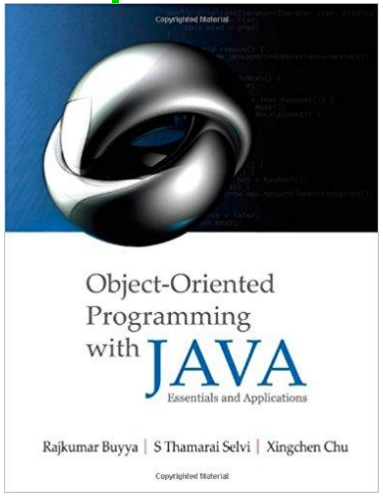
中国科学院深圳先进技术研究院
SHENZHEN INSTITUTE OF ADVANCED TECHNOLOGY
CHINESE ACADEMY OF SCIENCES

Inter-Process Communication (IPC):

Network Programming using TCP Java Sockets



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Object-Oriented Programming with JAVA

Essentials and Applications

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云中谁寄锦书来，雁字回时，月满西楼。
——（宋）李清照

Review

1. Provide a definition of a Distributed System

Review

1. Provide a definition of a Distributed System

- A system in which hardware or software components located at networked computers communicate and coordinate their actions only by passing message [Coulouris]

- A collection of independent computers that appears to its users as a single coherent system [Tanenbaum]

Review

2. Briefly explain the difference between a computer network and a distributed system.

Review

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A Computer Network: Is a collection of spatially separated, interconnected computers that exchange messages based on specific protocols. Computers are addressed by IP addresses.

A Distributed System: Multiple computers on the network working together as a system. The spatial separation of computers and communication aspects are hidden from users.

Review

3. List three reasons for using a distributed system.

Review

3. List three reasons for using a distributed system.

- Economy (cost effective)
- Reliability (fault tolerance)
- Availability (high uptime)
- Scalability (extendible)
- Functional Separation (Modularity)

The main motivation to build and use distributed systems is Resource Sharing

- Hardware Resources (Disks, printers, scanners etc.)
- Software Resources (Files, databases etc)
- Other (Processing power, memory, bandwidth)

Review

4. Briefly explain four consequences when using distributed systems, i.e. issues that arise that are not present otherwise.

Review

4. Briefly explain four consequences when using distributed systems, i.e. issues that arise that are not present otherwise.

- Concurrency
- Heterogeneity
- No Global Clock
- Independent Failures

Agenda

- Introduction
- Networking Basics
- Understanding Ports and Sockets
- Java Sockets
  - Implementing a Server
  - Implementing a Client
- Sample Examples
- Conclusions

Introduction

- Internet and WWW have emerged as global ubiquitous media for communication and are changing the way we conduct science, engineering, and commerce
- They are also changing the way we learn, live, enjoy, communicate, interact, engage, work, etc. It appears like the modern life activities are getting completely drive by the Internet

