CS 432: Distributed Systems

Distributed Systems Architectures

Reading

- Tanenbaum (2nd Edition): 2.1, 2.2
- Coulouris (5th Edition): 2.3

Introduction

- Distributed systems:
  - are complex pieces of software
  - have components that are dispersed across multiple machines
- It is important to organize these systems to manage their complexity
- Organization of a distributed system
  - Hardware architecture (physical realization)
  - Software architecture: how software components are organized and interacting

System Models

- Physical models

  Types of computers and devices that constitute a system and their interconnectivity (sharing in local network, internet-scale, ubiquitous computing, cloud computing, IoT)

- Architecture Models

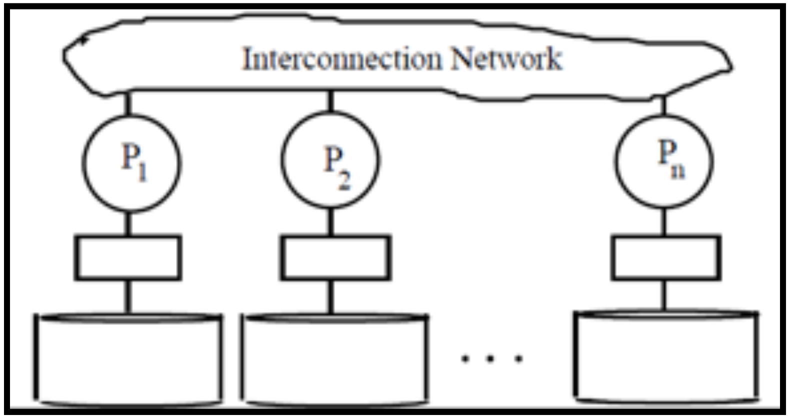
  The components of a distributed system and their interrelationships

- Fundamental Models
  - Interaction models
  - Failure models
  - Security models

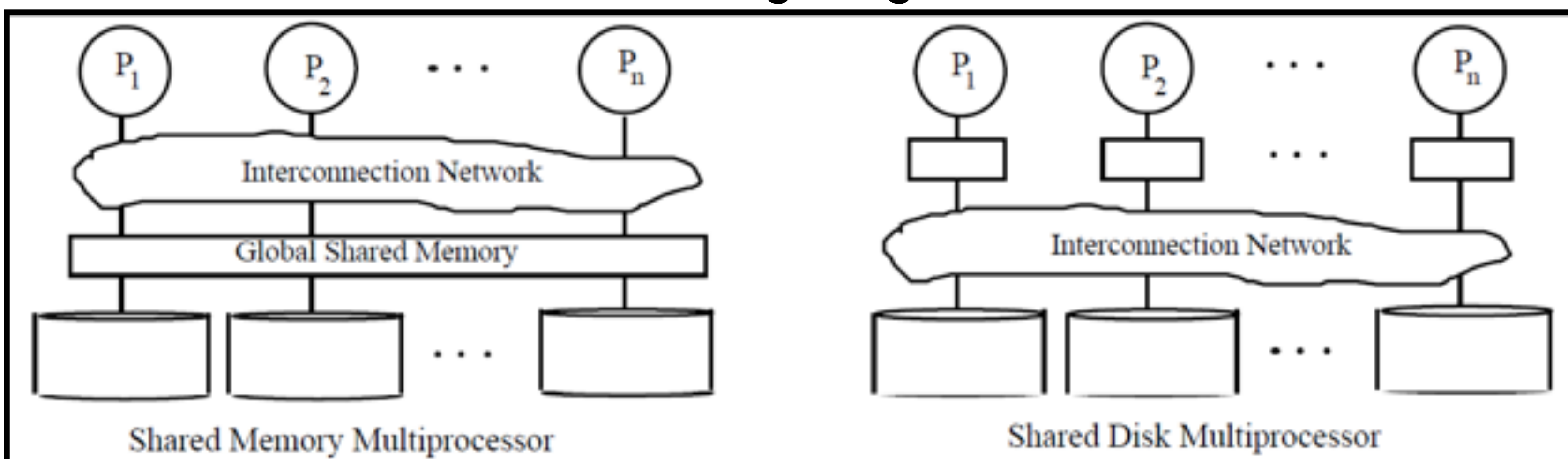
Outline

- Introduction
- **Hardware Architectures**
- Architecture Styles
- System Architectures
  - Centralized Architecture
    - Client-Server
    - Multiple-clients / multiple-servers
    - Mobile computing
    - Thin client
    - Application Layering
  - Decentralized Architecture: peer-to-peer
  - Hybrid Architecture

Hardware Architectures (Legacy)



Shared-nothing design



David J. DeWitt and Jim Gray. Parallel Database Systems: The Future of High Performance Database Systems. Communications of the ACM 35(6), 1992

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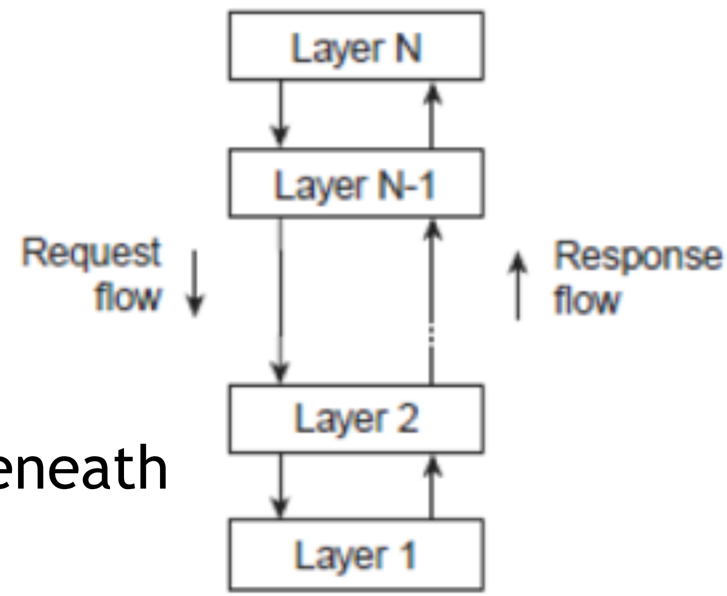
Architectural Styles

- Software architecture focuses on the software components and their interaction:
  - how components are connected to each other
  - data exchanged between components
  - how components are jointly configured into a system
- Mian objective: transparency
- Architecture Styles:
  - Layered architectures
  - Object-based architectures
  - Data-centered architectures
  - Event-based architectures

Layered Architecture

- Layering == Abstraction
- Components are organized in layers
- Calls are only allowed in one direction
- Each layer offers a software abstraction
    - Higher layers are unaware of its implementation and the layers beneath it
- Layered architecture is used for client-server model

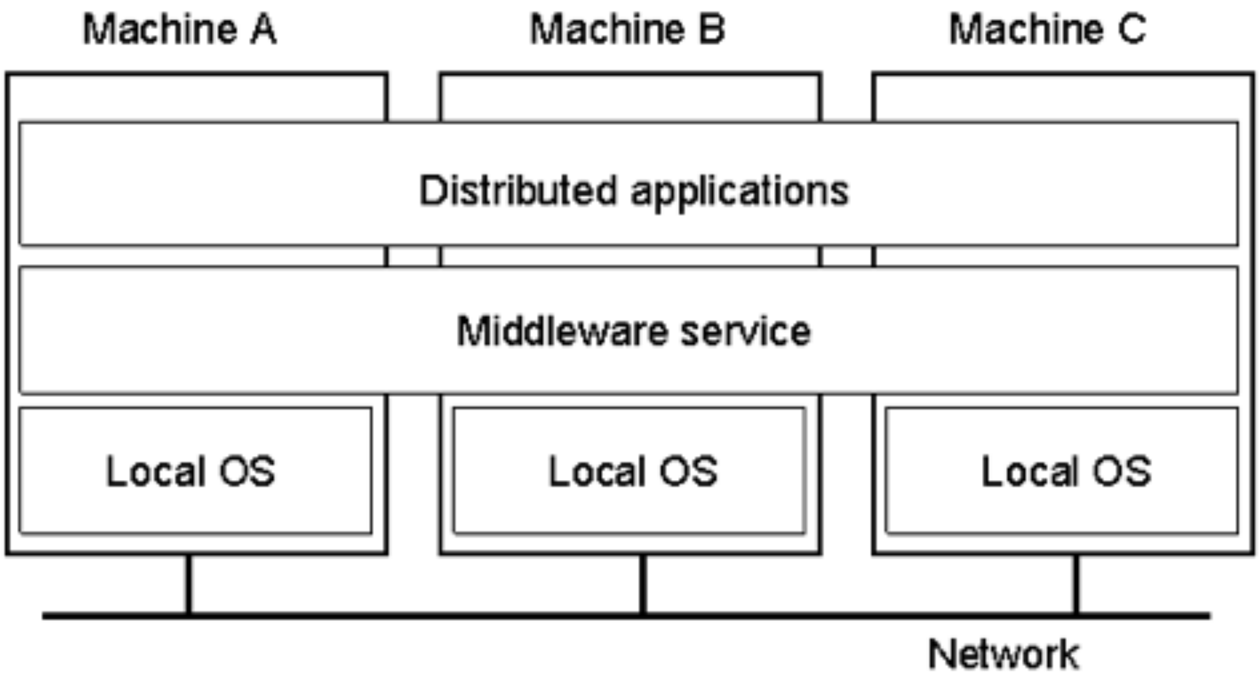


Tanenbaum and van Steen, Distributed Systems: Principles and Paradigms. Prentice-Hall, Inc. 2002

