06-06798 Distributed Systems

Lecture 4: Inter-Process Communication

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Overview

- Message passing
  - send, receive, group communication
  - synchronous versus asynchronous
  - types of failure, consequences
  - socket abstraction
- Java API for sockets
  - connectionless communication (UDP)
  - connection-oriented communication (TCP)

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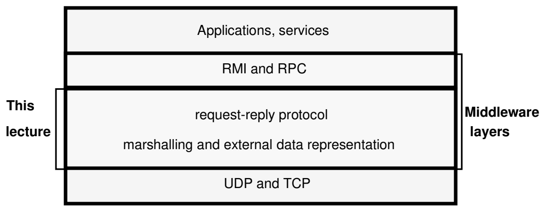
API for Internet programming...



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Inter-process communication

- Distributed systems
  - consist of components (processes, objects) which communicate in order to co-operate and synchronise
  - rely on message passing since no shared memory
- Middleware provides programming language support, hence
  - does not support low-level untyped data primitives (this is the function of operating system)
  - implements higher-level language primitives + typed data

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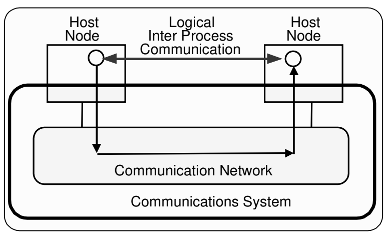
Inter-process communication



Possibly several processes on each host (use ports).
Send and receive primitives.

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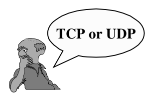
Communication service types

- Connectionless: UDP
  - 'send and pray' unreliable delivery
  - efficient and easy to implement
- Connection-oriented: TCP
  - with basic reliability guarantees
  - less efficient, memory and time overhead for error correction



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Connectionless service

UDP (User Datagram Protocol)
- messages possibly lost, duplicated, delivered out of order, without telling the user
- maintains no state information, so cannot detect lost, duplicate or out-of-order messages
- each message contains source and destination address
- may discard corrupted messages due to no error correction (simple checksum) or congestion

Used e.g. for DNS (Domain Name System) or RIP.

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Connection-oriented service

TCP (Transmission Control Protocol)
- establishes data stream connection to ensure reliable, in-sequence delivery
- error checking and reporting to both ends
- attempts to match speeds (timeouts, buffering)
- sliding window: state information includes
  - unacknowledged messages
  - message sequence numbers
  - flow control information (matching the speeds)

Used e.g. for HTTP, FTP, SMTP on Internet.

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Timing issues in DSs

- 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)

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Failure issues in DSs

- 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

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Omission and arbitrary failures

Class of failure	*Affects*	*Description*
Fail-stop	Process	Process halts and remains halted. Other processes may detect this state.
Crash	Process	Process halts and remains halted. Other processes may not be able to detect this state.
Omission	Channel	A message inserted in an outgoing message buffer never arrives at the other end's incoming message buffer.
Send-omission	Process	A process completes a *send*, but the message is not put in its outgoing message buffer.
Receive-omission	Process	A message is put in a process's incoming message buffer, but that process does not receive it.
Arbitrary (Byzantine)	Process or channel	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.

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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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Send and receive

- Send
  - send a message to a socket bound to a process
  - can be blocking or non-blocking
- Receive
  - receive a message on a socket
  - can be blocking or non-blocking
- Broadcast/multicast
  - send to all processes/all processes in a group

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Receive

- Blocked receive
  - destination process blocked until message arrives
  - most commonly used
- Variations
  - conditional receive (continue until receiving indication that message arrived or polling)
  - timeout
  - selective receive (wait for message from one of a number of ports)

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Asynchronous Send

- Characteristics:
  - unblocked (process continues after the message sent out)
  - buffering needed (at receive end)
  - mostly used with blocking receive
  - usable for multicast
  - efficient implementation
- Problems
  - buffer overflow
  - error reporting (difficult to match error with message)

Maps closely onto connectionless service.

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Synchronous Send

- Characteristics:
  - blocked (sender suspended until message received)
  - synchronisation point for both sender & receiver
  - easier to reason about
- Problems
  - failure and indefinite delay causes indefinite blocking (use timeout)
  - multicasting/broadcasting not supported
  - implementation more complex

Maps closely onto connection-oriented service.

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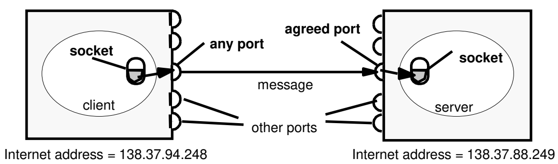
Sockets and ports



Socket = Internet address + port number.
Only one receiver but multiple senders per port.
Disadvantages: location dependence (but see Mach study, chap 18)
Advantages: several points of entry to process.

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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
  - no port sharing unless IP multicast
- Implementations
  - originally BSD Unix, but available in Linux, Windows,…
  - here Java API for Internet programming

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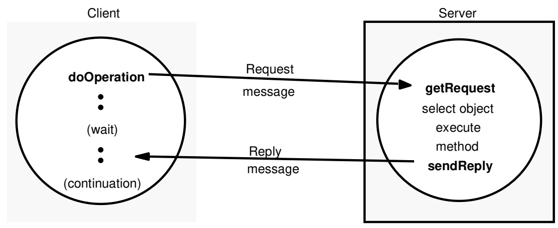
Client-Server Interaction

- Request-reply:
  - port must be known to client processes (usually published on a server)
  - client has a private port to receive replies
- Other schemes:

Name	*Messages sent by*		
	Client	*Server*	*Client*
R	*Request*		
RR	*Request*	*Reply*	
RRA	*Request*	*Reply*	*Acknowledge reply*

Request-Reply Communication



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.

Java API for Internet addresses

- Class *InetAddress*
  – uses DNS (Domain Name System)

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

32 bits	*32 bits*	*32 bits*	*32 bits*	
Internet address	port number	time	object number	interface of remote object

Java API for Datagram Comms

- Simple send/receive, with messages possibly lost/out of order
- Class *DatagramPacket*

message (=array of bytes)	message length	Internet addr	port no

– packets may be transmitted between sockets
– packets truncated if too long
– provides *getData, getPort, getAddress*

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

See textbook site cdk3.net/ipc for complete code.

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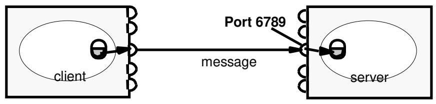
In the example...

- 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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UDP client example

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

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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();}
}
```

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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 textbook site cdk3.net/ipc for complete code.

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Java API for Data Stream Comms

- Class *ServerSocket*
  - socket constructor (for listening at a server port)
  - *getInputStream, getOutputStream*
  - *DataInputStream, DataOutputStream* (automatic marshaling/unmarshaling)
  - *close* to close a socket
  - raises *UnknownHost*, *IOException*, etc

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Data Marshaling/Unmarshaling

- Marshaling (=conversion of data into machine-independent format)
  - necessary due to heterogeneity & varying formats of internal data representation
- Approaches
  - CORBA CDR (Common Data Representation)
  - Java object serialisation, cf DataInputStream, DataOutputStream on previous and next slides

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());
           }catch (IOException e){System.out.println("IO:"+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)…..}
}
```


Summary

- IPC provides high-level language + typed data primitives:
  - socket abstraction, send/receive
  - synchronous/asynchronous communication
  - Java classes (different from operating system primitives)
  - automatic marshaling of data into machine-independent format
- For Java API to IP Multicast:
  - Class *MultiSocket* (subclass of *DatagramSocket*)
  - see textbook website for sample code