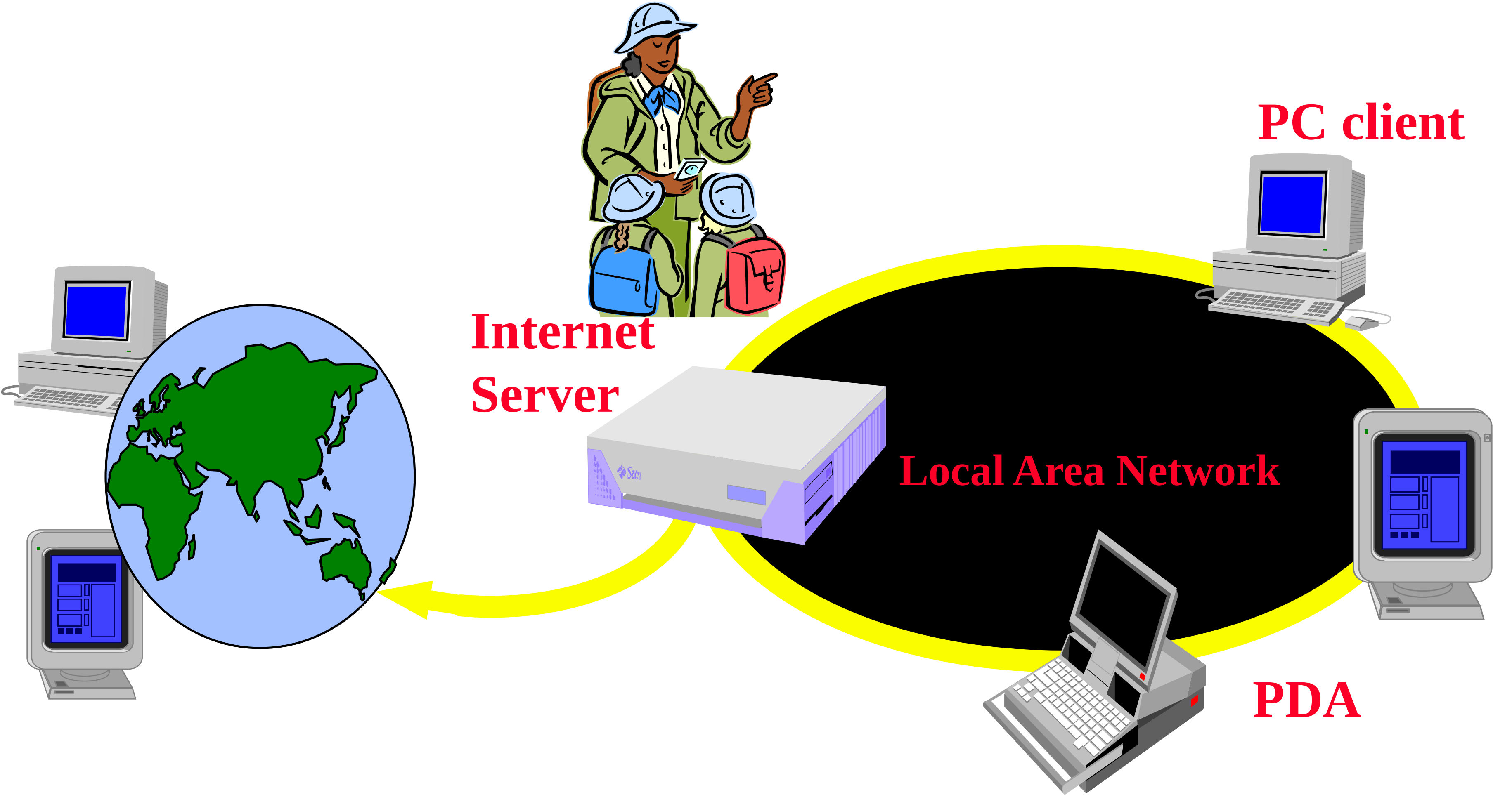
Turing Award 2016

- Professor at MIT
- Invented:
  - URI that would serve to allow any object
  - HTTP that allows for the exchange, retrieval, or transfer of an object over the Internet
  - Web browser that that retrieves and renders resources on the World Wide Web
  - HTML that allows web browsers to translate documents or other resources

Tim Berners-Lee

Citation: “*For inventing the World Wide Web, the first web browser, and the fundamental protocols and algorithms allowing the Web to scale.*”

Internet Applications Serving Local and Remote Users

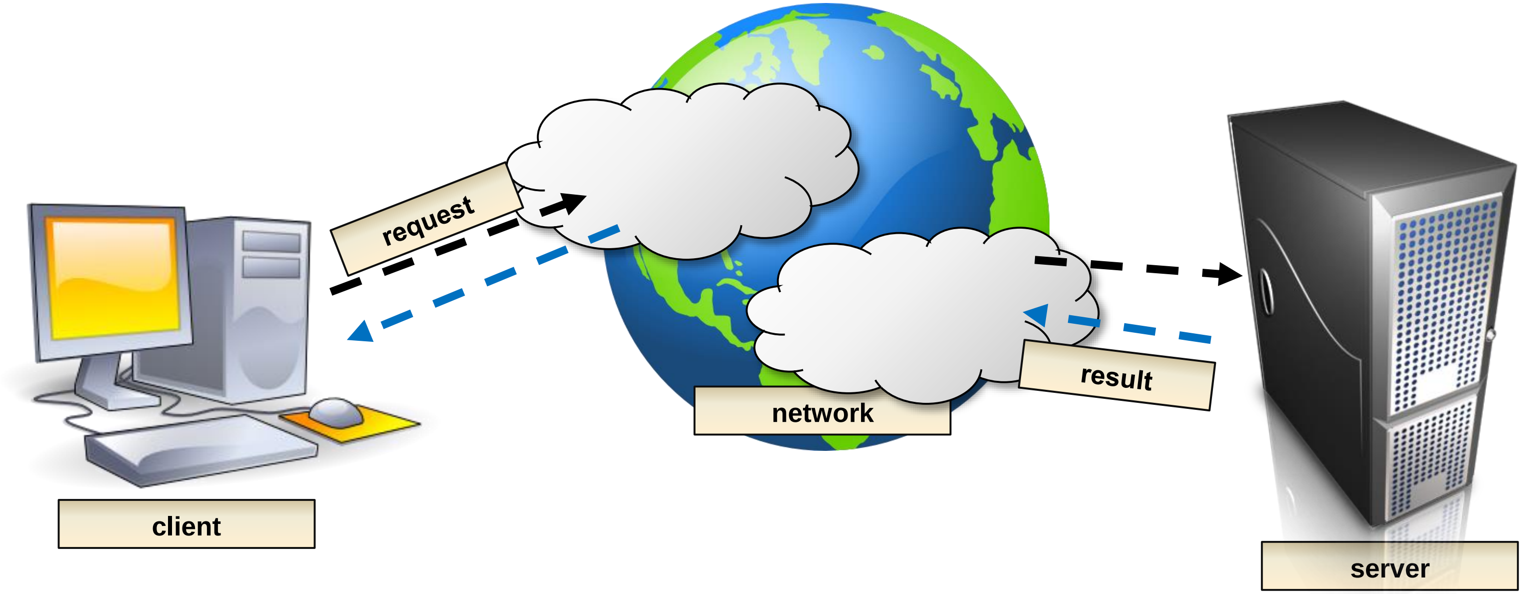


Increasing Demand for Internet Applications

- To take advantage of opportunities presented by the Internet, businesses are continuously seeking new and innovative ways and means for offering their services via the Internet.
- This created a huge demand for software designers with skills to create new Internet-enabled applications or migrate existing/legacy applications to the Internet platform.
- Object-oriented Java technologies—Sockets, threads, RMI, clustering, Web services—have emerged as leading solutions for creating portable, efficient, and maintainable large and complex Internet applications.

