# Chap 4. Inter-Process Communication

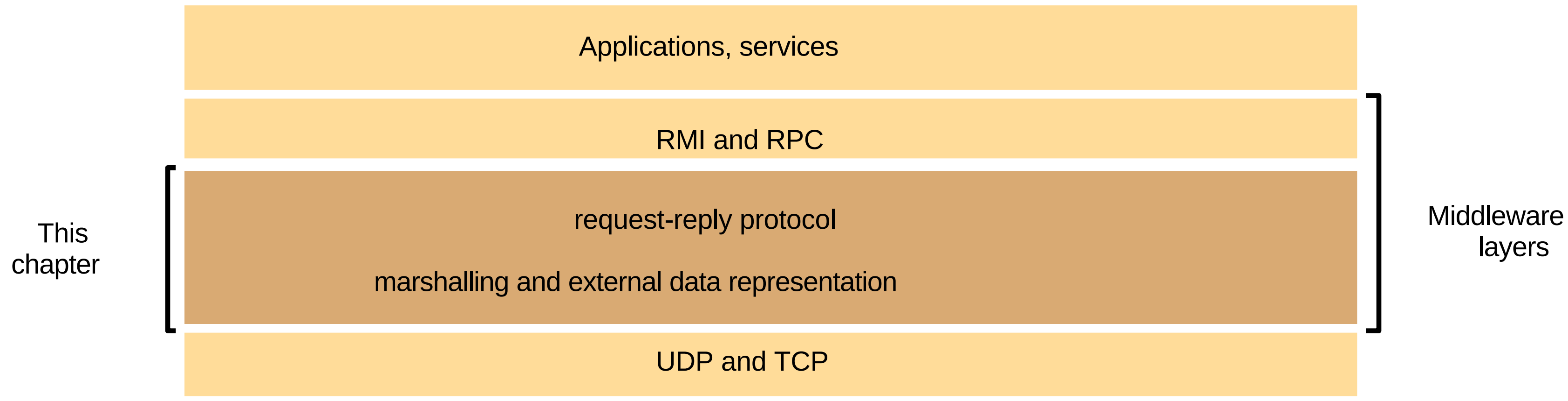
- **Road map**
  - 4.1. Intro
  - 4.2. API for the Internet Protocols
  - 4.3. External data representation and marshalling
  - 4.4. Client-Server Communication
  - 4.5. Group communication (self-read)
  - 4.6. Case study (self-read)

# 4.1. Intro

- Focus:
  - Characteristics of protocols for communication between processes to model distributed computing architecture
    - Effective means for communicating objects among processes at language level
  - Java API
    - Provides both datagram and stream communication primitives/interfaces – building blocks for communication protocols
  - Representation of objects
    - providing a common interface for object references
  - Protocol construction
    - Two communication patterns for distributed programming: C-S using RMI/RPC and Group communication using ‘broadcasting’

# 4.1. Intro

- **In Chapter 3**, we covered Internet transport (TCP/UDP) and network (IP) protocols without emphasizing how they are used at programming level
- **In Chapter 5**, we cover RMI facilities for accessing remote objects' methods AND the use of RPC for accessing the procedures in a remote server
- **Chapter 4** is on how TCP and UDP are used in a program to effect communication via socket (e.g. Java sockets) – the Middle Layers – for object request/reply invocation and parameter marshalling/representation



# 4.2. API for internet protocols

- IPC primitives
  - message passing between a pair of processes can be supported by two message communication operations: *send* and *receive*
  - *send* (destination, &msg);        *receive* (source, &buf)
  - Destination and source can be process id or port number (single receiver); Or mailbox (multiple receivers)
    - Typically, (IP, port#) pair

- Use of sockets as API for UDP and TCP implementation – much more specification can be found at *java.net*

Message:

| Header | Body |
|---|---|

# 4.2. API for internet protocols

- Synchronous communication
  - *Send* and *receive* processes synchronize at every message
  - Both <u>blocking</u>:
    - whenever a *send* is issued, blocks until corresponding receive is issued; whenever a *receive* is issued, blocks until message arrives
- Asynchronous communication
  - *Send* from client is <u>non-blocking,</u> proceeds as soon as the message has been copied to a local buffer
  - *Receive* could be non-blocking or <u>blocking</u>, the latter has no disadvantages in system environment supporting multi-threading like Java
    - Non-blocking receive is not very useful (you cannot proceed without message)

