Algorithms and Programming IV
Communication Paradigms in Distributed Systems

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Our topics today

Architectural Pattern

*Layered Architecture*

*Tiered Architecture*

Communication Paradigms

*Interprocess Communication*

- API for Internet Protocols
- UDP Datagram Communication
- TCP Stream Communication
Recap: Distributed System Model
Recap: Architectural Model

Architectural elements

- Communicating entities
  - Processes
  - Objects
  - Components
  - Web Services

- Communication paradigm
  - Inter-process communication
    - UDP sockets
    - TCP sockets
    - Multicast
  - Indirect communication
    - Remote invocation

- Roles and responsibilities
  - Architectural styles
    - Client-server
    - Peer-to-peer
  - Placement
    - Multiple server
    - Proxy/Cache
    - Mobile code

Architectural patterns
Architectural models

ARCHITECTURAL PATTERNS
Layered Architecture

- **Layer N**
- **Layer N-1**
- **Layer 2**
- **Layer 1**

Request flow → Response flow

- Applications, Services
- Middleware
- Operating system
- Computer and network hardware

Layered Architecture: Platform

Lowest level hardware and software layers for distributed systems and applications.

**Characteristics**
- Provide services to the layers above them.
- Implemented independently in each computer.
- Bringing the system’s programming interface up to a level that facilitates communication and coordination between processes.

**Examples**
- x86/Windows, Intel x86/Solaris, PowerPC/Mac OS X, Intel x86/Linux
Layered Architecture: Middleware

It is a layer of software whose purpose is to mask heterogeneity and to provide a convenient programming model to application programmers.

It is concerned with providing useful building blocks for the construction of software components that can work with one another.

Many distributed applications rely entirely on services provided by middleware to support their needs for communication and data sharing.
Tiered Architecture

- Tiered architectures are complementary to layering.
- Layering (logical decoupling) deals with the vertical organization of services into layers of abstraction.
- Tiering (physical decoupling) is a technique to organize functionality of a given layer and place this functionality into appropriate servers and, as a secondary consideration, on to physical nodes.
Two-tier Architecture

Client-Server

Request

Reply

Kernel

Kernel

Wait for result

Provide service

Time

Client

Server

Alternative Client-Server Organisations

Three-tier Architecture

Communication in a Multi-Tier System

Example: Internet Search Engine

Multi-Tier: Vertical Distribution

Distribution of server functionality over multiple servers.

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Horizontal Distribution

Involves replicating a server’s functionality over multiple computers to improve scalability (by reducing the load on individual servers) and reliability (by providing redundancy).

E: Replicated Web server

- Each server machine contains a complete copy of all hosted Web pages.
- Client requests are passed on to the servers in a round robin fashion.

# Recap: Architectural Model

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## Architectural styles

- Client-server
- Peer-to-peer
- Mobile code

## Architectural patterns

- Client-server
- Peer-to-peer
- Mobile code

## Communication paradigm

- Inter-process communication
  - UDP sockets
  - TCP sockets
  - Multicast
- Indirect communication
- Remote invocation
Architectural elements

COMMUNICATION PARADIGM
An Architectural Model of Distributed Systems

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How do they communicate, or, more specifically, what communication paradigm is used?
Types of Communication Paradigms

- Interprocess communication
- Remote invocation
- Indirect communication
Types of Communication Paradigms

Architectural elements
- Communicating entities:
  - Processes
  - Objects
  - Components
  - Web Services

Communication paradigm
- Interprocess communication
  - UDP sockets
  - TCP sockets
  - Multicast

Roles and responsibilities
- Architectural styles
  - Client-server
  - Peer-to-peer

Placement
- Multiple server
- Proxy/Cache
- Mobile code
Communication Paradigm

INTERPROCESS COMMUNICATION
Interprocess Communication

Interprocess Communication (IPC) mechanisms provide a low-level support to enable processes from different address spaces to connect and exchange information.

A process is an object of the operating system through which applications gain secure access to computer resources. Individual processes are isolated from each other for this purpose.

IPC is based on the exchange of messages (= bit sequences).