Elements of Client-Server Computing/Communication

a client, a server, and network

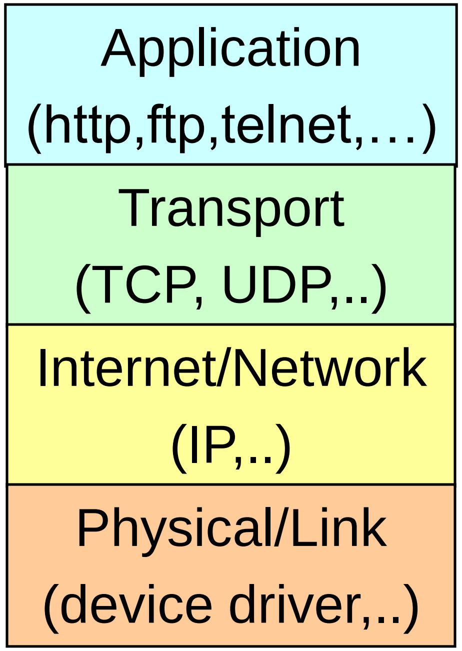


- Processes follow protocols that define a set of rules that must be observed by participants:
  - How the data exchange is encoded?
  - How events (sending, receiving) are synchronized (ordered) so that participants can send and receive data in a coordinated manner?
- In face-to-face communication, humans beings follow unspoken protocols based on eye contact, body language, gesture.

Networking Basics

- Physical/Link Layer
  - Functionalities for transmission of signals representing a stream of data from one computer to another
- Internet/Network Layer
  - IP (Internet Protocols) – a packet of data to be addressed to a remote computer and delivered
- Transport Layer
  - Functionalities for delivering data packets to a specific process on a remote computer
  - TCP (Transmission Control Protocol)
  - UDP (User Datagram Protocol)
  - Programming Interface:
    - Sockets
- Applications Layer
  - Message exchange between standard or user applications:
    - HTTP, FTP, Telnet, **WeChat,…**

- TCP/IP Stack



Application
(http,ftp,telnet,…)

Transport
(TCP, UDP,..)

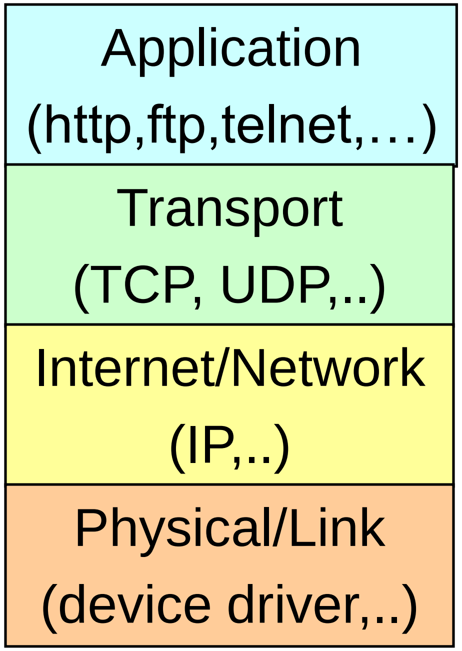
Internet/Network
(IP,..)

Physical/Link
(device driver,..)

Networking Basics

- TCP (Transmission Control Protocol) is a connection-oriented communication protocol that provides a reliable flow of data between two computers.
- Analogy: Speaking on Phone
- Example applications:
  - HTTP, FTP, Telnet
  - **WeChat** uses **TCP** for call signalling, and both **UDP** and **TCP** for transporting media traffic.

- TCP/IP Stack



Application (http,ftp,telnet,…)

Transport (TCP, UDP,..)

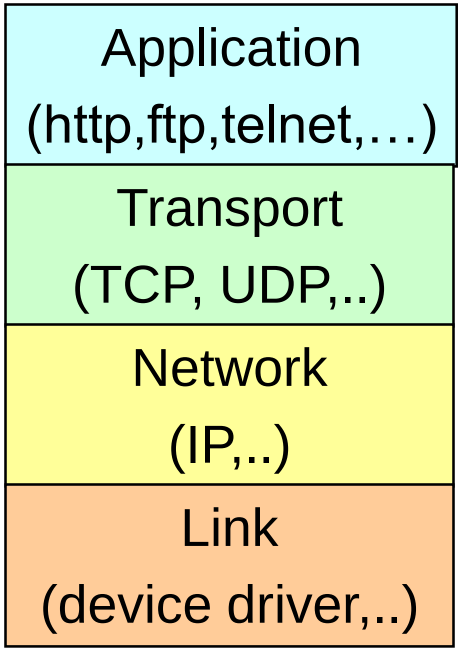
Internet/Network (IP,..)

Physical/Link (device driver,..)

Networking Basics

- UDP (User Datagram Protocol) is a connectionless communication protocol that sends independent packets of data, called *datagrams*, from one computer to another with no guarantees about arrival or order of arrival
- Similar to sending multiple emails/letters to friends, each containing part of a message.
- Example applications:
  - Clock server
  - Ping
  - Live streaming (event/sports broadcasting)

- TCP/IP Stack



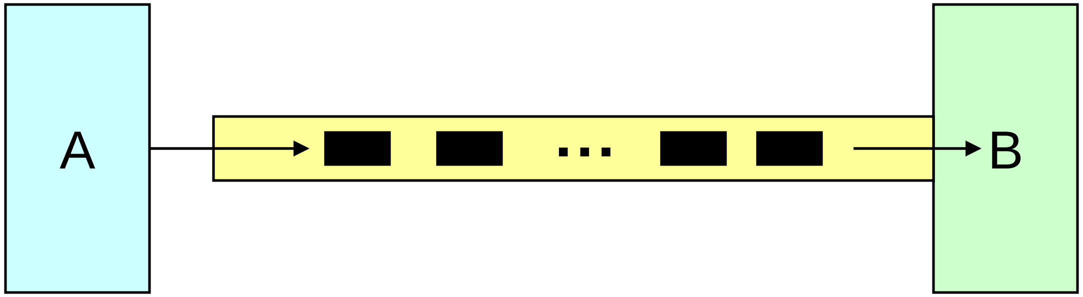
Application
(http,ftp,telnet,…)

Transport
(TCP, UDP,..)