# 4.2. API for internet protocols

## comparison

- Blocking

  Advantages: Ease of use and low overhead of implementation

  Disadvantage: low concurrency

- Non-blocking

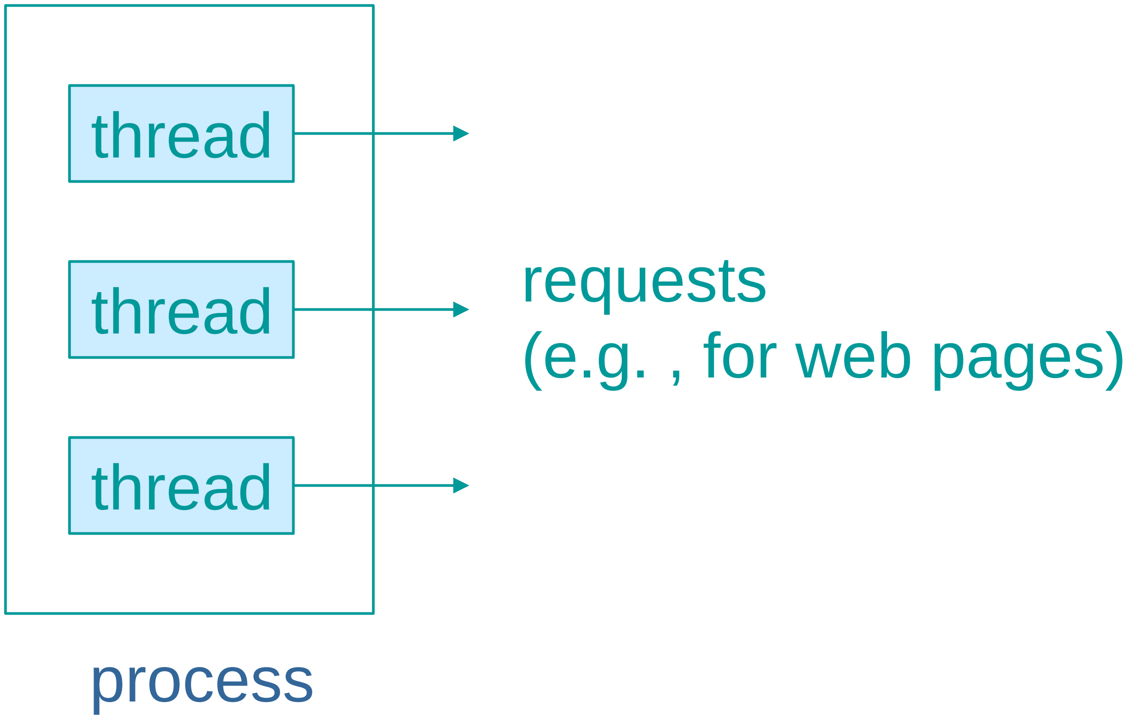
  Advantages: Flexibility, parallel operations

  Disadvantages: Programming tricky: Program is timing-dependent (interrupt can occur at arbitrary time, and execution irreproducible)