Distributed System Layers

Distributed applications, services,..
Hides lower layers and provides a communication platform

Communications and other hardware infrastructure



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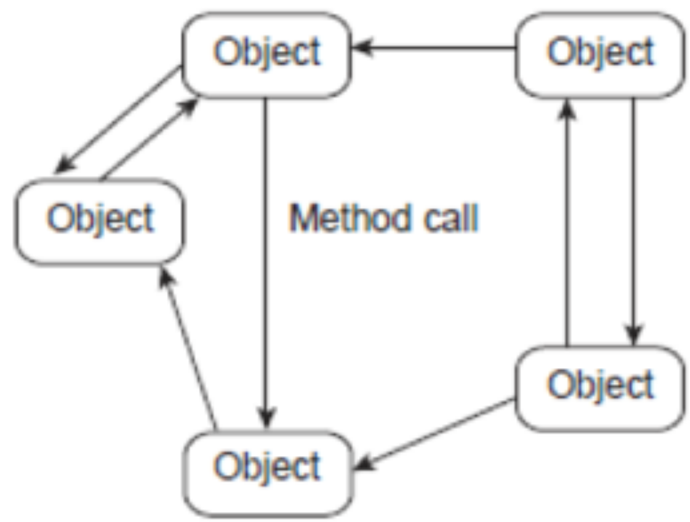
Object-based Architecture

- Each object corresponds to a component
- Components are connected through remote procedure calls (RPC)
- Object-based style is used for distributed object systems



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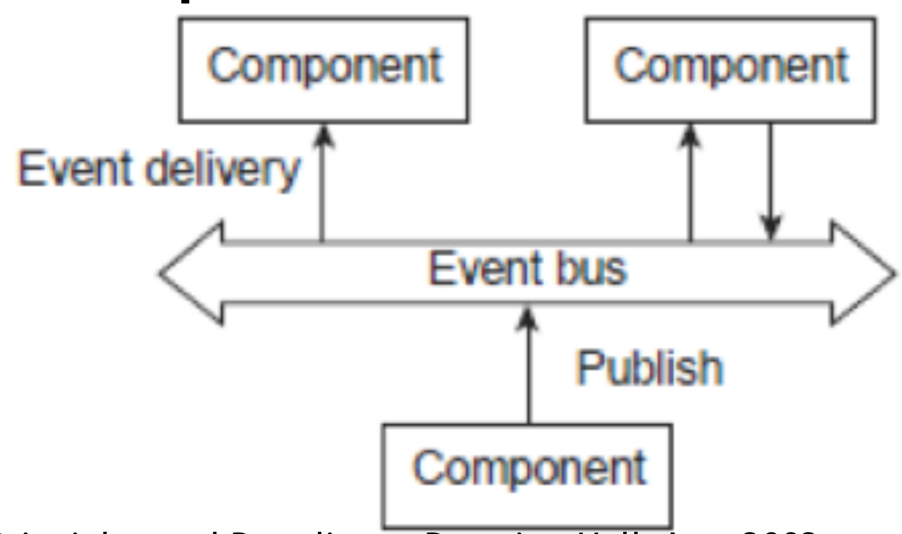
Data-centered Architecture

- Idea: Communication of processes is done through a common repository
- Examples:
  - Communication through files that are stored on a shared distributed file system
  - Shared Web-based data services

Event-based Architecture

- Processes communicate through the propagation of events
- Example: publish/subscribe systems
- Processes are loosely coupled
- Decoupled in space



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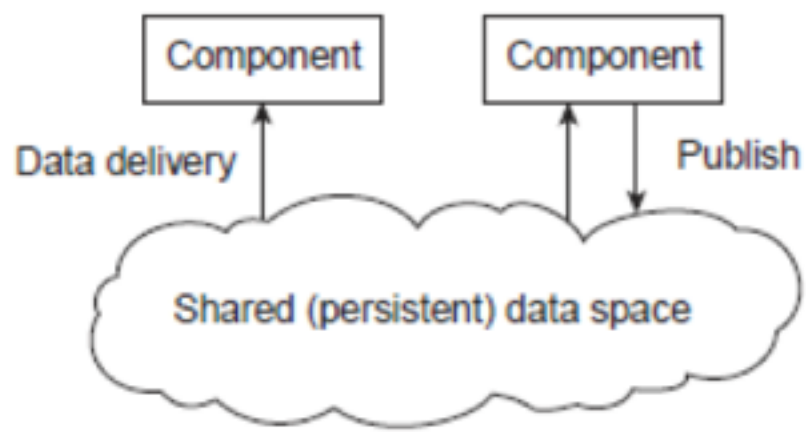
Event-based + Data-centered Architecture

- A.K.A. shared data spaces
- Decoupled in space and time
  - Processes do not need to be active when communication takes place



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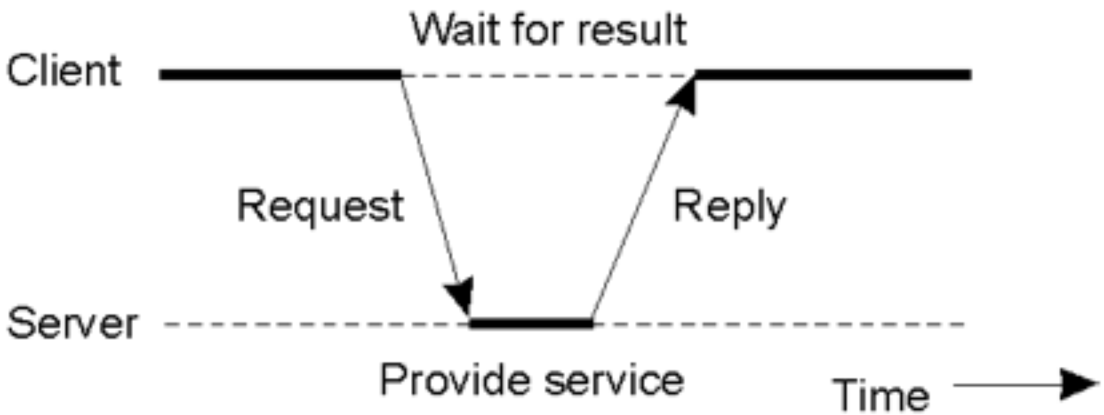
System Architectures

- Defines the structure of the system by identifying:
  - the components of the system
  - roles of each component
  - interrelationships and interactions between these components
  - how they map to the distributed infrastructure
- Goals: the architecture meets current and future demands
- Concerns: reliability, adaptability, manageability, cost-efficiency
- Types: Centralized, Decentralized, Hybrid

Client-Server Model

- Processes are divided into two groups:
  - Servers: processes offering services
  - Clients: processes requesting services
- Client-server interaction A.K.A. **request-reply**
- A connectionless protocol can be used (e.g. HTTP), however, mostly connection-oriented such as TCP/IP is used