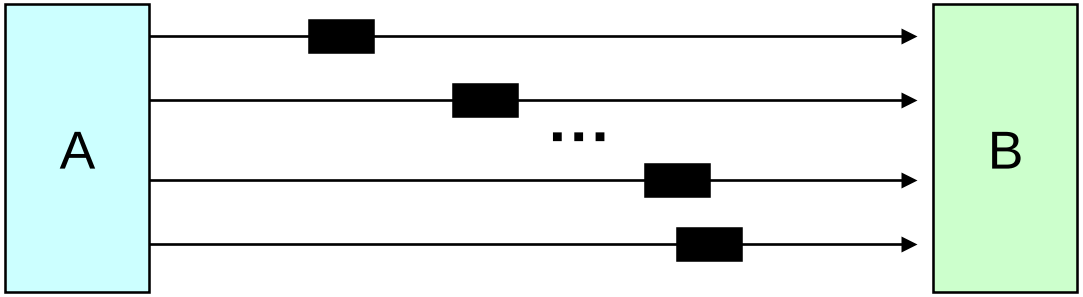
Network
(IP,..)

Link
(device driver,..)

TCP Vs UDP Communication



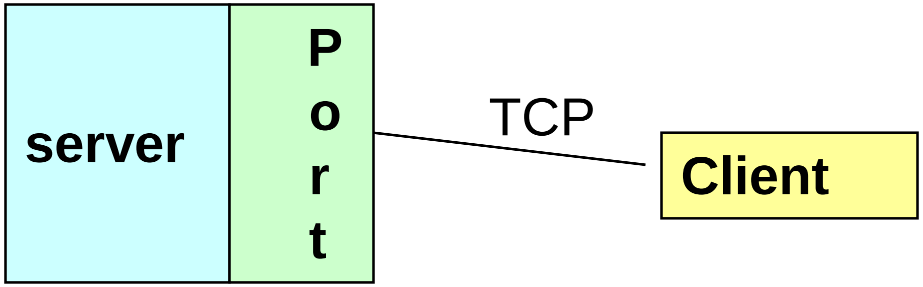
- Connection-Oriented Communication

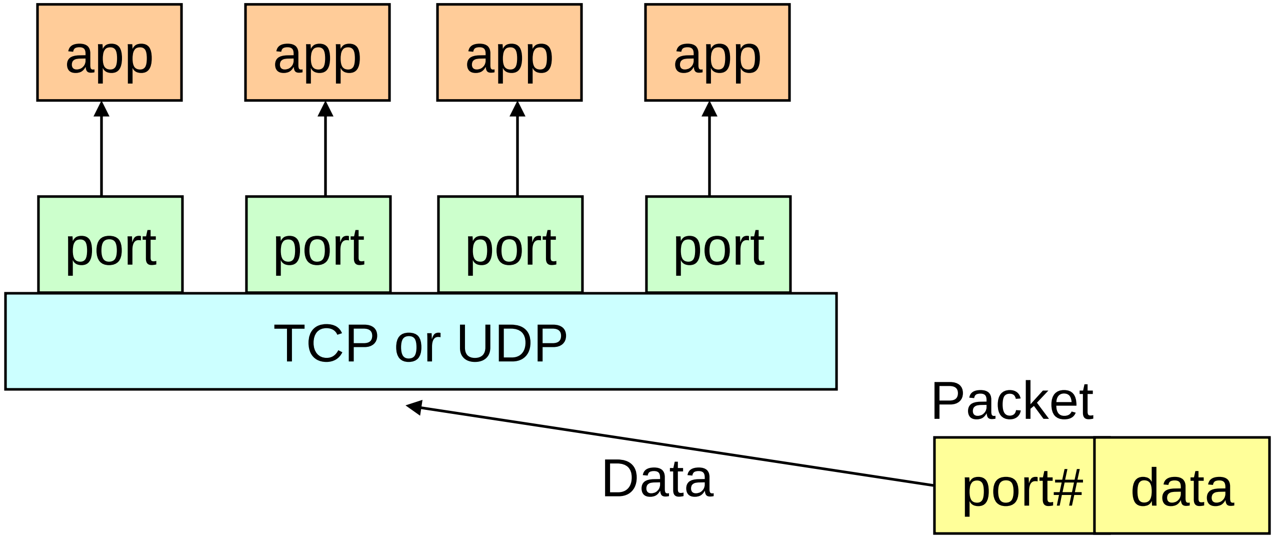


- Connectionless Communication

Understanding Ports

- The TCP and UDP protocols use *ports* to map incoming data to a particular *process* running on a computer.





