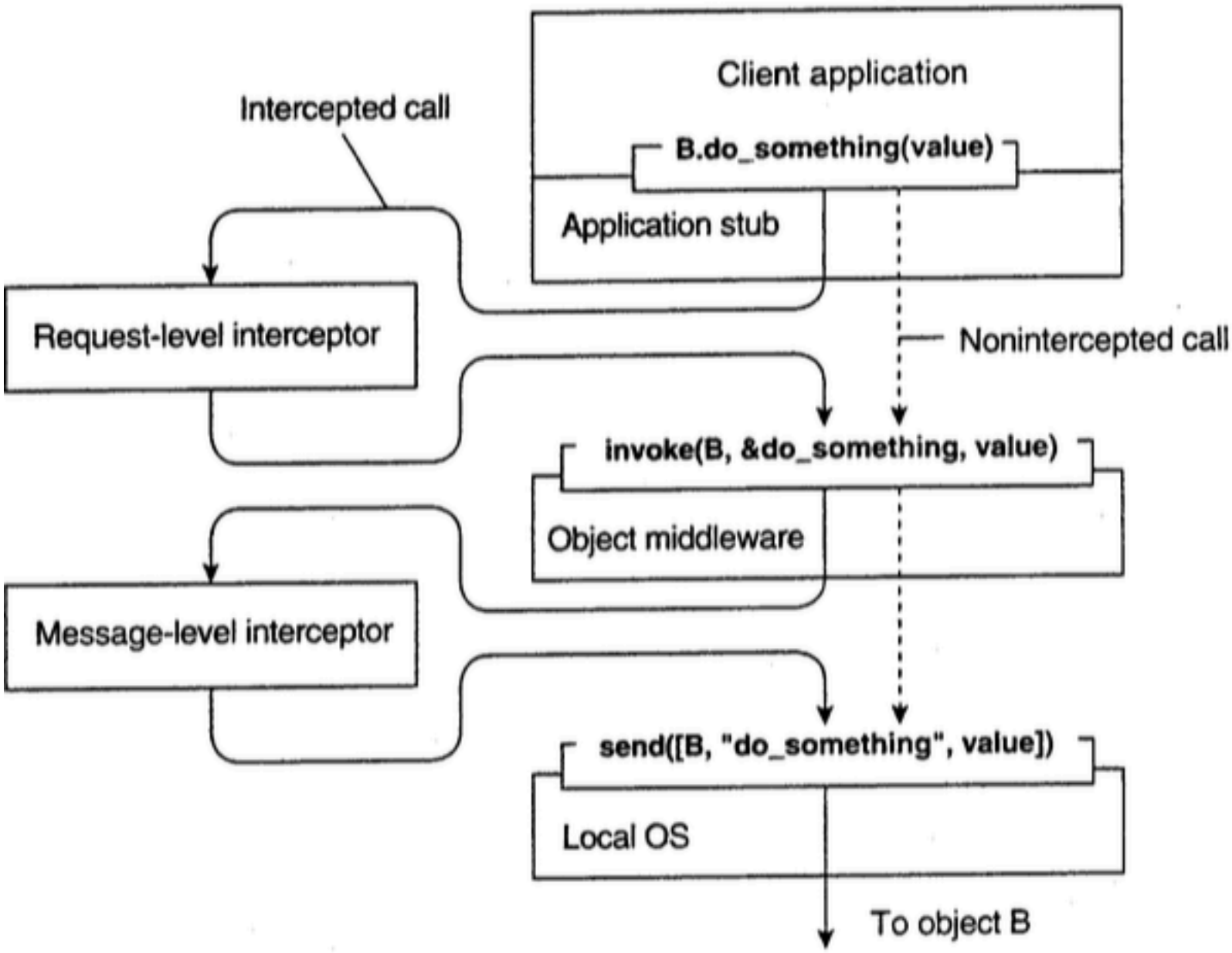


Figure 2-15. Using interceptors to handle remote-object invocations.

Adaptive Software

- Three techniques about software adaption:
  - Separation of concerns
    - Separate the parts that implement functionality from those that take care of reliability, performance, and security
  - Computation reflection
    - The ability of a program to inspect itself and if necessary, adapt its behavior
  - Computation-based design
    - Automatically selection of the best implementation of a component during runtime

Discussion about Middleware

- Middleware are usually bulky and complex:
  - Provide distribution transparency
  - Distributed applications have extra-functional requirements which conflicts with the aim at achieving this transparency
  - Necessary to adapt the applications ?
    - Environment changes: faulty hardware, security attacks
    - Distributed system can not be shut down

Self-management in Distributed Systems

- Distributed systems should:
  - Support as many applications as possible
    - shielding undesirable features inherent to network
  - Support application-specific solutions
    - full distributed transparency is not what most applications want
  - Adapting their execution behavior not to modify the software components they comprise
- Autonomic computing
  - High-level feedback control systems allowing automatic adaptions to changes

The Feedback Control Model

- Adaptions take place with feedback control loops
  - Uncontrollable parameters come from:
    - The environment distributed systems is executing
    - Unanticipated component interaction
  - Metric estimation component
    - Monitor the running distributed systems
  - Feedback analysis component (core component)
    - Analyzes the measurements and compares them to reference values
  - Adjustment component
    - Change the behavior of the system: scheduling priorities, switching services, moving data, redirecting requests etc.