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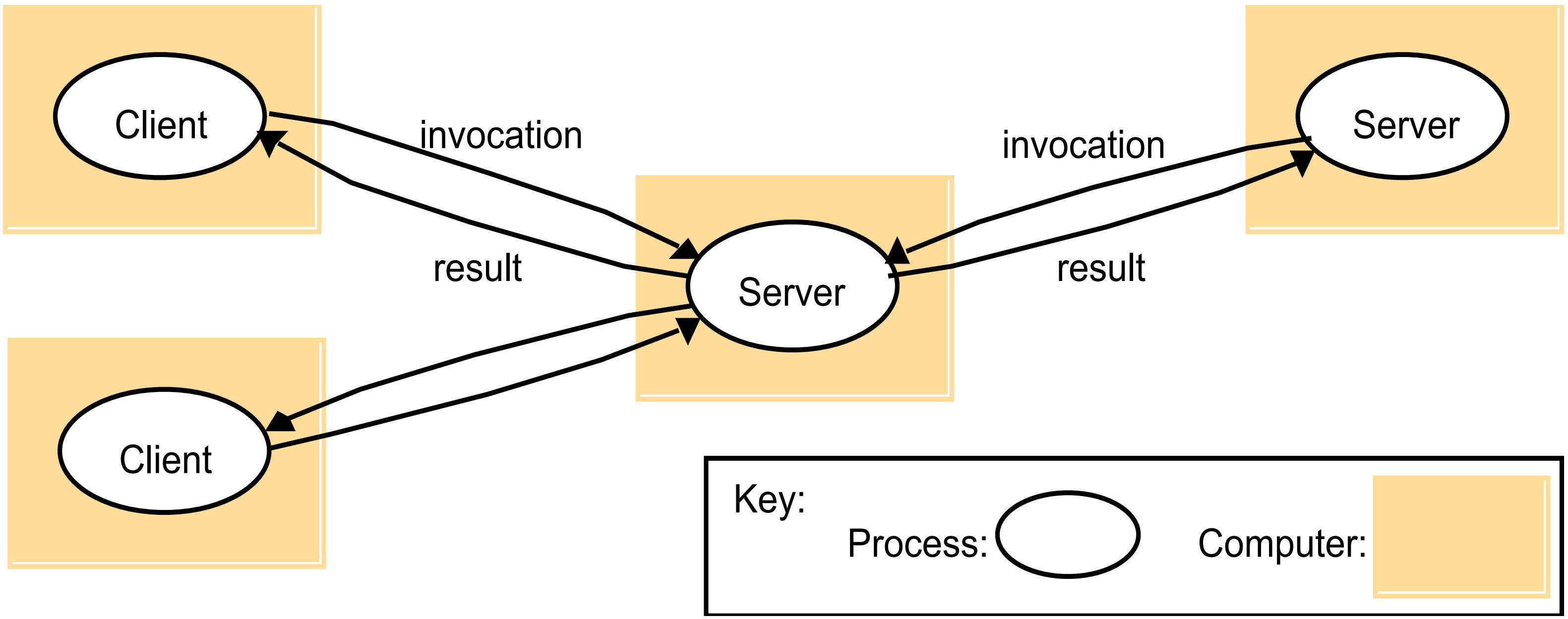
Client-Server Mechanism

- Client:
  - Clients is usually invoked by end users when they require service
  - A client usually blocks until server responds
- Server:
  - A process that provides service and usually with special privileges
  - A server waits for incoming requests
  - A server can have many clients making concurrent requests

Client-Server Communication



- Client processes interact with individual server processes in order to access shared resources
- Servers may be clients of other servers
  - Example: a web browser is a client of a web server, which can be a client of file server

An Example Client and Server (1)

- The *header.h* file used by the client and server

```
/* Definitions needed by clients and servers.              */
#define TRUE              1
#define MAX_PATH          255   /* maximum length of file name          */
#define BUF_SIZE          1024  /* how much data to transfer at once    */
#define FILE_SERVER       243   /* file server's network address        */

/* Definitions of the allowed operations */
#define CREATE            1     /* create a new file                    */
#define READ              2     /* read data from a file and return it  */
#define WRITE             3     /* write data to a file                 */
#define DELETE            4     /* delete an existing file              */

/* Error codes. */
#define OK                0     /* operation performed correctly        */
#define E_BAD_OPCODE      -1    /* unknown operation requested          */
#define E_BAD_PARAM       -2    /* error in a parameter                 */
#define E_IO              -3    /* disk error or other I/O error        */

/* Definition of the message format. */
struct message {
    long source;                /* sender's identity                    */
    long dest;                  /* receiver's identity                  */
    long opcode;                /* requested operation                  */
    long count;                 /* number of bytes to transfer          */
    long offset;                /* position in file to start I/O        */
    long result;                /* result of the operation              */
    char name[MAX_PATH];        /* name of file being operated on       */
    char data[BUF_SIZE];        /* data to be read or written           */
};
```

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An Example Client and Server (2)

- A sample server

```
#include <header.h>
void main(void) {
      struct message ml, m2;                   /* incoming and outgoing messages          */
      int r;                                   /* result code                             */

      while(TRUE) {                            /* server runs forever                     */
            receive(FILE_SERVER, &ml);         /* block waiting for a message             */
            switch(ml.opcode) {                /* dispatch on type of request             */
                  case CREATE:   r = do_create(&ml, &m2); break;
                  case READ:     r = do_read(&ml, &m2); break;
                  case WRITE:    r = do_write(&ml, &m2); break;
                  case DELETE:   r = do_delete(&ml, &m2); break;
                  default:       r = E_BAD_OPCODE;
            }
            m2.result = r;                     /* return result to client                 */
            send(ml.source, &m2);              /* send reply                              */
      }
}
```

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An Example Client and Server (3)

- A client using the server to copy a file

(a)

```
#include <header.h>
int copy(char *src, char *dst){              /* procedure to copy file using the server      */
    struct message ml;                       /* message buffer                               */
    long position;                           /* current file position                        */
    long client = 110;                       /* client's address                             */

    initialize( );                           /* prepare for execution                        */
    position = 0;
    do {
        ml.opcode = READ;                    /* operation is a read                          */
        ml.offset = position;                /* current position in the file                 */
        ml.count  = BUF_SIZE;                                                                /* how many bytes to read*/
        strcpy(&ml.name, src);               /* copy name of file to be read to message      */
        send(FILESERVER, &ml);               /* send the message to the file server          */
        receive(client, &ml);                /* block waiting for the reply                  */

        /* Write the data just received to the destination file.                             */
        ml.opcode = WRITE;                   /* operation is a write                         */
        ml.offset = position;                /* current position in the file                 */
        ml.count  = ml.result;               /* how many bytes to write                      */
        strcpy(&ml.name, dst);               /* copy name of file to be written to buf       */
        send(FILE_SERVER, &ml);              /* send the message to the file server          */
        receive(client, &ml);                /* block waiting for the reply                  */
        position += ml.result;               /* ml.result is number of bytes written         */
    } while( ml.result > 0 );                /* iterate until done                           */
    return(ml.result >= 0 ? OK : ml result); /* return OK or error code                      */
}
```

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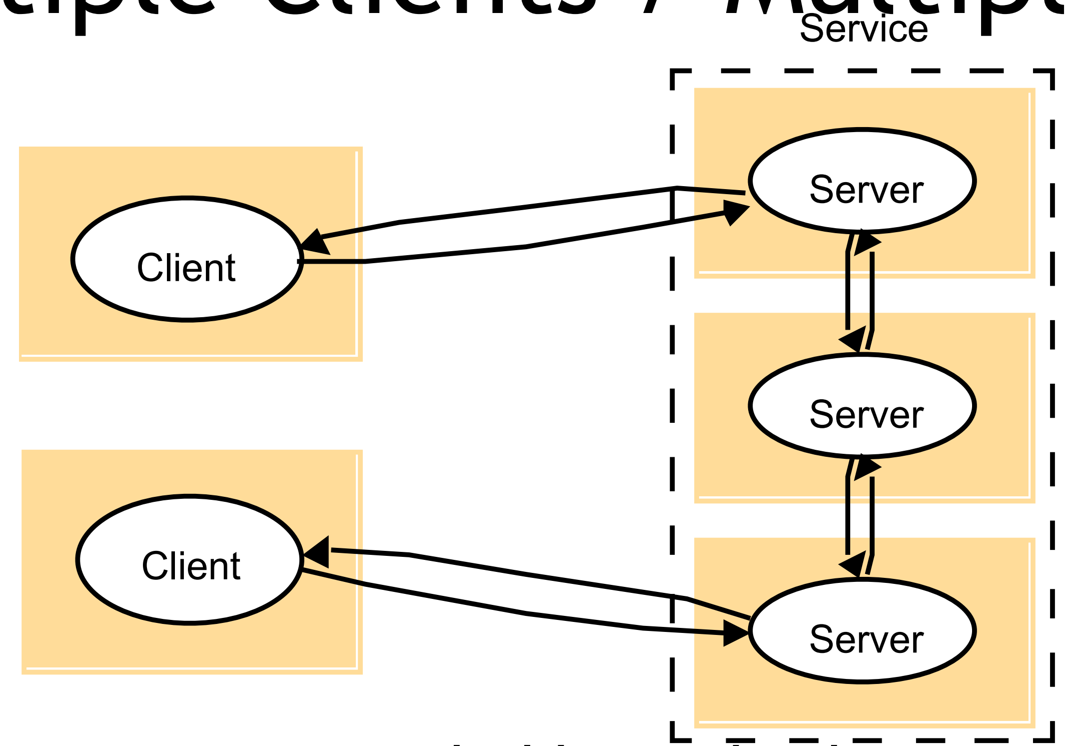
Advantages of the Client-Server Architecture

