COMP3221: Distributed Systems

Communciation 2/2

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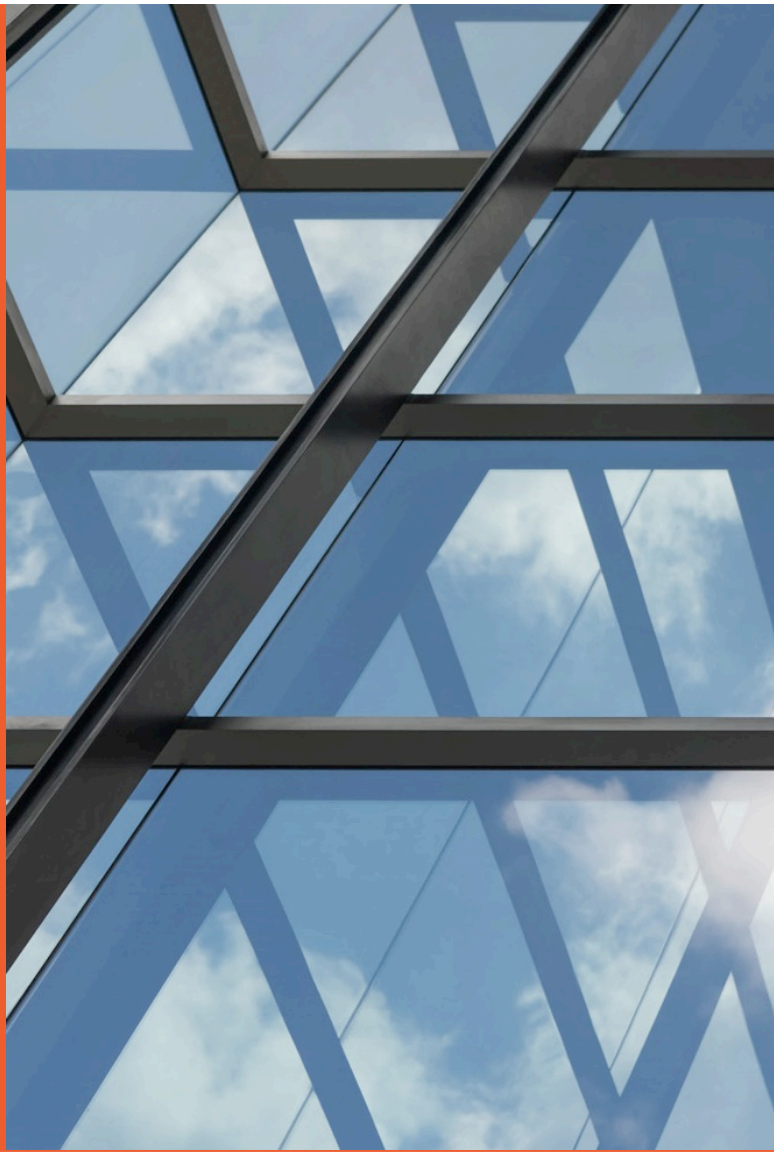

Introduction

- Previous lecture:
  - Message-based communication is complex (e.g., routing towards destination, subject to message losses)

- Today's lecture:
  - How to avoid message losses?
  - How to give the impression that everything happens locally (not remotely)?

Outilne

- The Problem of Message Loss
- The TCP/IP Solution
- Multithreaded TCP Server in Java
- Remote Procedure Call (RPC)
- Remote Method Invocation (RMI)
- RPC-like Techniques

The Problem of Message Loss

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Message loss

Cause

- Networks are in general unreliable
- Messages can be lost (never been delivered even if sent)

- Examples:
  - A server receives too many requests simultaneously so it cannot treat all
  - A router drops the message because its queue is full

Message losses may impact the computation of a distributed system

Message loss

Coordinated Attack Problem

- Constraints of the problem
  - Two armies, each led by a general on separate mountains surrounding a battlefield (distributed system)
  - Can only communicate via messengers (message passing)
  - Messengers can be killed before reaching destination (message losses)

- Goal: they want to coordinate an attack
  - If they attack at different times, they both die
  - If they attack at the same time, they win

Message loss

Coordinated Attack Problem (con't)

- There is no protocols to make sure they will win!