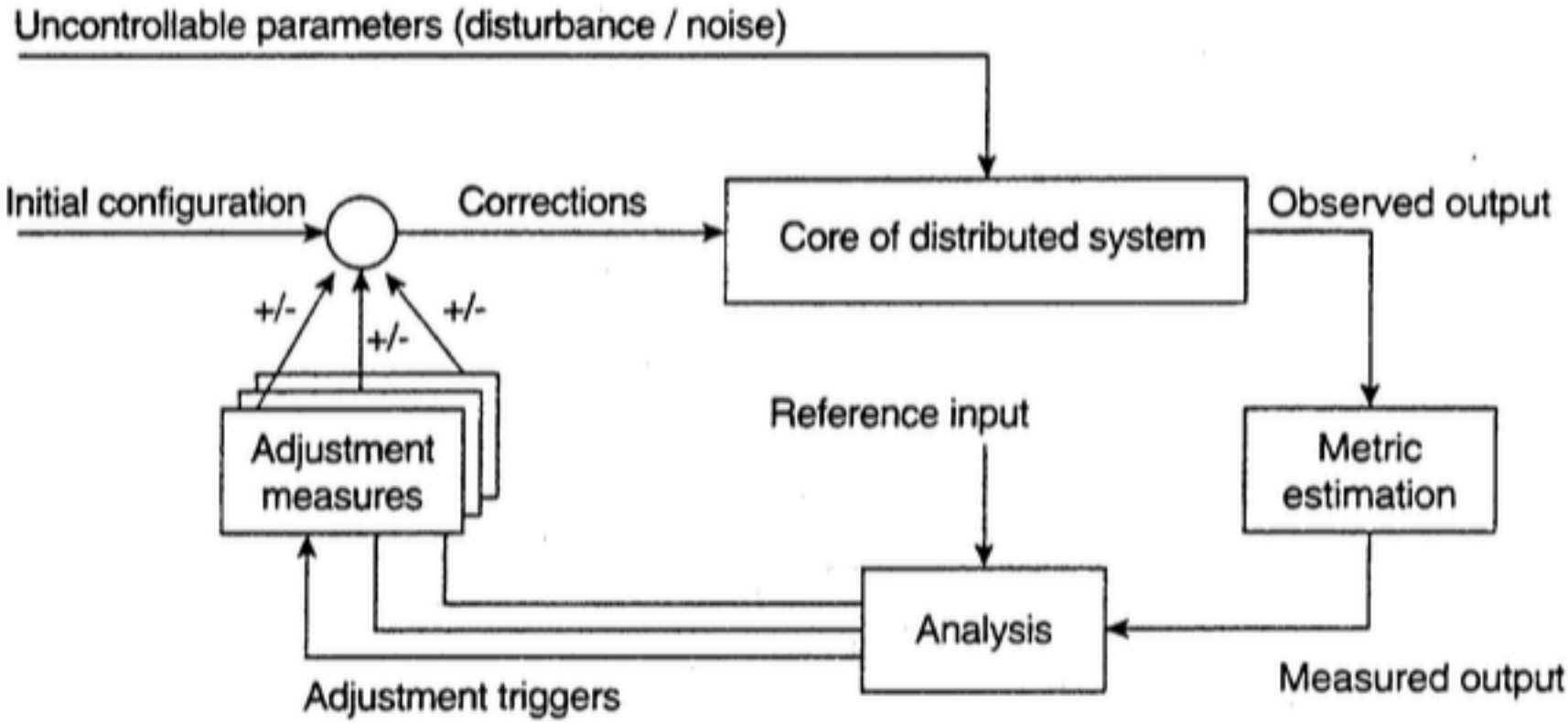


Figure 2-16. The logical organization of a feedback control system.

