Transport layer protocols

Lecture 15: Operating Systems and Networks
Behzad Bordbar

Interprocess communication
- Synchronous and asynchronous comm.
- Message destination
- Reliability
- Ordering

Asynchronous vs. Synchronous
- Synchronize communication: sender and receiver
- synchronize on every message, i.e. blocking operations
- Asynchronous
  - send is non-blocking
  - receive can be blocking/non-blocking
Which one is better?

Message destination: Socket + Port

Operations of Request-Reply
- public byte[] doOperation (RemoteObjectRef o, int methodId, byte[] arguments)
  - sends a request message to the remote object and returns the reply.
  - the arguments specify the remote object, the method to be invoked and the arguments of that method.
- public byte[] getRequest ()
  - acquires a client request via the server port.
- public void sendReply (byte[] reply, InetAddress clientHost, int clientPort);
  - sends the reply message reply to the client at its Internet address and port.

Sockets
- Characteristics:
  - endpoint for inter-process communication
  - message transmission between sockets
  - socket associated with either UDP or TCP
  - processes bound to sockets, can use multiple ports
- Implementations
  - originally BSD Unix, but available in Linux, Windows,...
  - here Java API for Internet programming

Asynchronous and synchronous communication
- Message destination
- Reliability
- Ordering

A client sends a doOperation message to a server, which responds with a reply message.

Message destination: Socket + Port

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Java API for Internet addresses

- Class InetAddress
  - uses DNS (Domain Name System)

Java code:
```java
InetAddress ac = InetAddress.getByName("gromit.cs.bham.ac.uk");
```
- throws UnknownHostException
- encapsulates detail of IP address (4 bytes for IPv4 and 16 bytes for IPv6)

Remote Object Reference

- An identifier for an object that is valid throughout the distributed system
  - must be unique
  - may be passed as argument, hence need external representation

<table>
<thead>
<tr>
<th>32 bits</th>
<th>32 bits</th>
<th>32 bits</th>
<th>32 bits</th>
<th>Interface of remote object</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internet address</td>
<td>port number</td>
<td>time</td>
<td>object number</td>
<td></td>
</tr>
</tbody>
</table>

Reliability

- Reliable communication:
  - messages are guaranteed to be delivered despite a
  - ‘reasonable’ number of packets being dropped or lost
- Unreliable communication:
  - messages are not guaranteed to be delivered in the face of even a single packet dropped or lost
- >>> Failure

Failure in point to point comm.

- DSs expected to continue if failure has occurred:
  - message failed to arrive
  - process stopped (and others may detect this)
  - process crashed (and others cannot detect this)
- Types of failures
  - benign
    - omission, stopping, timing/performance
  - arbitrary (called Byzantine)
    - corrupt message, wrong method called, wrong result

Omission and arbitrary failures

<table>
<thead>
<tr>
<th>Class of failure</th>
<th>Affects</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fail-stop</td>
<td>process</td>
<td>Process halts and remains halted. Other processes may detect this state.</td>
</tr>
<tr>
<td>Crash</td>
<td>process</td>
<td>Process halts and remains halted. Other processes may not be able to detect this state.</td>
</tr>
<tr>
<td>Omission</td>
<td>channel</td>
<td>A message inserted in an outgoing message buffer never arrives at the other end’s incoming message buffer.</td>
</tr>
<tr>
<td>Send omission</td>
<td>process</td>
<td>A process completes a send but the message is not put in its outgoing message buffer.</td>
</tr>
<tr>
<td>Receive omission</td>
<td>process</td>
<td>A message is put in a process’s incoming message buffer, but that process does not receive it.</td>
</tr>
<tr>
<td>Arbitrary (Byzantine)</td>
<td>process or channel</td>
<td>Process/channel exhibits arbitrary behaviour: it may send/transmit arbitrary messages at arbitrary times, commit omissions; a process may stop or take an incorrect step</td>
</tr>
</tbody>
</table>

Timing

- failure can be caused because of timing:
  - No global time
  - Computer clocks
    - may have varying drift rate
    - rely on GPS radio signals (not always reliable), or synchronise via clock synchronisation algorithms
  - Event ordering (message sending, arrival)
    - carry timestamps
    - may arrive in wrong order due to transmission delays (cf email)
Types of interaction

• **Synchronous interaction model:**
  - known upper/lower bounds on execution speeds, message transmission delays and clock drift rates
  - more difficult to build, conceptually simpler model

• **Asynchronous interaction model** (more common, cf Internet, more general):
  - arbitrary process execution speeds, message transmission delays and clock drift rates
  - some problems impossible to solve (e.g. agreement)
  - if solution valid for asynchronous then also valid for synchronous.

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Java API for Datagram Comms

• Simple send/receive, with messages possibly lost/out of order
• Class `DatagramPacket`
  - packets may be transmitted between sockets
  - packets truncated if too long
  - provides `getData`, `getPort`, `getAddress`

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In the example...

• **UDP Client**
  - sends a message and gets a reply
• **UDP Server**
  - repeatedly receives a request and sends it back to the client

See textbook website for Java code

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Request-Reply Communication

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Java API for Datagram Comms

• **Class `DatagramSocket`**
  - `socket constructor` (returns free port if no arg)
  - `send` a `DatagramPacket`, non-blocking
  - `receive` `DatagramPacket`, blocking
  - `setSoTimeout` (receive blocks for time `T` and throws `InterruptedIOException`)
  - `close` `DatagramSocket`
  - throws `SocketException` if port unknown or in use

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UDP client example

```java
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);
        } catch (IOException e) {System.out.println("IO: " + e.getMessage());} } finally {
            if(aSocket != null) aSocket.close();
        }
    }
```
UDP server example

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();}
    }
}

Java API for Data Stream Comms

- **Data stream abstraction**
  - attempts to match the data between sender/receiver
  -marshaling/unmarshaling
- **Class Socket**
  - used by processes with a connection
  -`connect`, request sent from client
  -`accept`, issued from server; waits for a connect request, blocked if none available

See the API

Java API for Data Stream Comms

- **Class ServerSocket**
  - socket constructor (for listening at a server port)
  -`getInputStream`, `getOutputStream`
  -`DatagramInputStream`, `DatagramOutputStream`
  (automatic marshaling/unmarshaling)
  - `close` to close a socket
  - raises `UnknownHostException`, `IOException`, etc

In the next example...

- **TCP Client**
  - makes connection, sends a request and receives a reply
- **TCP Server**
  - makes a connection for each client and then echoes the client’s request

TCP client example

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 Sec 4.3
            String data = in.readUTF();
            System.out.println("Received: "+data);
            s.close();
        } catch (UnknownHostException e) {System.out.println("Sock:"+e.getMessage());}
        catch (EOFException e) {System.out.println("EOF:"+e.getMessage());}
        finally {if(s!=null) try {s.close();} catch (IOException e) {}}
    }
}

TCP server example

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
TCP server example ctd

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)…..}
}

Group Communication:

- Multicast: an operation that sends a single message from one process to each of the members of a group of processes
- Fault tolerance based on replicated services
- Finding the discovery servers in spontaneous networking
- Better performance through replicated data
- Propagation of event notifications

IP multicast

- multicast group is specified by a class D Internet address
  - membership is dynamic, to join make a socket
  - programs using multicast use UDP and send datagrams to multicast addresses and (ordinary) port
  (For example of Java code see book)

Summary

- some of the main issues design of Distributed systems: timing, failure and interaction architecture
- Request-Reply Communication – sockets and ports, API 4 Internet address, remote object reference
- TCP and UDP client server programming