- Efficient division of labor
- Horizontal and vertical scaling of resources
- Better price/performance on client machines
- Ability to use familiar tools on client machines
- Client access to remote data (via standards)
- Full DBMS functionality provided to client workstations
- Overall better system price/performance

Problems with the Multiple Client / Single Server Architecture

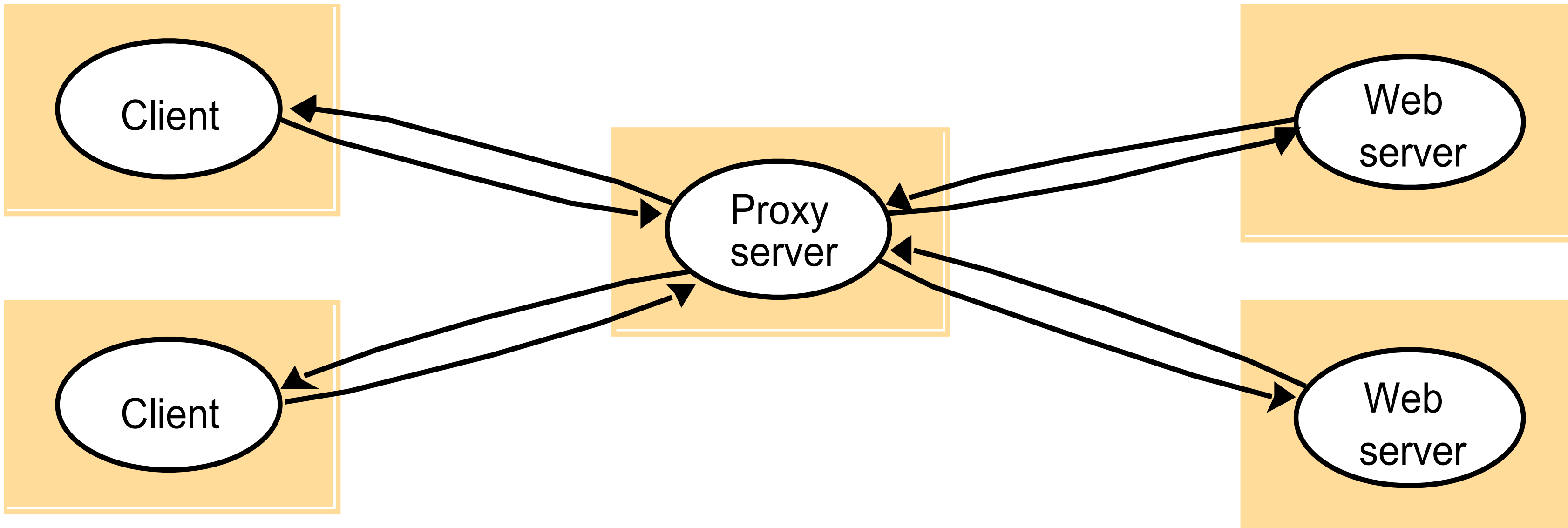
- Server forms a bottleneck
- Server forms a single point of failure
- System scaling is difficult

Multiple Clients / Multiple Servers



- Same service provided by multiple servers
- Data is partitioned (and/or replicated), each web server manages its own set of resources
- A user can employ a browser to access resources at any of the servers

Multiple Clients / Multiple Servers Using Proxy Server



- A ***cache*** is a store of recently used data objects that is closer to one client or a particular set of clients than the objects themselves
- Web proxy servers provide a shared cache of web resources

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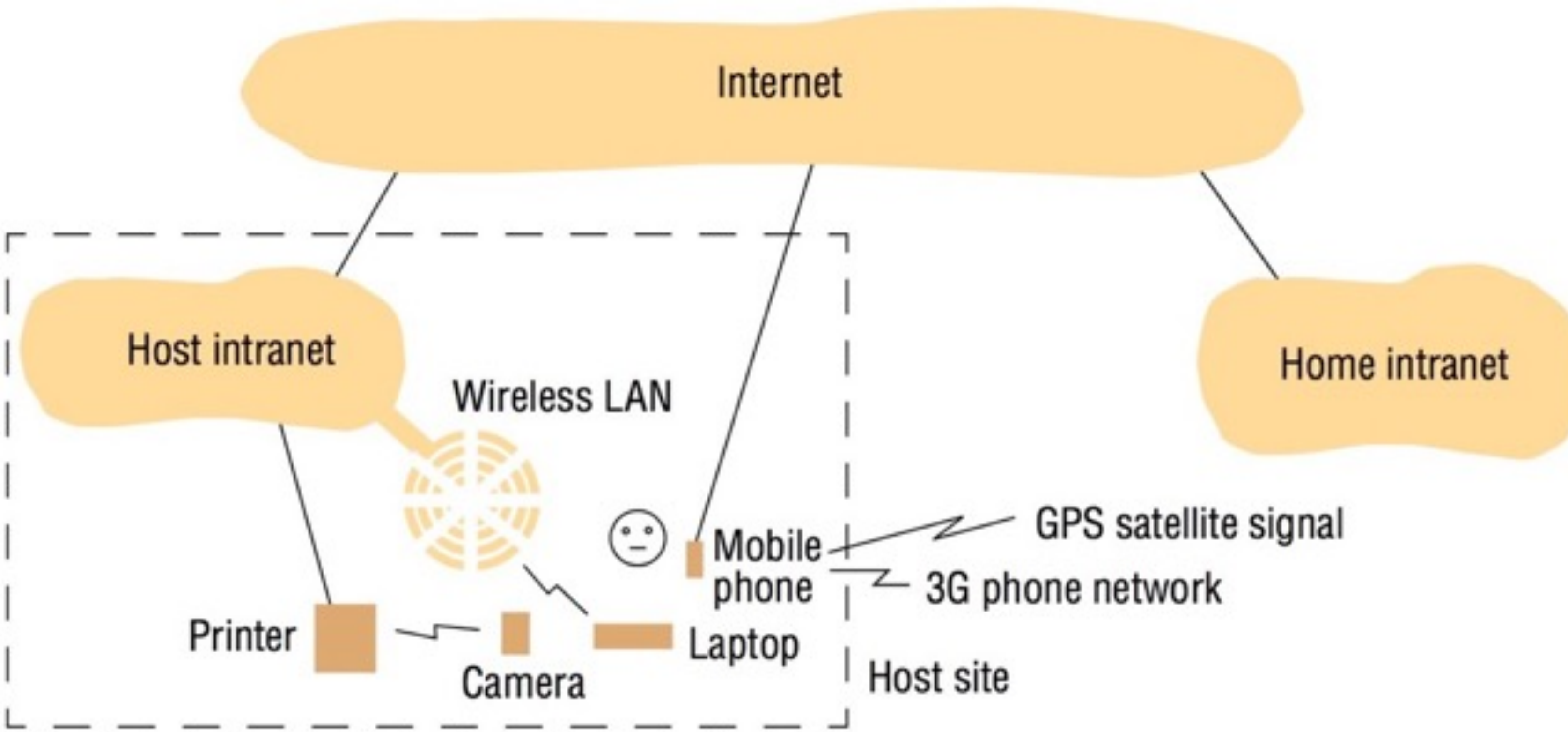
Mobile Computing



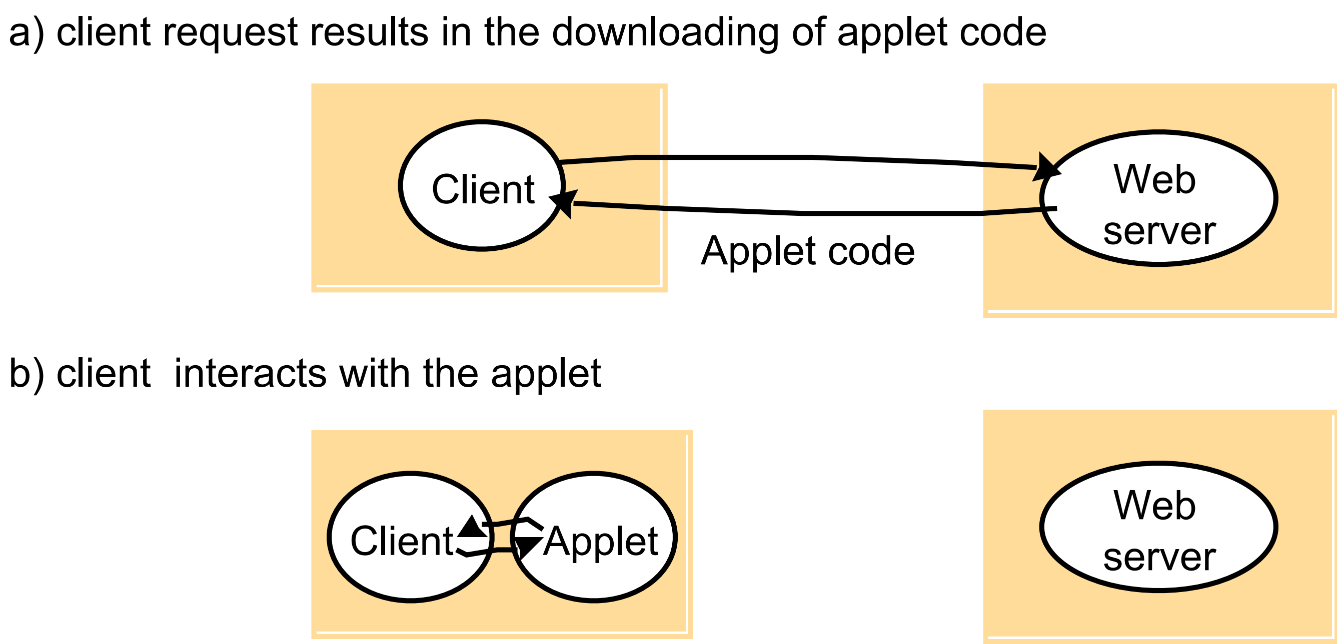
Mobile computing is the performance of computing tasks while the user is on the move, or visiting places other than their usual environment