System Monitoring with Astrolabe

- General monitoring of large distributed systems
  - Organizing a large collections of hosts into a hierarchy of zones
  - The lowest-level zones consists of a single host
  - The top-level zone covers all hosts
- Each host runs an Astrolabe process called agent
  - Agent collects information of the hosts in each zone
    - Local information of each host is stored in a set of attributes:
    - Only the attributes of the lowest-level are writable
  - Agent communicates with each other

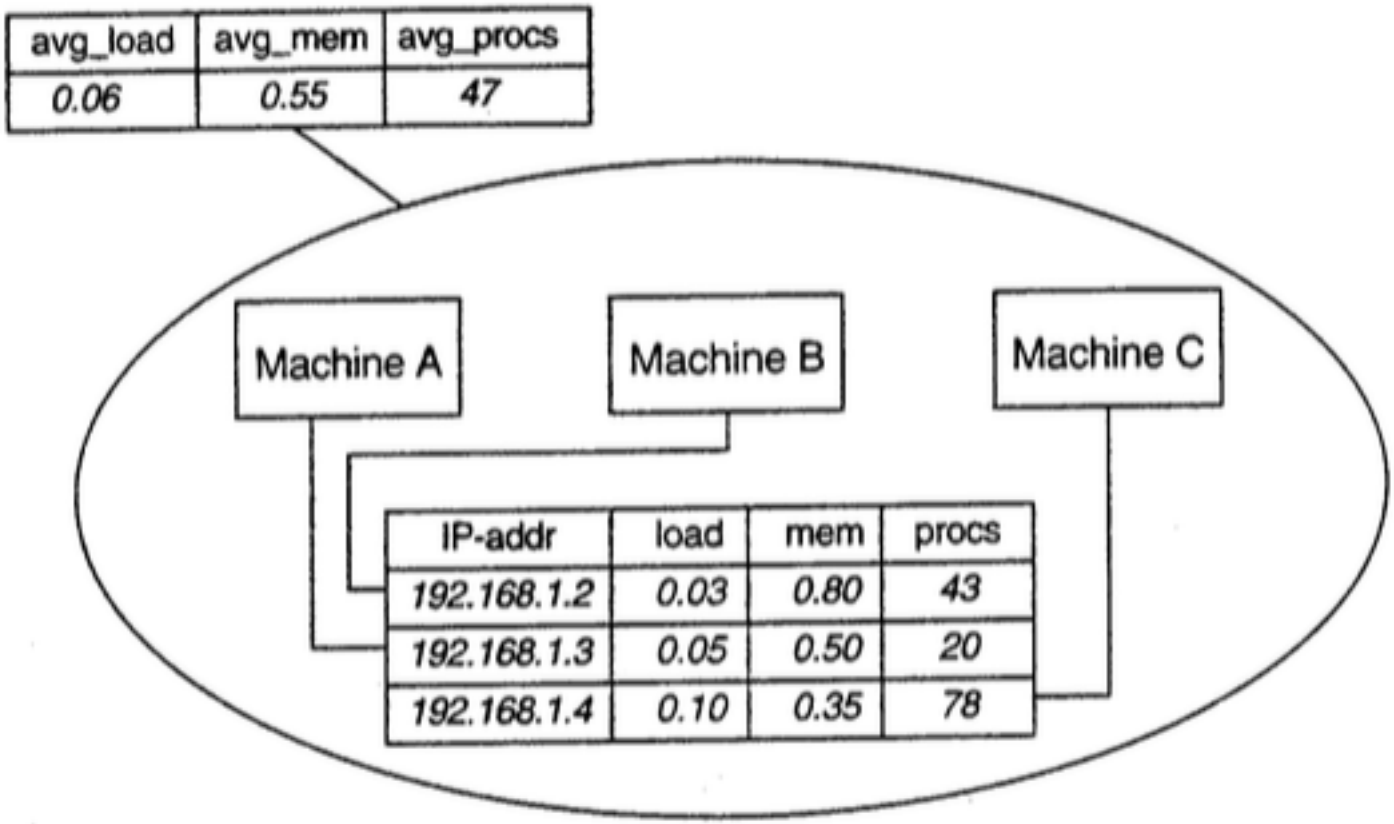


Figure 2-17. Data collection and information aggregation in Astrolabe.

Automatic Component Repair Management in Jade

- Detecting component failures and replacing them automatically during runtime
- Repair Management Domain:
  - A number of nodes
    - Each node represents a server
    - Equipped with failure detectors
  - A node manager
    - Adding and removing nodes from domain
- Crucial data has been lost ?

Summary

- Software architecture and System architecture
  - Software architecture: logical organization
  - System architecture: implementation
- Architecture Styles:
  - Layered architecture
  - Object orientation architecture
  - Event orientation and Data-space architecture
- Centralized and Decentralized architectures
  - Centralized: client-server architectures
  - Decentralized: peer-to-peer architectures: structured and unstructured
- Self-managing distributed systems
  - Feedback-control loops