- A message is sent by the one process (the sender).
- It is received by another process (the receiver).
Motivation for IPC

process $p$

send $m$

Communication channel

Outgoing message buffer

Incoming message buffer

process $q$

receive
Protocols

- Protocol refers to a set of rules and formats to be used for communication between processes in order to perform a given task.

  - Specification of the sequence of messages that must be exchanged.
  - Specification of the format of the data in the messages.
Protocol layers in the ISO Open Systems Interconnection (OSI) model

Connection-oriented communication: sending and receiving processes synchronize at every message = send and receive are blocking operation

Connectionless communication: send and receive operations are non-blocking
A typical message as it appears on the network

Data link layer header

Network layer header

Transport layer header

Session layer header

Presentation layer header

Application layer header

Message

Bits that actually appear on the network

Data link layer trailer

Layers ISO Model vs. TCP/IP Model

- Application
- Presentation
- Session
- Transport
- Network
- Data link
- Physical

- Application
- Transport
- Internet
- Network Access
TCP/IP Model

<table>
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<th>Application</th>
<th>Transport</th>
<th>Internet</th>
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UDP vs. TCP

UDP (User Datagram Protocol)
• UDP differs from the IP service only in the additional specification of the ports: a message is sent as a datagram through the network without the arrival at the destination port being guaranteed (connectionless service).

TCP (Transmission Control Protocol)
• TCP establishes a virtual connection between a client port and a provider port and thus two opposing, reliable, sequence-true (FIFO) byte streams (connection-oriented service).
Realizing Interprocess Communication

UDP features
• UDP datagram encapsulated inside an IP package
• Header includes source and destination port numbers
• No guarantee of delivery
• Message size is limited
• Restricted to applications and services that do not require reliable delivery of single or multiple messages

TCP features
• Provides reliable delivery of arbitrarily long sequences of bytes via stream-based programming abstraction
• Connection-oriented service
• Before data is transferred, a bidirectional communication channel is established
Sockets

On approach to realize interprocess communication consists of transmitting a message between a socket in one process to a socket in another process,

Internet address = 138.37.94.248
Internet address = 138.37.88.249

Ports vs. Sockets

A **port** is a communication endpoint for Internet transport services. It is identified by a port number in the range [0..65535]. The range [0..1023] is reserved for standard services, the range [1024..49151] for other services (cf. Internet Assigned Numbers Authority, www.iana.org).

A **socket** is a communication endpoint provided with a port number for use by processes. In the case of a TCP connection, a provider-side socket is associated with a client-side socket.
Interprocess communication

API FOR INTERNET PROTOCOLS
Java API: package java.net

Java provides class InetAddress that represents Internet addresses.

Method static InetAddress getByName(String host)
Can throw an UnknownHostException

Example

```java
System.out.println(InetAddress.getByName("www.fu-berlin.de"));
www.fu-berlin.de/160.45.170.10
System.out.println(InetAddress.getByName("localhost"));
localhost/127.0.0.1
System.out.println(InetAddress.getLocalHost());
wing.local/192.168.183.35
```
API for Internet protocols

UDP DATAGRAM COMMUNICATION
**UDP Sockets**

1. Client creates socket bound to a local port

2. Server binds its socket to a server port

3. Client/Server send and receive datagrams

4. Ports and sockets are closed
Issues related to Datagram Communication

Message Size

• Receiving process needs to specify an array of bytes of a particular size in which to receive a message. If the received message is too big, it is truncated.

Blocking

• Datagram communication is carried out with a non-blocking `send` and a blocking `receive` operation.

Timeouts

• Timeouts can be set, in order to avoid that the receive operation waits indefinitely.

Receive from any

• The receive method does not specify an origin for messages.
Failure Model of UDP Datagrams

**Integrity**
- Messages should not be corrupted or duplicated
- Use of checksum reduces probability that received message is corrupted

**Failures**
- Omission failures: messages maybe dropped occasionally because of checksum error or no buffer space is available at source/destination
- Ordering: Messages can sometimes be delivered out of order
Using UDP for Applications

Advantage of UDP datagrams is that they do not suffer from overheads associated with guaranteed message delivery.