Characteristics of Mobile Computing

- Users who are away from their ‘home’ intranet can still access their ‘home’ intranet resources via the devices they carry with them
- Users can also access their ‘hosting’ intranet resources.

  (*location-aware*, *context-aware computing*)

Applets as an Example of Mobile Code



- Advantages: does not suffer from the delays or variability of the network bandwidth ➔ good interactive response
- Disadvantages: Mobile code is a potential security threat to the local resources in the destination computer

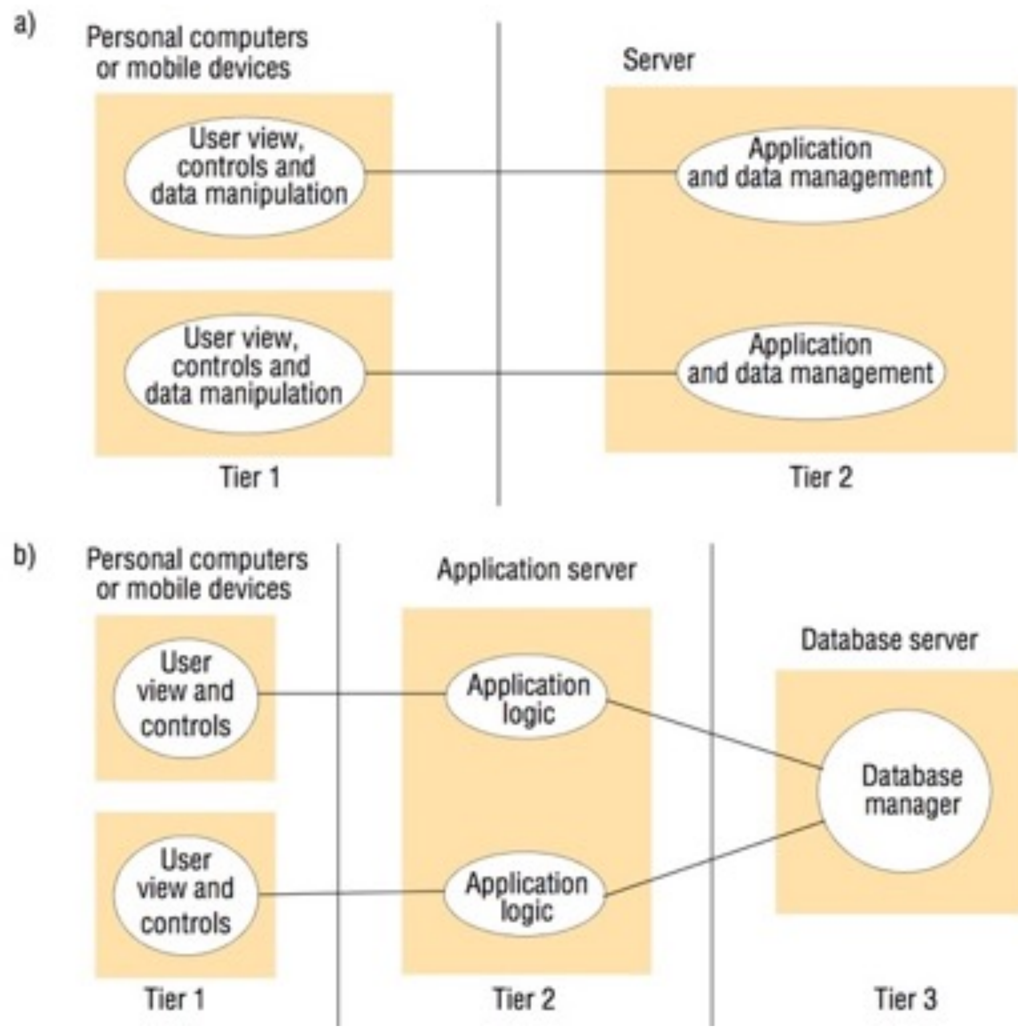
Mobile Agents

- A **mobile agent** is a running program (code and data) that travels from one computer to another in a network carrying out a task on someone's behalf, such as collecting information, and eventually returning with the results
- Remote invocations vs. mobile agents (data vs code)
- Advantages:
  - Reduction in communication cost and time
- Disadvantages:
  - Potential security threat to the resources in computers that they visit
  - Unable to complete their task if they are refused access to the information they need

Application Layering / Multitier systems

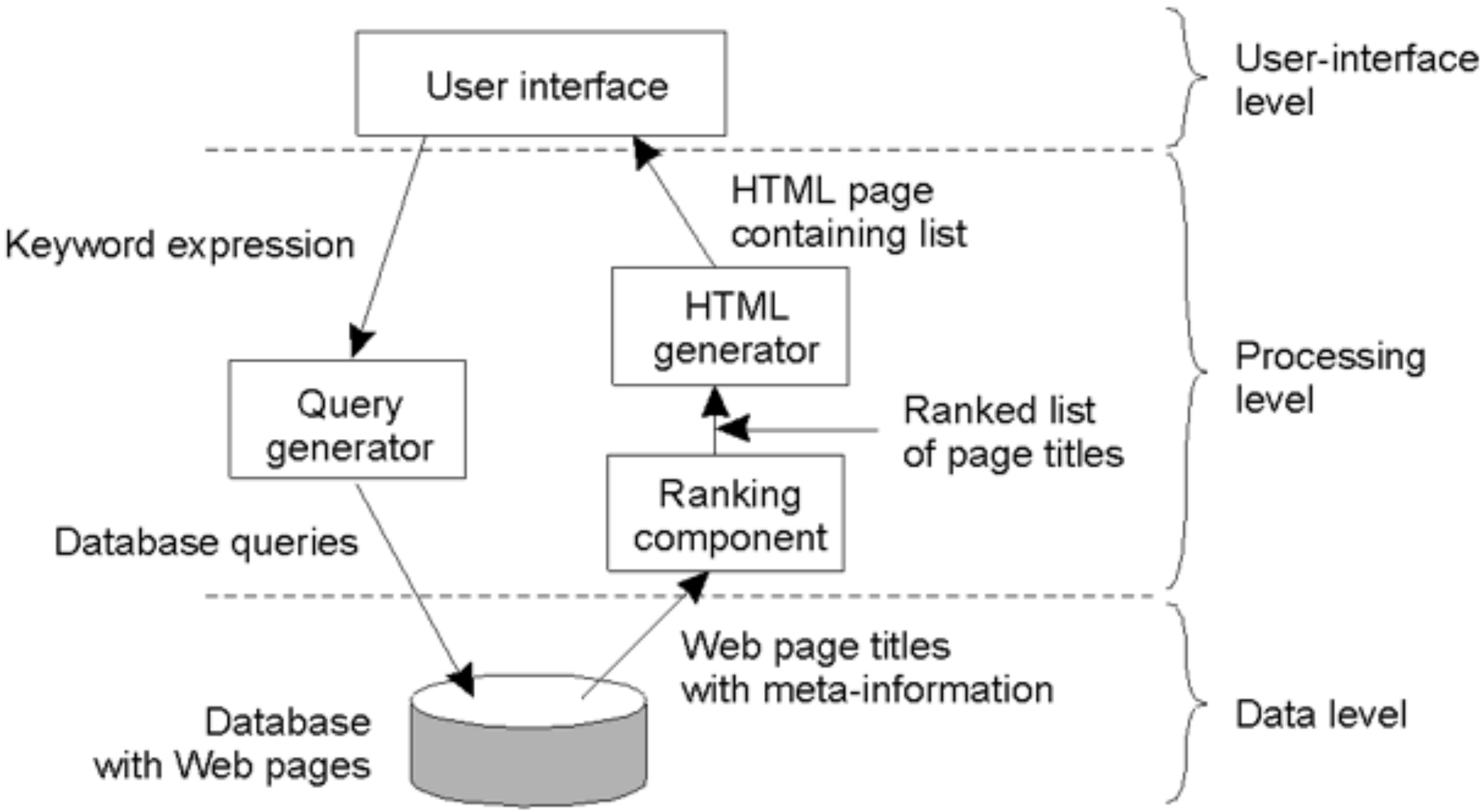
- Tiered architectures are complementary to layering:
  - **Layering** deals with the vertical organization of services into layers of abstraction
  - **Tiering** organizes functionality of a given layer and place this functionality into appropriate servers and on to physical nodes
- Layers of a three-tier architecture
  - User interface (presentation logic): user interaction and updating the view of the application as presented to the user
  - Application/ processing logic: application-specific processing
  - Data logic: the persistent storage of the application, e.g., DBMS