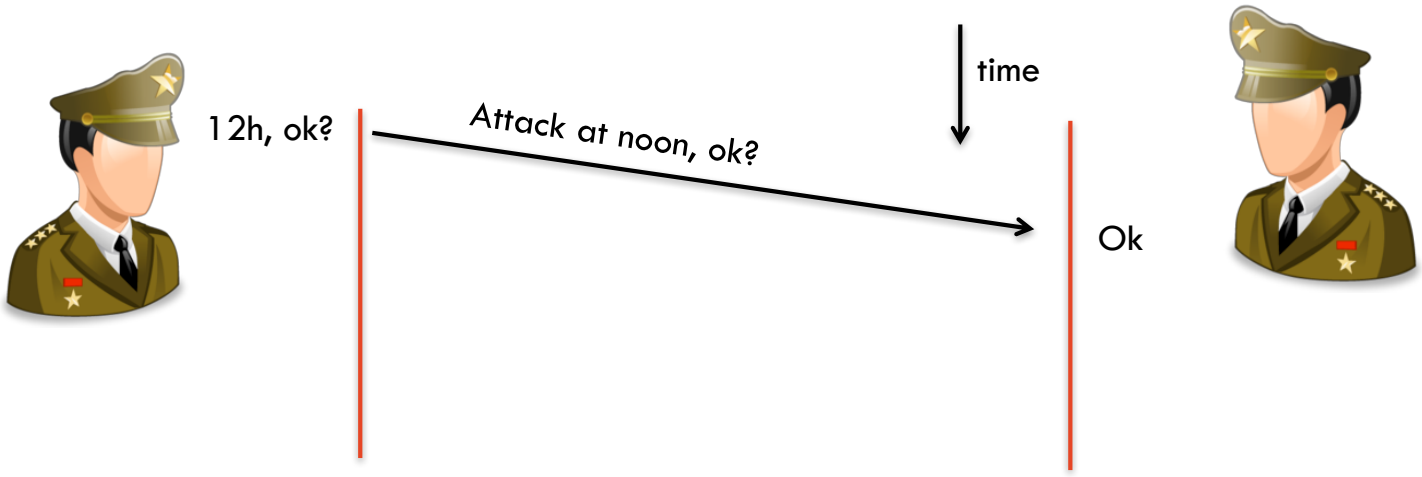
12h!

time

Message loss

Coordinated Attack Problem (con't)

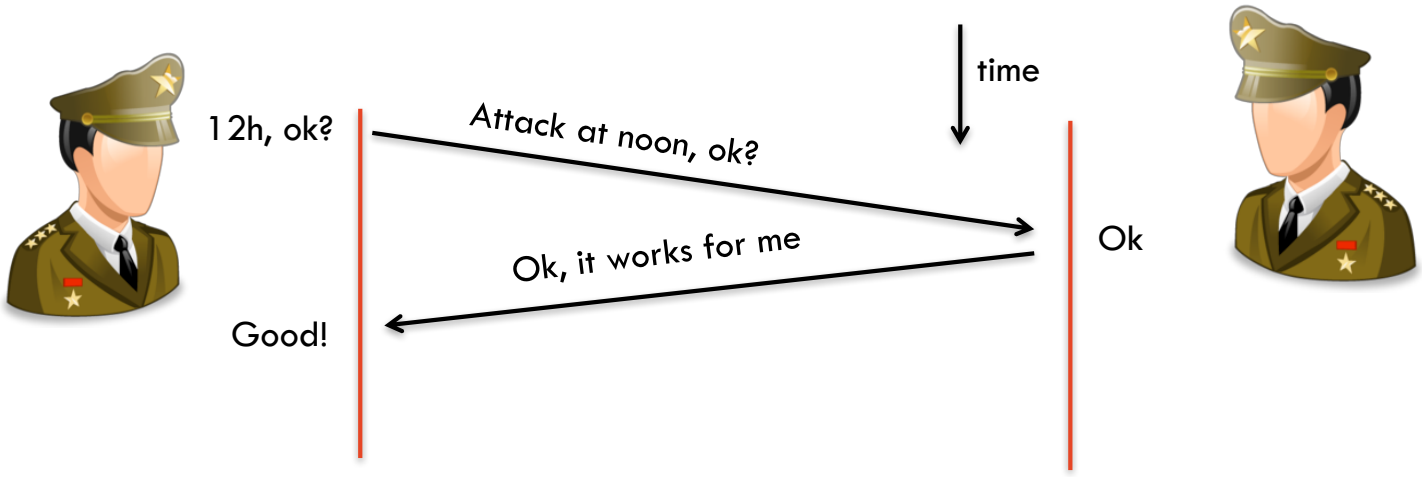
- There is no protocols to make sure they will win!