Understanding Ports

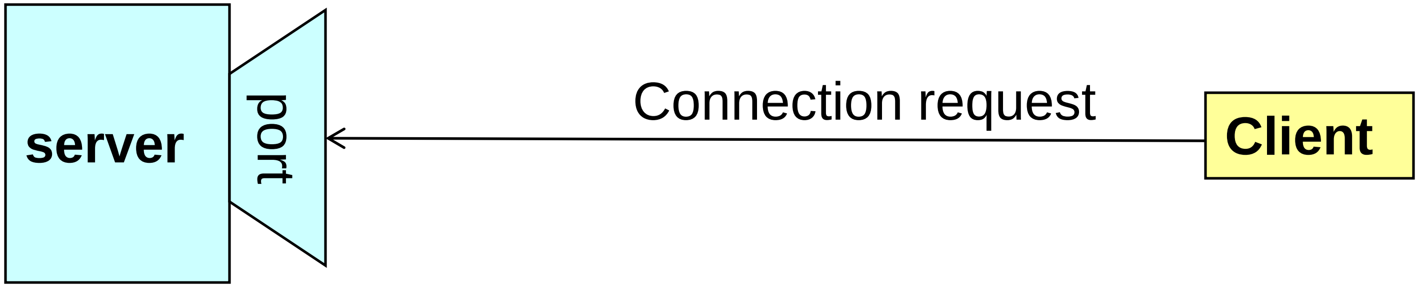
- Port is represented by a positive (16-bit) integer value (0~65535)
- Some ports have been reserved to support common/well known services:
  - ftp 21/tcp
  - telnet 23/tcp
  - smtp 25/tcp
  - http 80/tcp
  - login 513/tcp
  - https://en.wikipedia.org/wiki/List_of_TCP_and_UDP_port_numbers
- User-level processes/services generally use port number value >= 1024

Sockets

- Sockets provide an interface for programming networks at the transport layer
- Network communication using Sockets is very much similar to performing file I/O
  - In fact, socket handle is treated like file handle.
  - The streams used in file I/O operation are also applicable to socket-based I/O
- Socket-based communication is programming language independent.
  - That means, a socket program written in Java language can also communicate to a program written in Java or non-Java socket program

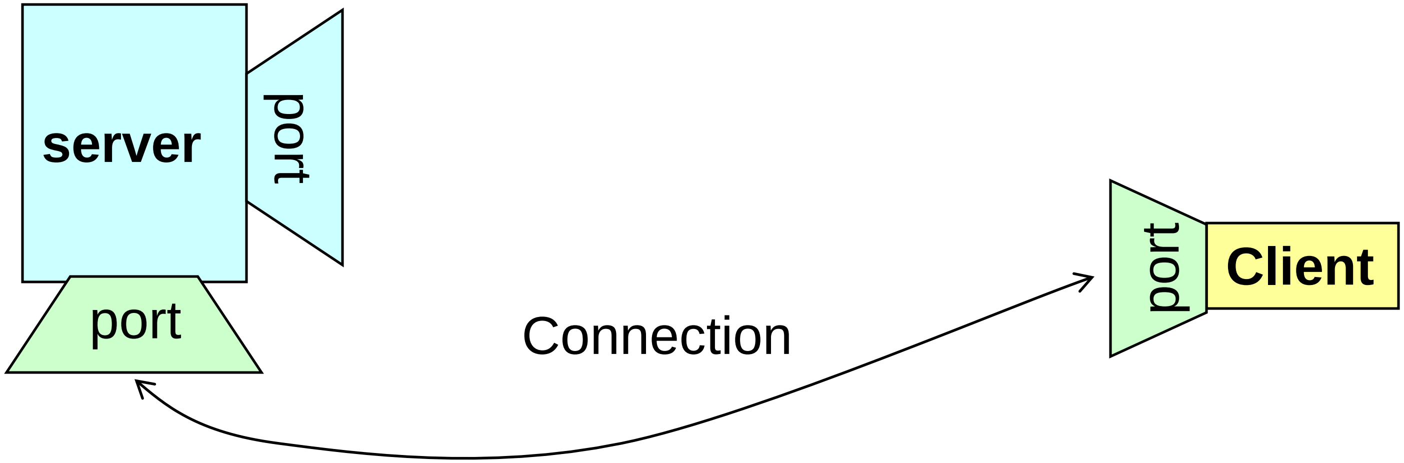
Socket Communication

- A server (program) runs on a specific computer and has a socket that is bound to a specific port. The server waits and listens to the socket for a client to make a connection request.



Socket Communication

- If everything goes well, the server accepts the connection. Upon acceptance, the server gets a new socket bounds to a different port. It needs a new socket (consequently a different port number) so that it can continue to listen to the original socket for connection requests while serving the connected client.



Multi-Client vs Server

- Be like John Snow facing troops
- OR Captain Jack Sparrow’s running from savages