Two-tier and Three-tier Architectures



Instructor's Guide for Coulouris, Dollimore, Kindberg and Blair, Distributed Systems: Concepts and Design Edn. 5 © Pearson Education 2012

Example of Multitier Systems: Internet Search Engines



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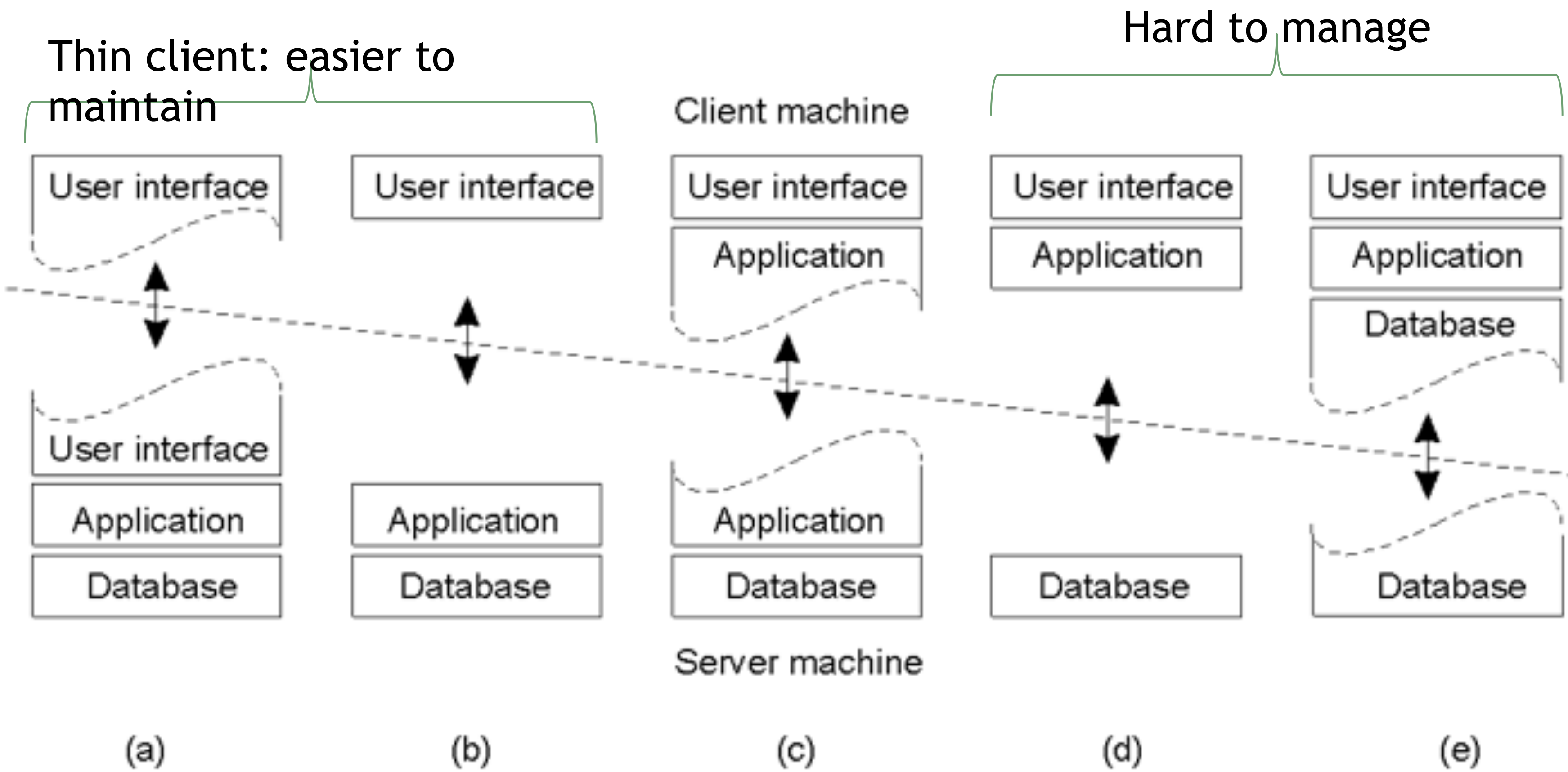
Alternatives of Multitier Systems



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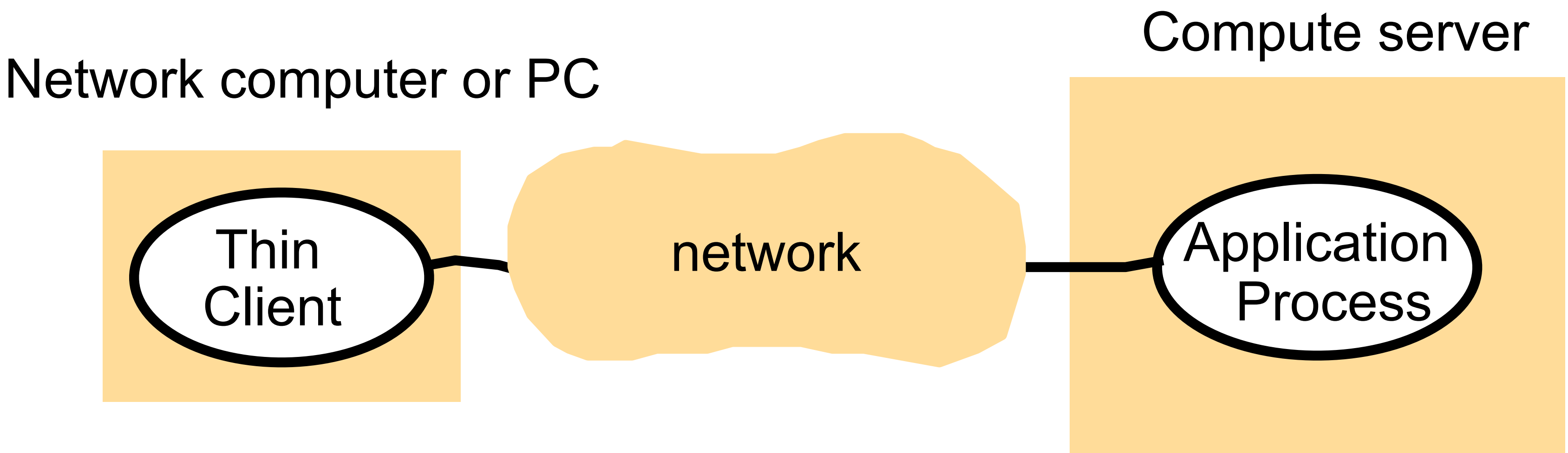
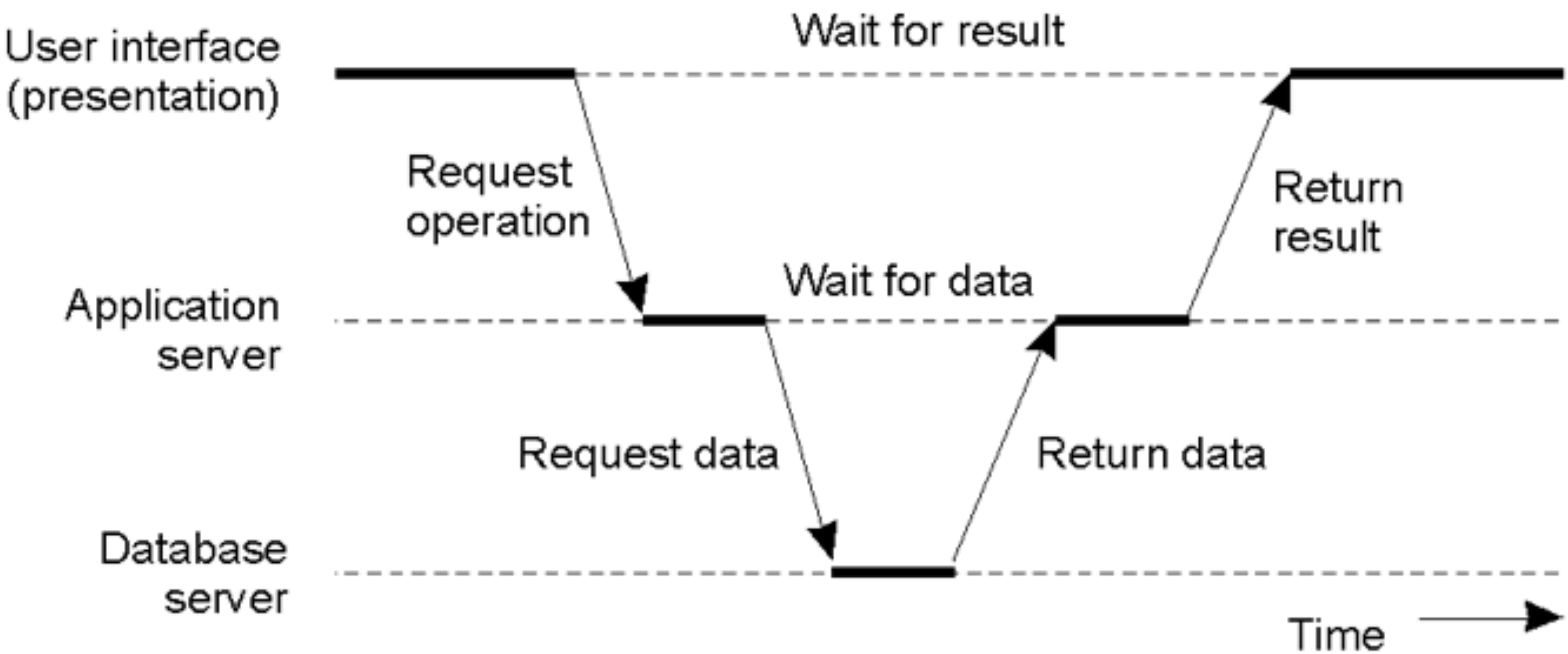
Thin Clients