Message loss

Coordinated Attack Problem (con't)

- There is no protocols to make sure they will win!



Message loss

Coordinated Attack Problem (con't)

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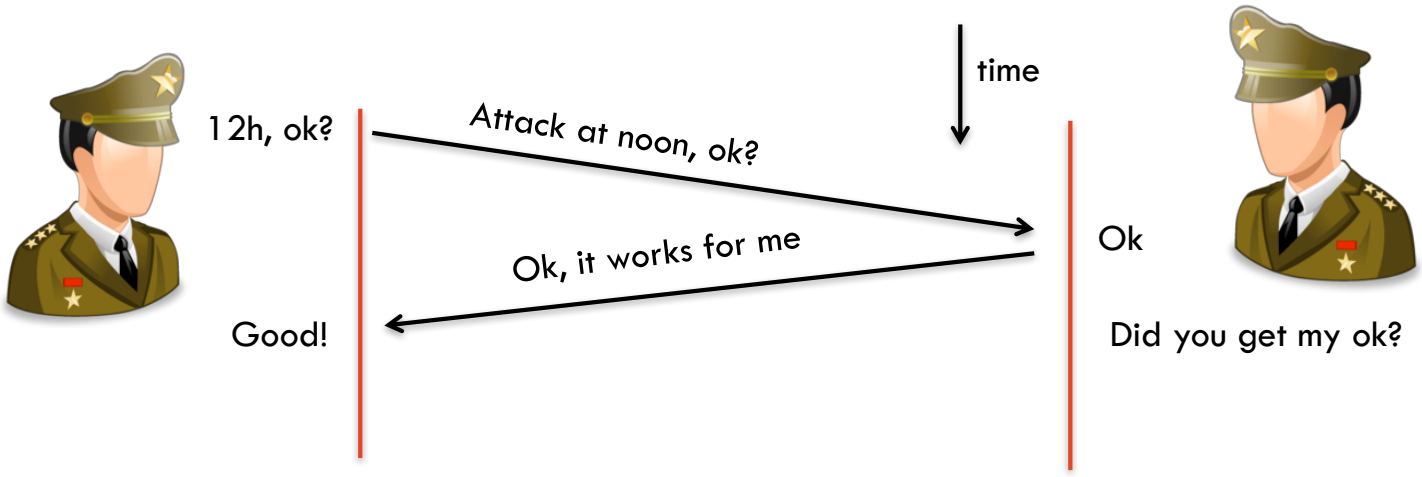
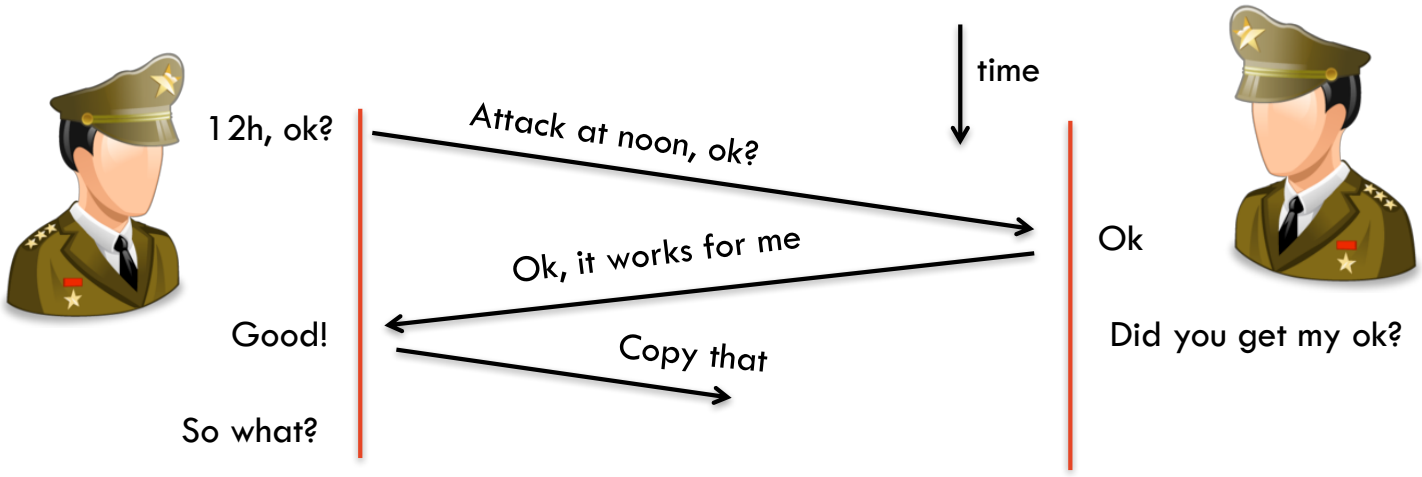