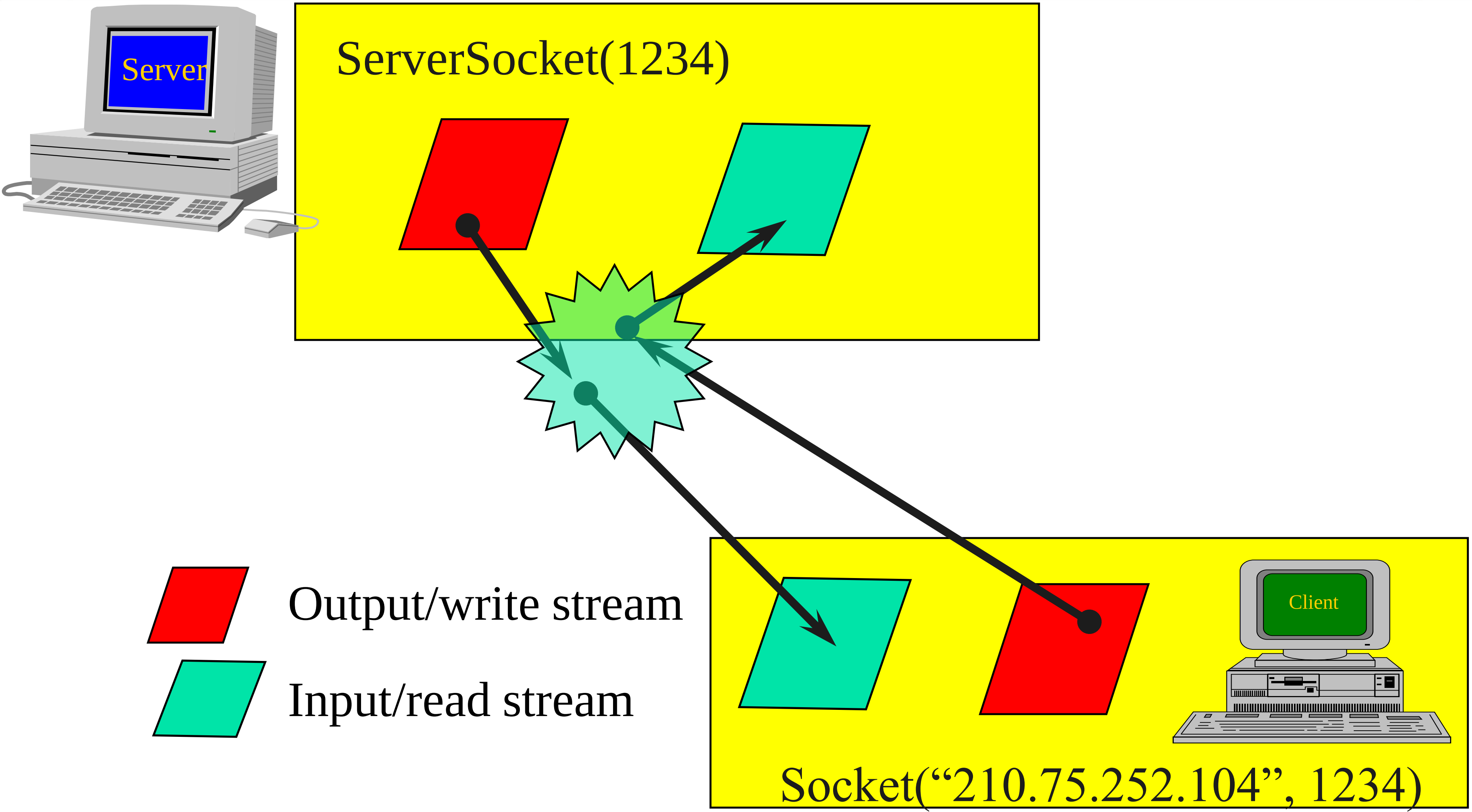
Game of Thrones

Pirates of the Caribbean

Sockets and Java Socket Classes

- A socket is an endpoint of a two-way communication link between two programs running on the network.
- A socket is bound to a port number so that the TCP layer can identify the application that data destined to be sent.
- Java’s .net package provides two classes:
  - Socket – for implementing a client
  - ServerSocket – for implementing a server

Java Sockets



Server

ServerSocket(1234)

🟥 Output/write stream

🟩 Input/read stream

Client

Socket(“210.75.252.104”, 1234)

It can be host_name like “https://www.siat.ac.cn/

Implementing a Server

1. Open the Server Socket:

```
ServerSocket server;
DataOutputStream os;
DataInputStream is;
server = new ServerSocket( PORT );
```

2. Wait for the Client Request:

```
Socket client = server.accept();
```

3. Create I/O streams for communicating to the client

```
is = new DataInputStream( client.getInputStream() );
os = new DataOutputStream( client.getOutputStream() );
```

4. Perform communication with client

```
Receive from client: String line = is.readLine();
Send to client: os.writeBytes("Hello\n");
```

5. Close sockets: `client.close();`

For multithreaded server:

```
while(true) {
```

i. wait for client requests (step 2 above)

ii. create a thread with “client” socket as parameter (the thread creates streams (as in step (3) and does communication as stated in (4). Remove thread once service is provided.

```
}
```

Implementing a Client

1. Create a Socket Object:

```
client = new Socket( server, port_id );
```

2. Create I/O streams for communicating with the server.

```
is = new DataInputStream(client.getInputStream() );
 os = new DataOutputStream( client.getOutputStream() );
```

3. Perform I/O or communication with the server:

- Receive data from the server:

```
String line = is.readLine();
```

- Send data to the server:

```
os.writeBytes("Hello\n");
```

4. Close the socket when done:

```
client.close();
```

A simple server (simplified code)

```
// SimpleServer.java: a simple server program
import java.net.*;
import java.io.*;
public class SimpleServer {
  public static void main(String args[]) throws IOException {
    // Register service on port 1234
    ServerSocket s = new ServerSocket(1234);
    Socket s1=s.accept(); // Wait and accept a connection
    // Get a communication stream associated with the socket
    OutputStream s1out = s1.getOutputStream();
    DataOutputStream dos = new DataOutputStream (s1out);
    // Send a string!
    dos.writeUTF("Hi there");
    // Close the connection, but not the server socket
    dos.close();
    s1out.close();
    s1.close();
  }
}
```

A simple client (simplified code)

```
// SimpleClient.java: a simple client program
import java.net.*;
import java.io.*;
public class SimpleClient {
  public static void main(String args[]) throws IOException {
    // Open your connection to a server, at port 1234
    Socket s1 = new Socket(“www.siat.ac.cn",1234);
    // Get an input file handle from the socket and read the input
    InputStream s1In = s1.getInputStream();
    DataInputStream dis = new DataInputStream(s1In);
    String st = new String (dis.readUTF());
    System.out.println(st);
    // When done, just close the connection and exit
    dis.close();
    s1In.close();
    s1.close();
  }
}
```