- Moving complexity away from the end-user device towards services in the Internet
- Advantage: the user does not need high end computing machines
- Disadvantage: delays due to accessing remote data, graphics, ..

Communication in Multitier Systems



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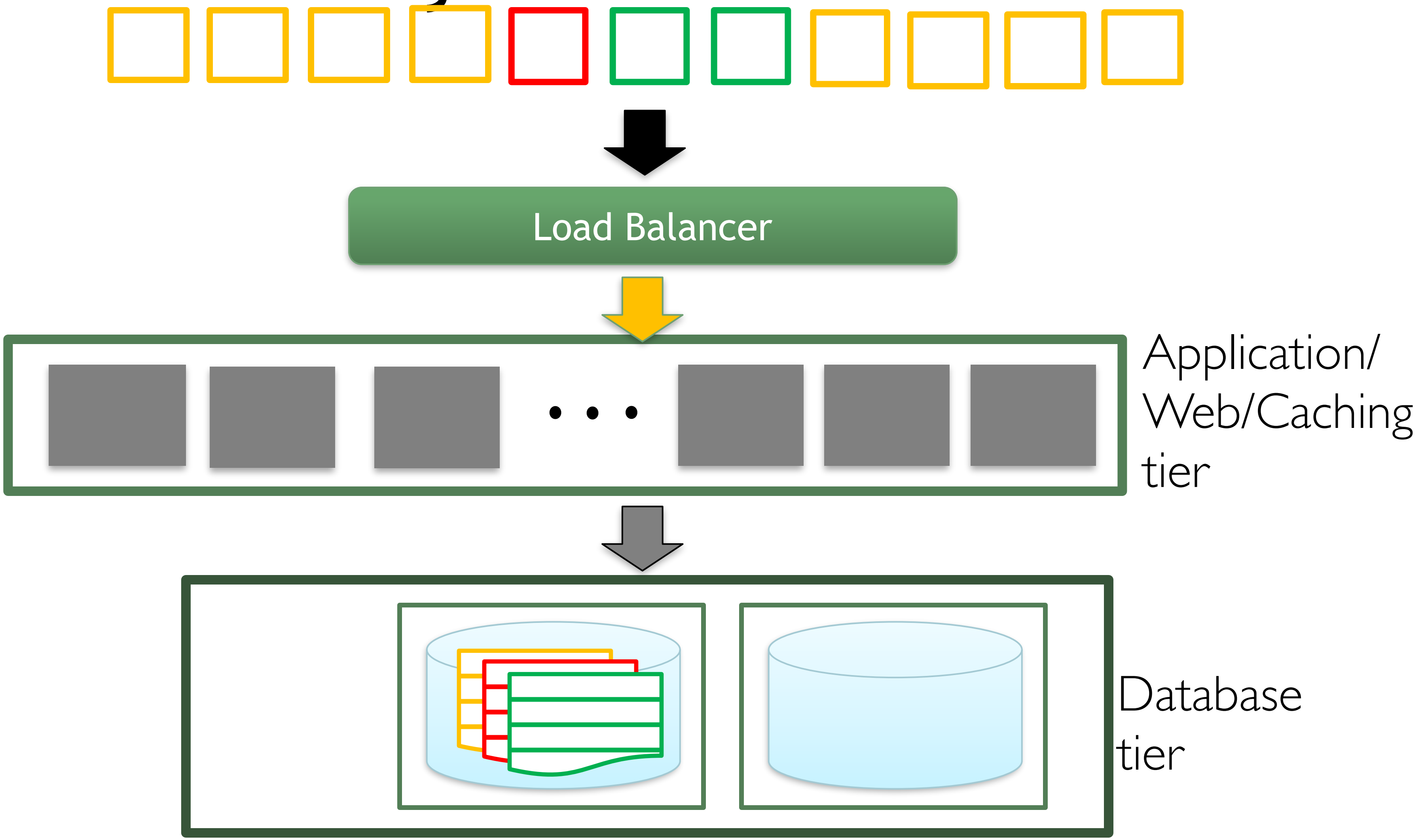
Advantages of Multitier Systems

- Frees clients from dependencies on the exact implementation of the database
- It allows “business logic” to be concentrated in one place
- Software updates are restricted to the middle layer
- Performance improvements are possible by batching requests from many clients to the database
- Database and business logic tiers could be implemented by multiple servers for scalability

Elasticity in a Multitenant DB



Sudipto Das, Shoji Nishimura, Divyakant Agrawal, Amr El Abbadi: Albatross: Lightweight Elasticity in Shared Storage Databases for the Cloud using Live Data Migration. VLDB 2011.

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Decentralized Architectures

- Vertical distribution (multitier systems) vs horizontal distribution (peer-to-peer)
- The processes that constitute a peer-to-peer system are all equal
- The interaction between processes is symmetric: each process will act as a client and a server at the same time
- Peer-to-peer systems can be divided into:
  - **Structured P2P**: nodes are organized through a distributed data structure (e.g., DHT)
  - **Unstructured P2P**: nodes have randomly selected neighbors
  - **Hybrid P2P**: some nodes are appointed special functions