Message loss

Coordinated Attack Problem (con't)

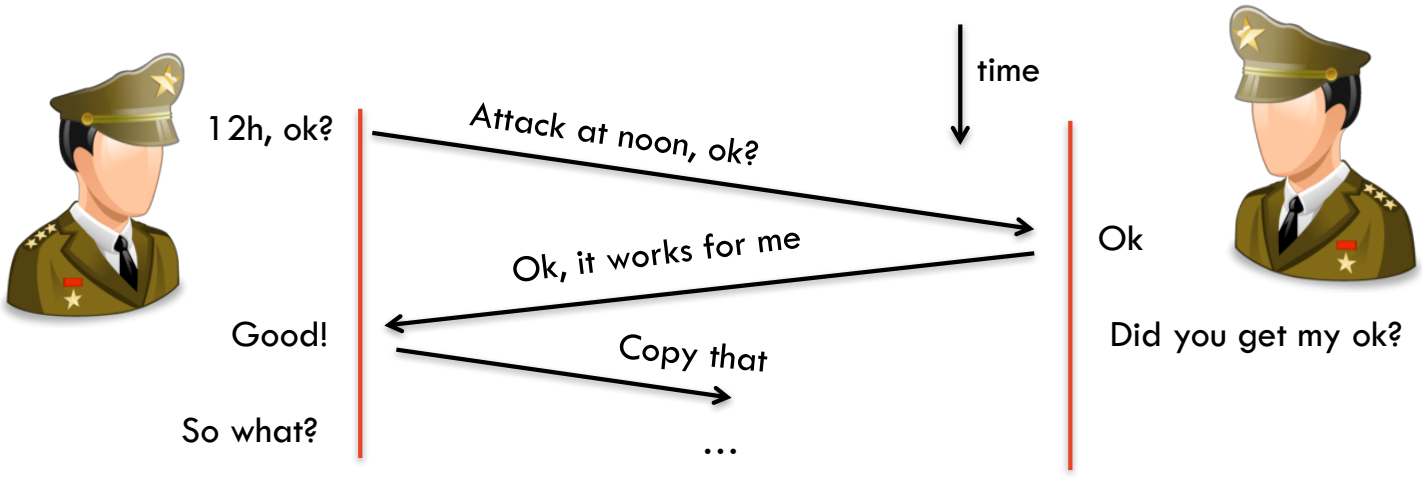
- There is no protocols to make sure they will win!



Message loss

Coordinated Attack Problem (con't)

- There is no protocols to make sure they will win!



Message loss

Analogy in networking

- Constraints of the problem
  - Two remote entities of a distributed system
  - Can only communicate through messages
  - The network is unreliable: messages can be dropped
- Goal: they want to make sure to do something simultaneously