Run

- Run Server on a host at SIAT

  -
    ```
    [mx@siat] java SimpleServer &
    ```

- Run Client on any machine (including SIAT):

  -
    ```
    [mx@siat] java SimpleClient
    Hi there
    ```

- If you run client when server is not up:

  -
    ```
    [mx@siat] sockets [1:147] java SimpleClient
    Exception in thread "main" java.net.ConnectException: Connection refused
            at java.net.PlainSocketImpl.socketConnect(Native Method)
            at java.net.PlainSocketImpl.doConnect(PlainSocketImpl.java:320)
            at java.net.PlainSocketImpl.connectToAddress(PlainSocketImpl.java:133)
            at java.net.PlainSocketImpl.connect(PlainSocketImpl.java:120)
            at java.net.Socket.<init>(Socket.java:273)
            at java.net.Socket.<init>(Socket.java:100)
            at SimpleClient.main(SimpleClient.java:6)
    ```

Socket Exceptions

```
try {
    Socket client = new Socket(host, port);
    handleConnection(client);
}
catch(UnknownHostException uhe) {
    System.out.println("Unknown host: " + host);
    uhe.printStackTrace();
}
catch(IOException ioe) {
System.out.println("IOException: " + ioe);
    ioe.printStackTrace();
}
```

ServerSocket & Exceptions

- public **ServerSocket**(int port) throws IOException
  - Creates a server socket on a specified port
  - A port of 0 creates a socket on any free port. You can use **getLocalPort**() to identify the (assigned) port on which this socket is listening
  - The maximum queue length for incoming connection indications (a request to connect) is set to 50. If a connection indication arrives when the queue is full, the connection is refused
- Throws:
  - IOException - if an I/O error occurs when opening the socket
  - SecurityException - if a security manager exists and its checkListen method doesn't allow the operation

Server in Loop: Always up

```
// SimpleServerLoop.java: a simple server program that runs forever in a single thead
import java.net.*;
import java.io.*;
public class SimpleServerLoop {
  public static void main(String args[]) throws IOException {
    // Register service on port 1234
    ServerSocket s = new ServerSocket(1234);
    while(true)
    {
            Socket s1=s.accept(); // Wait and accept a connection
            // Get a communication stream associated with the socket
            OutputStream s1out = s1.getOutputStream();
            DataOutputStream dos = new DataOutputStream (s1out);
            // Send a string!
            dos.writeUTF("Hi there");
            // Close the connection, but not the server socket
            dos.close();
            s1out.close();
            s1.close();
    }
  }
}
```

Java API for UDP Programming

- Java API provides datagram communication by means of two classes
  - DatagramPacket
    - | Msg | length | Host | serverPort |
  - DatagramSocket

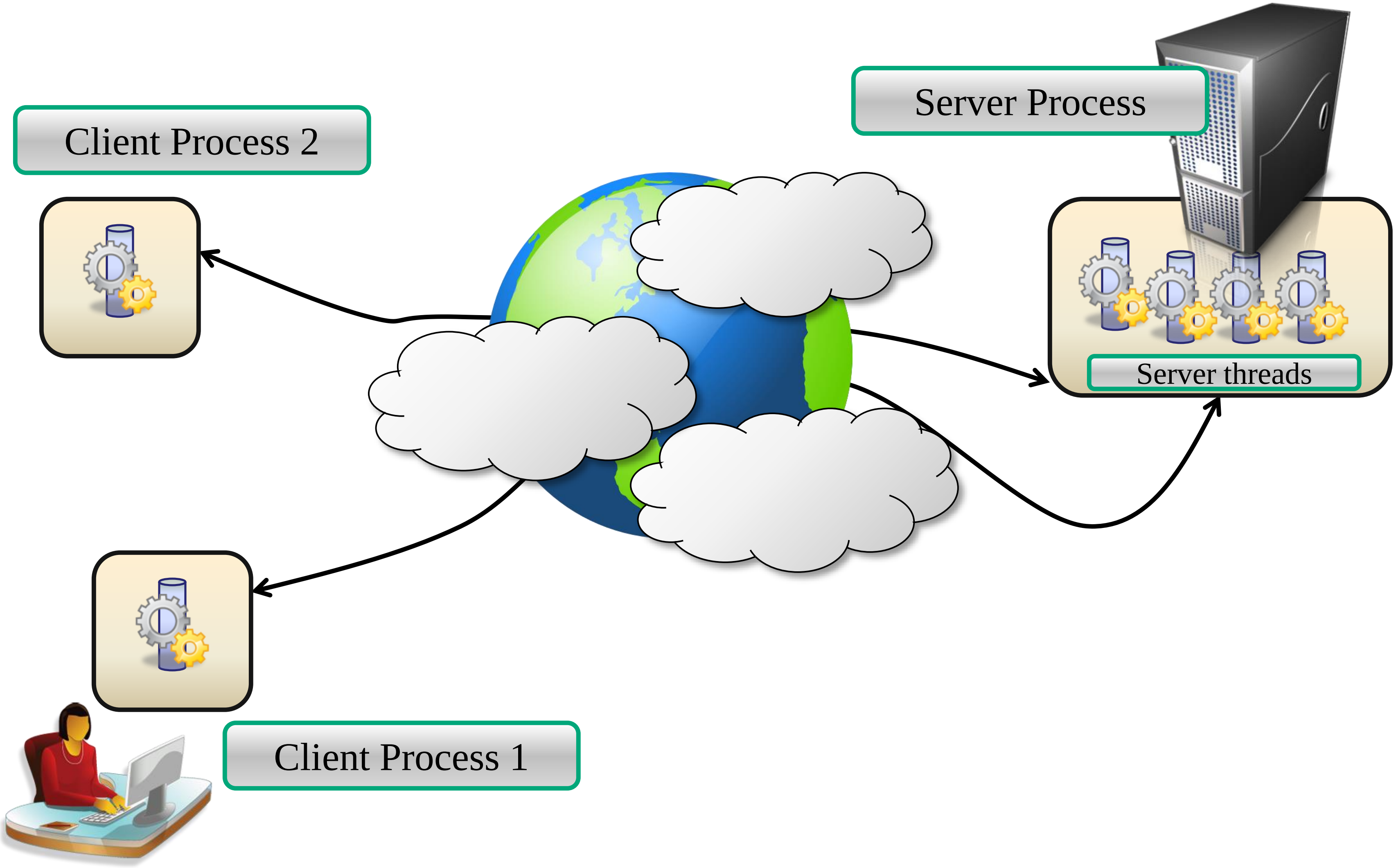
UDP Client: Sends a Message and Gets reply