➔Use blocking versions with **multiple threads**

# 4.2. API for internet protocols

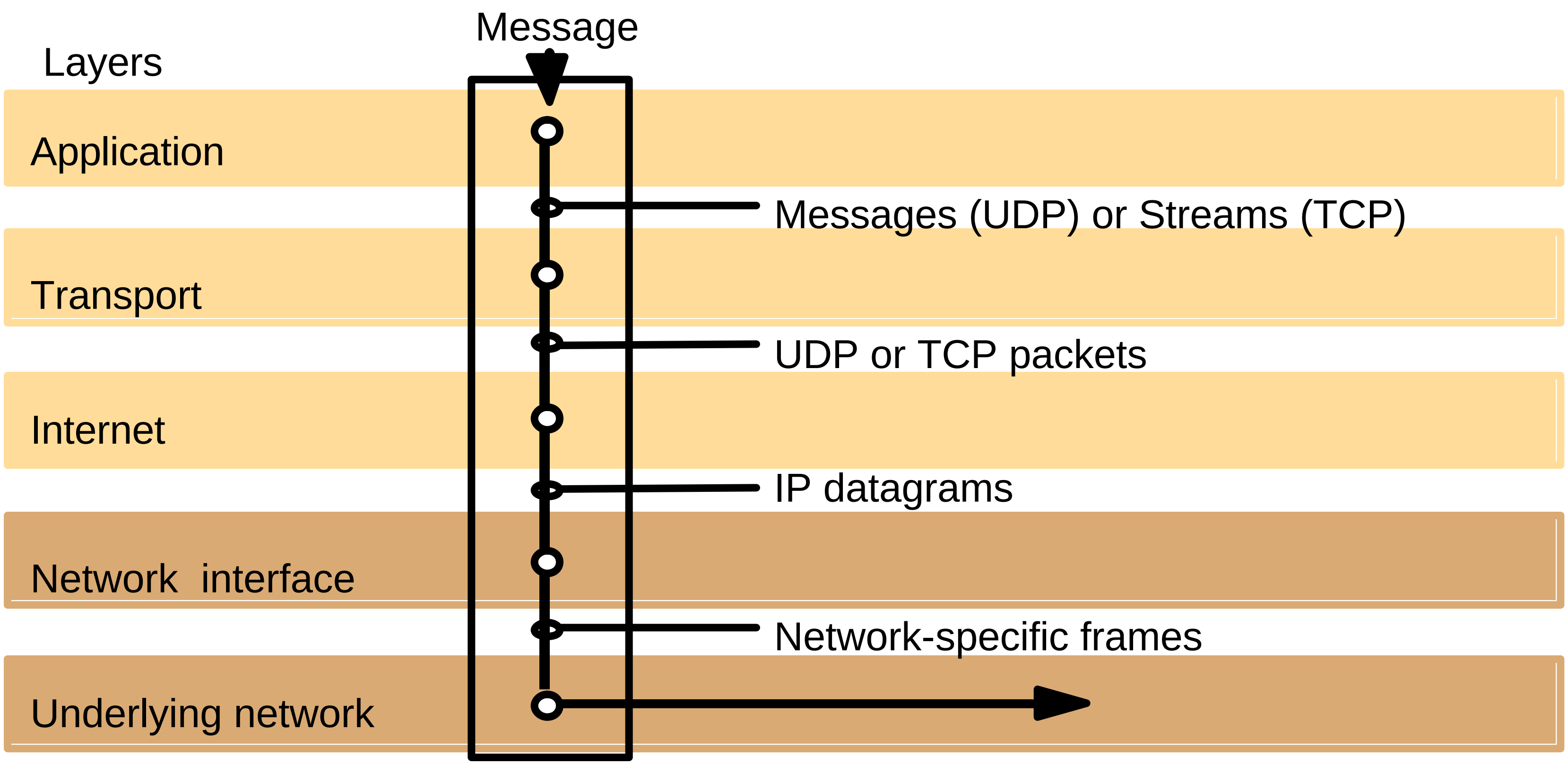
## Using blocking operation without penalty