Example 1: Domain Name System

• DNS primarily uses UDP on port number 53 to serve requests
• DNS queries consist of a single UDP request from the client followed by a single UDP reply from the server

Example 2: VOIP

• No reason to re-transmit packets with bad speech data
• Speech data must be processed at the same rate as it is sent - there is no time to retransmit packets with errors
UDP datagram communication

JAVA API FOR UDP DIAGRAMS
Java API for UDP diagrams

Datagram communication is provided by two classes `DatagramPacket` and `DatagramSocket`

`DatagramPacket`:
- Constructor that makes an instance out of an array of bytes comprising a message
- Constructor for use when receiving a message, message can be retrieved by the method `getData`

`DatagramSocket`:
- Constructor that takes port number as argument for use by processes
- No-argument constructor for choosing a free local port
Example: UDP Echo Server

```java
import java.net.*;

class UDPServer {
    public static void main(String args[]) throws Exception {
        DatagramSocket serverSocket = new DatagramSocket(9876);
        byte[] receiveData = new byte[1024];
        byte[] sendData = new byte[1024];

        // ...
```java
... while (true) {
    DatagramPacket receivePacket = new DatagramPacket(receiveData, receiveData.length);
    serverSocket.receive(receivePacket);
    String sentence = new String(receivePacket.getData());
    InetAddress IPAddress = receivePacket.getAddress();
    int port = receivePacket.getPort();
    String capitalizedSentence = sentence.toUpperCase();
    sendData = capitalizedSentence.getBytes();
    DatagramPacket sendPacket = new DatagramPacket(sendData, sendData.length, IPAddress, port);
    serverSocket.send(sendPacket);
}
```
Example: Java Client (UDP)

```java
import java.io.*;
import java.net.*;

class UDPClient {
    public static void main(String args []) throws Exception {
        BufferedReader inFromUser = new BufferedReader(new InputStreamReader(System.in));
        DatagramSocket clientSocket = new DatagramSocket();
        InetAddress IPAddress = InetAddress.getByName("localhost");
        byte[] sendData = new byte[1024];
        byte[] receiveData = new byte[1024];
        String sentence = inFromUser.readLine();
        
        // Create input stream
        // Create client socket
        // Translate host-name to IP address using DNS