```
import java.net.*;
import java.io.*;
public class UDPClient
{
    public static void main(String args[]){
        // args give message contents and server hostname
        // "Usage: java UDPClient <message> <Host name> <Port number>"
        DatagramSocket aSocket = null;
          try {
                aSocket = new DatagramSocket();
                byte [] m = args[0].getBytes();
                InetAddress aHost = InetAddress.getByName(args[1]);
                int serverPort = 6789;  // Or Integer.valueOf(args[2]).intValue() if use <Port number> args[2]
                DatagramPacket request = new DatagramPacket(m,  args[0].length(), aHost, serverPort);
                aSocket.send(request);
                byte[] buffer = new byte[1000];
                DatagramPacket reply = new DatagramPacket(buffer, buffer.length);
                aSocket.receive(reply);
                System.out.println("Reply: " + new String(reply.getData()));
          }
          catch (SocketException e){System.out.println("Socket: " + e.getMessage());}
          catch (IOException e){System.out.println("IO: " + e.getMessage());}
          finally
        {
           if(aSocket != null) aSocket.close();
        }
     }
}
```

UDP Sever: repeatedly received a request and sends it back to the client

```
import java.net.*;
import java.io.*;
public class UDPServer{
        public static void main(String args[]){
        DatagramSocket aSocket = null;
            try{
                aSocket = new DatagramSocket(6789); // fixed port number
                byte[] buffer = new byte[1000];
                while(true){
                    DatagramPacket request = new DatagramPacket(buffer, buffer.length);
                   aSocket.receive(request);
                   DatagramPacket reply = new DatagramPacket(request.getData(),
                        request.getLength(), request.getAddress(), request.getPort());
                   aSocket.send(reply);
                }
            }catch (SocketException e){System.out.println("Socket: " + e.getMessage());}
             catch (IOException e) {System.out.println("IO: " + e.getMessage());}
        finally {if(aSocket != null) aSocket.close();}
    }
}
```

Multithreaded Server: For Serving Multiple Clients Concurrently

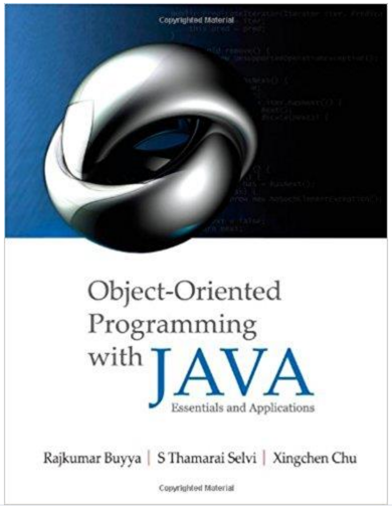


Summary

- Programming client/server applications in Java is fun and challenging
- Programming socket programming in Java is much easier than doing it in other languages such as C
- TCP for Connection-oriented communication, more reliable, flow control
- UDP for connection-less communication
- Keywords:
  - Clients, servers, TCP/IP, port number, sockets, Java sockets

References

- Chapter 13: Socket Programming
  - R. Buyya, S. Selvi, X. Chu, **“Object Oriented Programming with Java: Essentials and Applications”,** McGraw Hill, New Delhi, India, 2009.
  - Sample chapters at book website: http://www.buyya.com/java/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Demo

Exploring an Interactive Client/Server

Client:

1. Create a socket specifying the server address and port
2. Read data from user inputs using the Scanner class
3. Write data using the stream associated with the socket

Server:

1. Create a listening socket bound to a server port
2. Wait for clients to request a connection (Listening socket maintains a queue of incoming connection requests)
3. Server accepts a connection and creates a new stream socket for the server to communicate with the client. A pair of sockets in client and server are connected by a pair of streams, one in each direction. A socket has an input stream and an output stream.

Paper Review (Assignment 2)

- Golgi: Performance-Aware, Resource-Efficient Function Scheduling for Serverless Computing
- Lifting the Fog of Uncertainties: Dynamic Resource Orchestration for the Containerized Cloud
- μConAdapter: Reinforcement Learning-based Fast Concurrency Adaptation for Microservices in Cloud
- Is Machine Learning Necessary for Cloud Resource Usage Forecasting?
- LatenSeer: Causal Modeling of End-to-End Latency Distributions by Harnessing Distributed Tracing
- Gödel: Unified Large-Scale Resource Management and Scheduling at ByteDance
- Carbon Containers: A System-level Facility for Managing Application-level Carbon Emissions