- Some threads may be blocked while others continue to be active

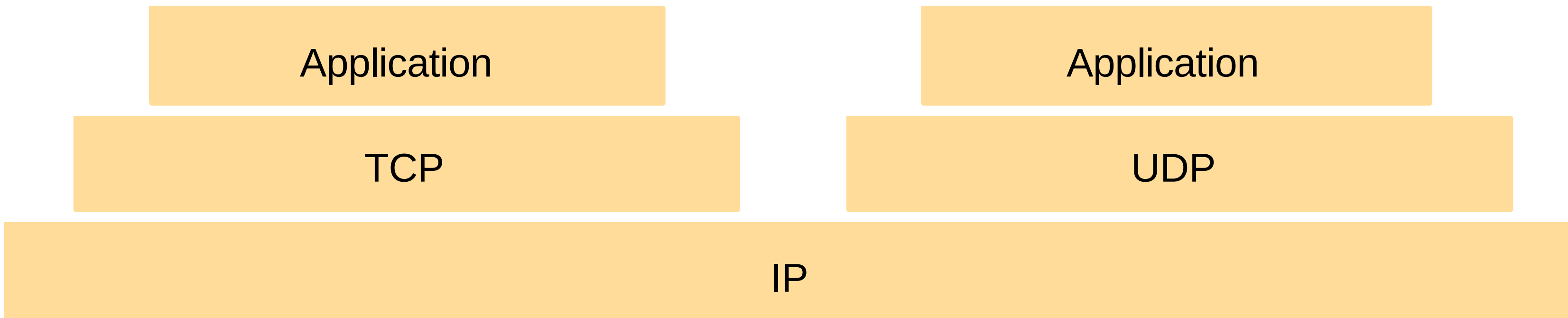
# 4.2. API for internet protocols

- TCP/IP layers



# 4.2. API for internet protocols

- The programmer's conceptual view of a TCP/IP Internet




Recall: UDP, TCP, API

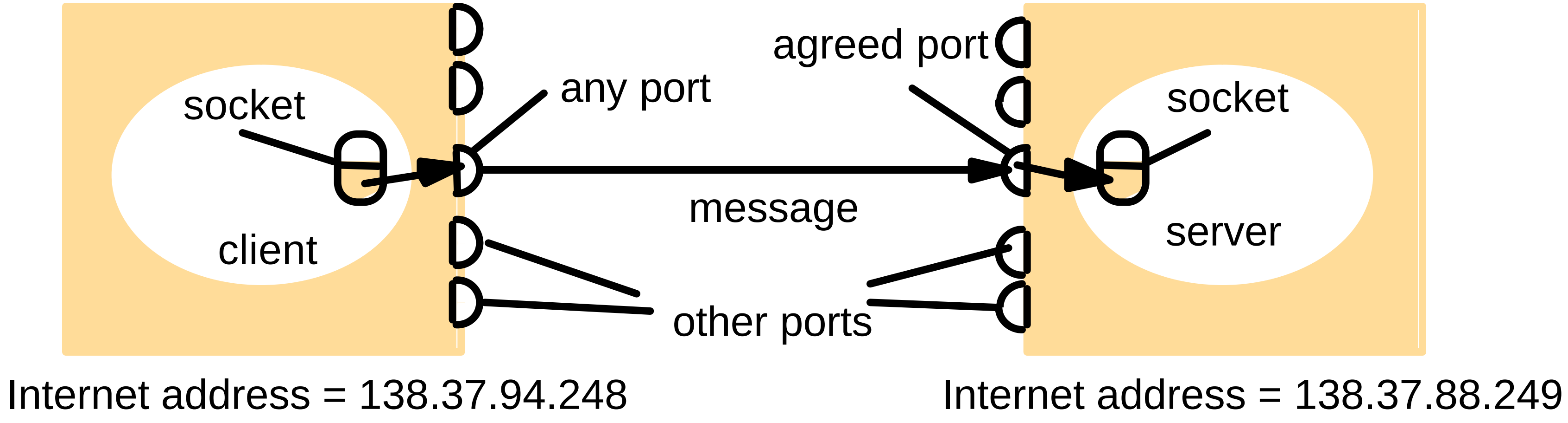
- UDP (User Datagram Protocol): offers no guarantee of delivery, a datagram protocol
- TCP (Transmission Control Protocol): reliable connection-oriented protocol, establishment of bi-directional communication channel
- API (Application programming interface)

# 4.2. API for internet protocols

- Message destinations
  - Messages are sent to a pair (Internet address, local port)
  - Local port: an integer, message destination within a computer
    - Each computer has $2^{16}$ possible ports available to local processes for receiving messages
    - 0-1023: well-known for restricted use of privileged processes
    - 1024-49151: registered ports, holds service descriptions
    - 49152-65535: private purposes
    - In practice, non-restricted ports can be used for private purposes, then, cannot use registered services simultaneously
  - a port has exactly one receiver (except for multicast ports)
  - receiving process can have many ports for different message types
  - server processes usually publish their service-ports for clients

# 4.2. API for internet protocols

- Sockets : originated from BSD Unix
  - Provide an abstraction of endpoints for both TCP and UDP communication
  - Inter-process communication consists of transmitting a message between a socket in one process and a socket in another process
  - A socket must be bound to a local port and an IP address
  - Processes may use the same socket for sending and receiving messages
  - Sockets are typed/associated with a particular protocol, either TCP or UDP



# 4.2. API for internet protocols

- Java API for internet protocols

  - For either TCP or UDP, Java provides an InetAddress class, which contains a method: getByName(DNS) for obtaining IP addresses, irrespective of the number of address bits (32 bits for IPv4 or 128 bits for IPv6) by simply passing the DNS hostname. For example, a user Java code invokes:

    *InetAddress aComputer = InetAddress.getByName("www.cs.sfu.ca")*

  - The class encapsulates the details of the representation of the IP address

# 4.2. API for internet protocols

- UDP Datagram communication
  - Steps:
    - Client finds an available port for UPD connection
    - Client binds the port to local IP (obtained from InetAddress.getByName(DNS) )
    - Server finds a designated port, publicizes it to clients, and binds it to local IP
    - Sever process issues a receive method and gets the IP and port # of sender (client) along with the message
  - Issues
    - **Message size** – receiver needs to specify a buffer of certain size to receive a massage. If message too big, truncated on arrival
    - **Blocking** – <u>send</u> is non-blocking, returns when the message gets the UDP and IP layers; <u>receive</u> is blocking until a datagram is received or timeout
    - **Timeouts** – reasonably large time interval can be set on <u>receiver</u> sockets to avoid indefinite blocking if required by program
    - **Receive from any** – no specification of sources (senders)