        DatagramPacket packet = new DatagramPacket(sendData, sendData.length, IPAddress, 1234);
        clientSocket.send(packet);
        try {
            packet = clientSocket.receive(new byte[1024]);
            System.out.println(new String(packet.getData(), 0, packet.getOffset()));
        } catch (Exception e) {
            System.out.println(e.toString());
        }
    }
}
```
sendData = sentence.getBytes();
DatagramPacket sendPacket = new DatagramPacket(sendData, sendData.length, IPAddress, 9876);
clientSocket.send(sendPacket);

DatagramPacket receivePacket = new DatagramPacket(receiveData, receiveData.length);
clientSocket.receive(receivePacket);

String modifiedSentence = new String(receivePacket.getData());
System.out.println("FROM SERVER: " + modifiedSentence);
clientSocket.close();
API for Internet protocols

TCP STREAM COMMUNICATION
TCP Sockets Communication

1. Server bind port

2. Server is ready and listening

3. Server is waiting for request, client sends request, server accepts

4. Client and server are connected - bidirectional!

5. Connection is closed
Socket Programming with TCP

Client must contact server
- Server process must first be running
- Server must have created socket that welcomes client’s contact

Client contacts server by:
- Creating client-local TCP socket
- Specifying IP address, port number of server process

When client creates socket: client TCP establishes connection to server TCP

When contacted by client, server TCP creates new socket for server process to communicate with client, which allows server to talk with multiple clients.
Hiding Network Characteristics by TCP

Application can choose the **message size**, means how much data it writes to a stream or reads from it.

TCP protocol uses an **acknowledgement** scheme to avoid lost data.

TCP supports **flow control** that means if the writer is too fast for the reader, then the writer is blocked until the reader consumed sufficient data.

Message identifiers are used by each IP packet. The recipient can therefore detect and reject **duplicates** or can **reorder** message if needed.

Before a pair of communication processes communicate they **establish a connection**.
Failure Model of TCP

In order to realize **reliable communication**, TCP streams use **checksums** to detect and reject corrupt packages and **sequence numbers** to detect and reject duplicate packets.

To deal with lost packages TCP streams use **timeouts and retransmissions**.

A broken connection has the following effects:

- The processes using the connection cannot distinguish between network failure and failure of the process at the other end of the connection
- The communication processes cannot tell whether the messages they have sent recently have been received or not.
Use of TCP

Many frequently used services run over TCP connections with reserved port numbers.

- **HTTP** [RFC 2068]: The Hypertext Transfer Protocol is used for communication between web browser and web server.
- **FTP** [RFC 959]: The File Transfer Protocol allows directories on a remote computer to be browsed and files to be transferred from one computer to another over a connection.
- **Telnet** [RFC 854]: Telnet provides access by means of a terminal session to a remote computer.
- **SMTP** [RFC 821]: The Simple Mail Transfer Protocol is used to send mail between computer.

TCP Stream Communication

JAVA API FOR TCP
Java API for TCP streams

Java interface provides two classes `ServerSocket` and `Socket`.

**ServerSocket**
- Class is intended to be used by server to create a socket at a server port for listening for connect requests from clients.

**Socket**
- Class is for use by a pair of processes with a connection
- The client uses a constructor to create a socket, specifying the DNS hostname and port of a server.
TCP Echo Server

public class EchoServer {
    public static void main(String args[]) throws IOException {
        ServerSocket listen = new ServerSocket(1234);
        while (true) {
            Socket socket = listen.accept();
            BufferedReader in = new BufferedReader(new InputStreamReader(socket.getInputStream()));
            PrintStream out = new PrintStream(socket.getOutputStream());
            //...
        }
    }
}
while (true) {

String message = in.readLine();

if (message == null) {
    break;
}

String answer = message.replace('i', 'o');
out.println(answer);

in.close();
out.close();

socket.close();
System.out.println("Socket closed.");

}}
public class Client {

    public static void main(String args[]) throws IOException {

        Socket socket = new Socket("localhost", 1234);
        PrintStream out = new PrintStream(socket.getOutputStream());

        BufferedReader in = new BufferedReader(new InputStreamReader(socket.getInputStream()));
        BufferedReader keyboard = new BufferedReader(new InputStreamReader(System.in));

        . . .
    }
}
while (true) {
    String message = keyboard.readLine();

    if (message == null)
        break;

    out.println(message);
    String answer = in.readLine();
    System.out.println("echo:" + answer);
}

in.close();
out.close();
socket.close();
}
Notice!

However, the service echo is quite limited in that it cannot have several sessions at the same time. If you want to use the service, you may have to wait until an active user closes the session.

What might be a solution?
Example EchoServer Extended

```java
public class EchoServerExtended extends Thread {
    private Socket socket;
    private BufferedReader in;
    private PrintStream out;

    public EchoServerExtended(Socket socket) throws IOException{
        this.socket = socket;
        this.in = new BufferedReader(new InputStreamReader(socket.getInputStream()));
        this.out = new PrintStream(socket.getOutputStream());
    }
```
Further tasks of you as developer…

Sockets only provide the basic mechanisms, there is still work to be done, for example the implementation of more complex system models such as Request-Reply (for client-server) or group communication.

Above all, however, the necessity of homogeneous data representation in heterogeneous environments is a major issue.

These are the basic techniques for more complex middleware such as RPC, Java RMI. We talk about it soon 😊
Recap: Architectural Model

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  - Web Services

Communication paradigm
- Inter-process communication
  - UDP sockets
  - TCP sockets
  - Multicast
- Indirect communication
- Remote invocation

Roles and responsibilities
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Placement
- Multiple server
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Architectural patterns

Open Topics Interprocess Communication

- External data representation and marshalling
- Multicast communication
- Network virtualization: Overlay networks
Middleware Layers

Applications, services

Remote invocation, indirect communication

Underlying inter-process communication primitives:
Sockets, message passing, multicast support

UDP and TCP

References

Main resources for this lecture:


Algorithms and Programming IV
Interprocess Communication (cont.)

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Algorithms and Programming IV
Remote Invocation

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