Decentralized Architectures

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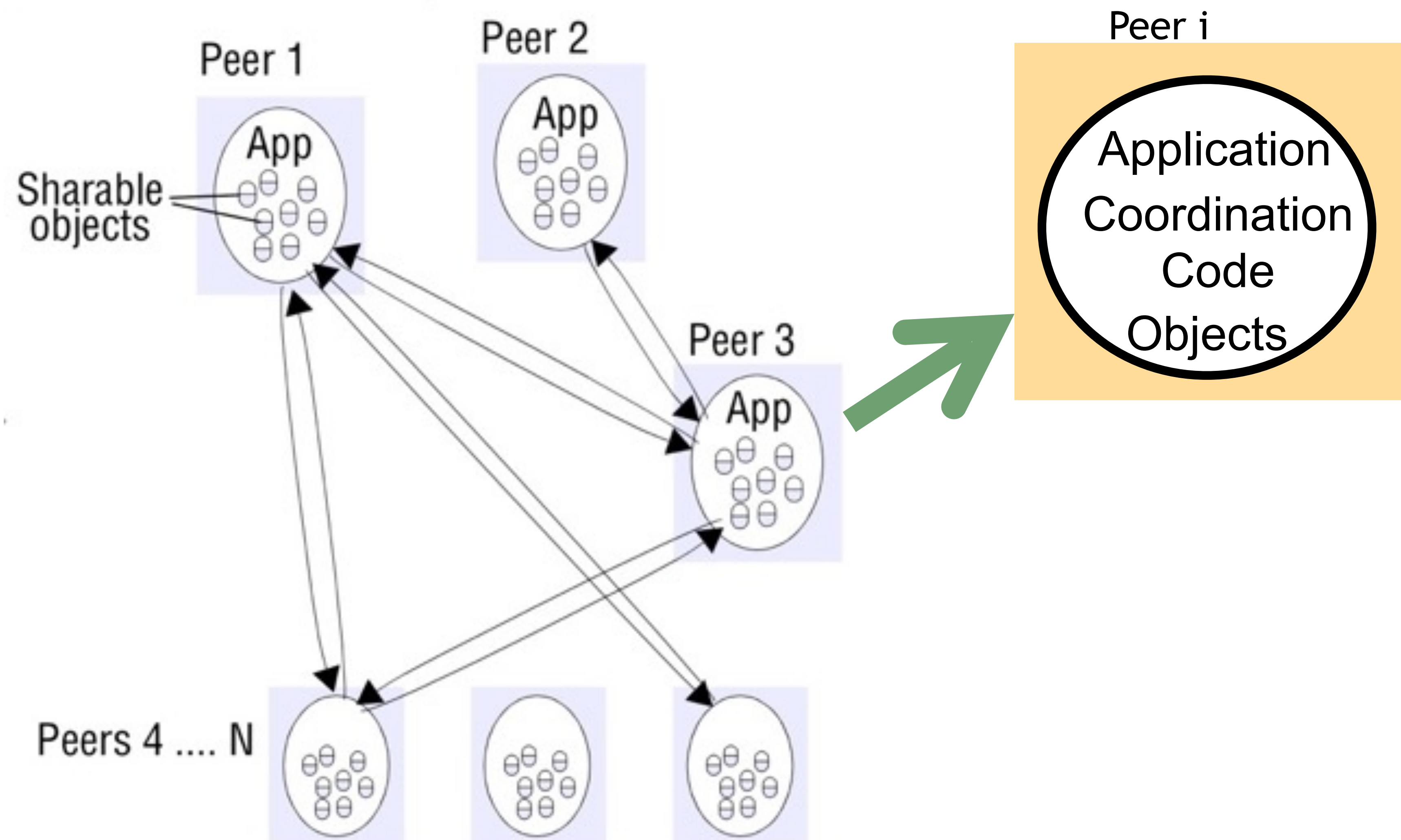
- The processes that constitute a peer-to-peer system are all equal.
- The interaction between processes is symmetric: each process will act as a client and a server at the same time.
- Peer-to-peer systems can be divided into:

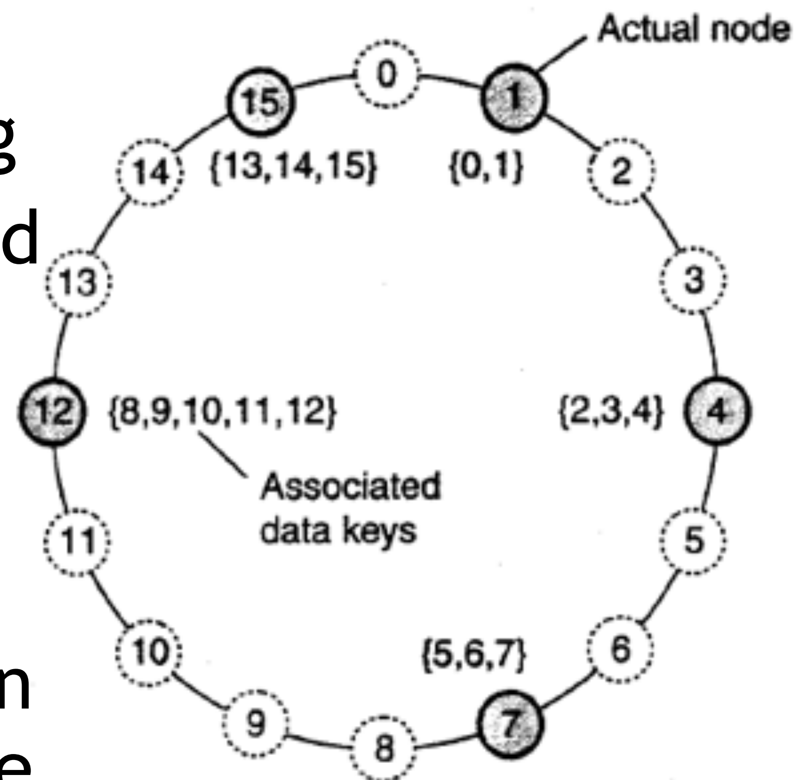
Organize the processes in an overlay network, that is, a network in which the nodes are formed by the processes and the links represent the possible communication channels (e.g., TCP connections ➔ application-level multicasting).

Peer-to-Peer Systems



Structured Peer-to-Peer

- Chord System: nodes are logically organized in a ring
- Mapping between nodes and the data they own is required
- Function lookup(k) returns the network address of the node owning k. Lookups can be done in O(log(N)), where N is the number of nodes



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Unstructured Peer-to-Peer

- Rely on **randomized algorithms** for constructing overlay networks that resembles a **random graph**
- Main idea:
  - Each node maintains a list of neighbors, but that this list is constructed in a more or less random way.
  - Data items are assumed to be randomly placed on nodes.
  - Goal is that each node constructs a partial view of the graph.

Examples of Peer-to-Peer Applications

- File sharing
  - Napster, Gnutella, KaZaa
  - Second generation projects
    - Oceanstore, PAST, Freehaven, FreeNet
- Distributed Computation
  - SETI@home, Entropia, Parabon, United Devices, Popular Power
- Other Applications
  - Content Distribution (BitTorrent)
  - Instant Messaging (Jabber), Anonymous Email
  - Groupware (Groove)
  - P2P Databases

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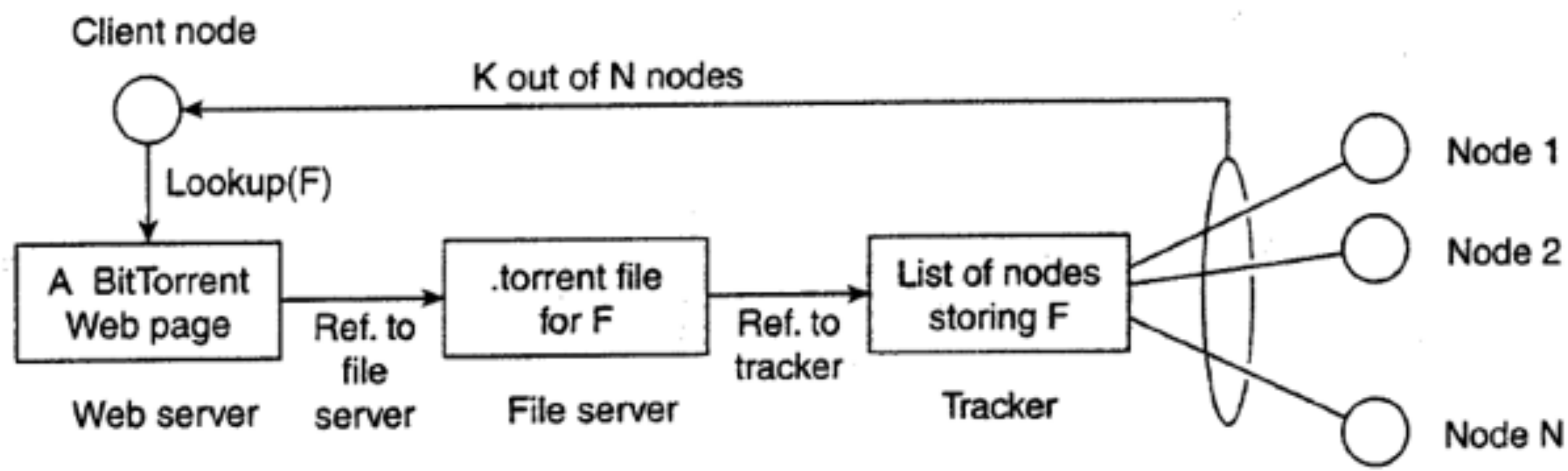
Hybrid Architecture

- Solution with client-server architectures are combined with decentralized architectures



- BitTorrent :
  - A centralized server is needed to let the client know about the nodes from which chunks of the file can be downloaded
  - Once the client joins the system as a node, a decentralized architecture will be used

Summary

- Hardware architectures: shared noting, shared memory, and shared disk architectures
- Software architectures: layered, object-based, data centred, and event-based architectures
- System architectures: centralized, decentralized, and hybrid architectures

Thank You