# 4.2. API for internet protocols

- UDP Failure Models:
  - Omission failure: due to omission of send or receive (either checksum error or no buffer space at source or destination)
  - Ordering failure: due to out-of-order delivery
  - Applications using UDP are left to provide their own checks to achieve the quality of reliable communication they require (why and how?)
    - UDP lacks built-in checks
    - but failure can be modeled by implementing an ACK mechanism

# 4.2. API for internet protocols

## UDP client sends a message to the server & gets a reply

```
import java.net.*; //defines socket-related classes
import java.io.*; //defines stream-related classes
public class UDPClient{
  public static void main(String args[]){ // args give message contents and server hostname
   DatagramSocket aSocket = null;
    try {
     aSocket = new DatagramSocket();
     byte [] m = args[0].getBytes();
     InetAddress aHost = InetAddress.getByName(args[1]);
     int serverPort = 6789;
     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();}
  }
}
```

# 4.2. API for internet protocols

UDP server repeatedly receives 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);
		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();}
    }
}
```

# 4.2. API for internet protocols

- TCP Stream Communication issues:
  - Message sizes – user application has option to choose how much data it writes to a stream or reads from it
  - Lost messages / Flow control: dealt with by TCP
  - Message duplication and ordering – message identifiers are associated with each IP packet so as for recipient to detect and reject duplicates or re-order
  - Message destinations – a connection is established first. Once established, no IP addresses in packets needed ( Each connection socket is bidirectional – using two streams: output/write and input/read)
    - To establish a connection, client sends *connect* request to server, then server sends *accept* request to client
    - Could be a overhead for a single C-S request and reply

# 4.2. API for internet protocols

- TCP Stream Communication: other issues
  - Matching of data items – both client/sender and server/receiver must agree on data types in the stream
  - Threads – server creates a separate thread in accepting a connection, then it can block waiting for input without delaying other clients

- Failure Model
  - Integrity: uses <u>checksums</u> for detection/rejection of corrupt data and <u>seq #s</u> for detection/rejection of duplicates
  - Validity: uses timeout with retransmission techniques to take care of packet losses

  - Uses – TCP sockets used for such services as: HTTP, FTP, Telnet, SMTP

# 4.2. API for internet protocols

TCP client makes connection to server, sends request and receives reply

```
import java.net.*; //Defines socket-related classes
import java.io.*;  //Defines stream-related classes
public class TCPClient {
    public static void main (String args[]) {
    // arguments supply message and hostname of destination
    Socket s = null;
       try{
           int serverPort = 7896;
           s = new Socket(args[1], serverPort);
           DataInputStream in = new DataInputStream( s.getInputStream());
           DataOutputStream out = new DataOutputStream( s.getOutputStream());
           out.writeUTF(args[0]);          // UTF is a string encoding see Sn 4.3
           String data = in.readUTF();
           System.out.println("Received: "+ data) ;
              }catch (UnknownHostException e){
                      System.out.println("Sock:"+e.getMessage());
       }catch (EOFException e){System.out.println("EOF:"+e.getMessage());
       }catch (IOException e){System.out.println("IO:"+e.getMessage());}
    }finally {if(s!=null) try {s.close();}catch (IOException
    e){System.out.println("close:"+e.getMessage());}}
    }
}
```

# 4.2. API for internet protocols

TCP server makes a connection for each client and then echoes the client’s request

```
import java.net.*;
import java.io.*;
public class TCPServer {
    public static void main (String args[]) {
     try{
        int serverPort = 7896;
        ServerSocket listenSocket = new ServerSocket(serverPort);
        while(true) {
                    Socket clientSocket = listenSocket.accept();
                    Connection c = new Connection(clientSocket);
        }
     } catch(IOException e) {System.out.println("Listen :"+e.getMessage());}
    }
}

// this figure continues on the next slide
```

# 4.2. API for internet protocols

```
class Connection extends Thread {
    DataInputStream in;
    DataOutputStream out;
    Socket clientSocket;
    public Connection (Socket aClientSocket) {
        try {
        clientSocket = aClientSocket;
        in = new DataInputStream( clientSocket.getInputStream());
        out =new DataOutputStream( clientSocket.getOutputStream());
        this.start();
        } catch(IOException e)  {System.out.println("Connection:"+e.getMessage());}
    }
    public void run(){
        try {                                   // an echo server
        String data = in.readUTF();
        out.writeUTF(data);
        } catch(EOFException e) {System.out.println("EOF:"+e.getMessage());
        } catch(IOException e) {System.out.println("IO:"+e.getMessage());}
        } finally{ try {clientSocket.close();}catch (IOException e){/*close failed*/}}
    }
}
```