This is impossible, even if all messages go through

TCP/IP

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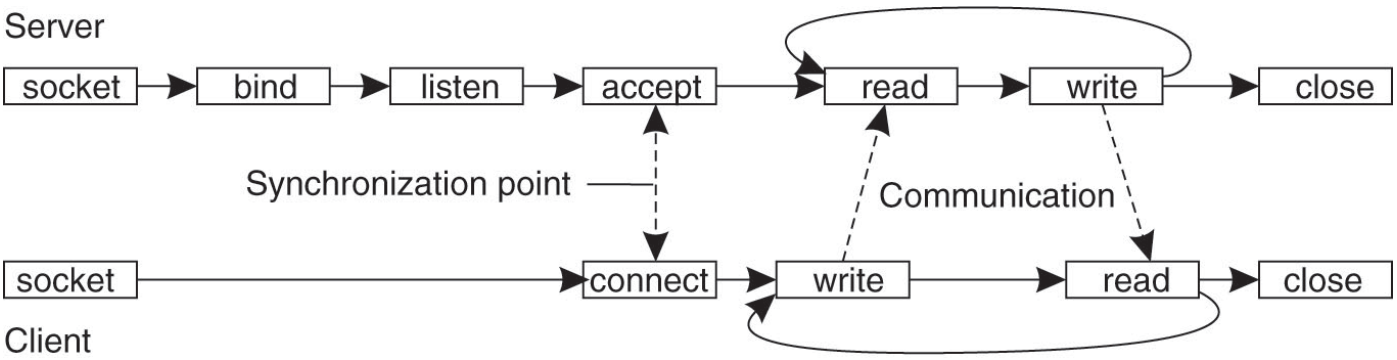
TCP/IP

TCP uses sockets

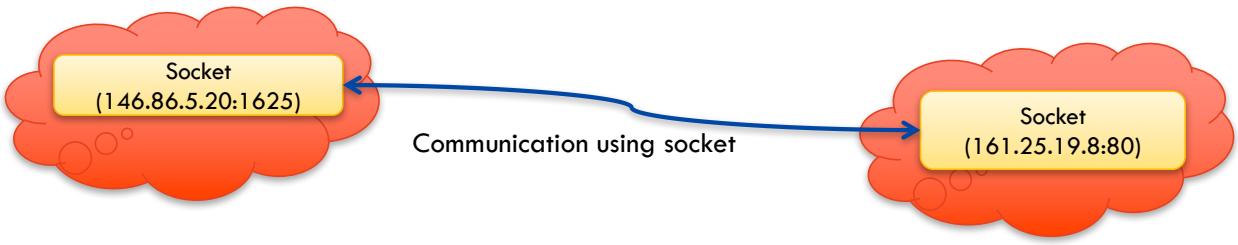
- Recall socket states



TCP/IP

TCP is connection-oriented

- Connection: simply an end-to-end agreement to perform reliable data transmission

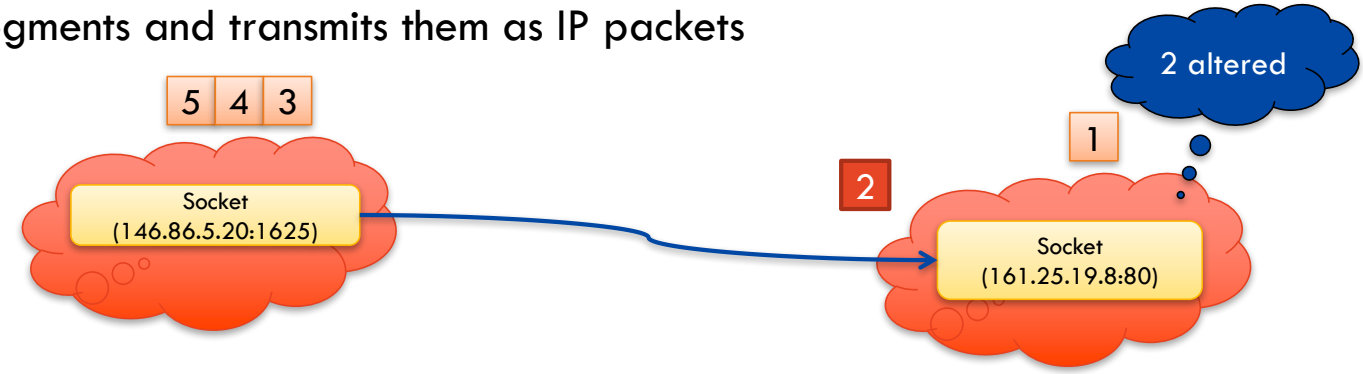


- Before any data is transferred the sending and receiving processes must cooperate in the establishment of a bidirectional communication

TCP/IP

TCP segments are numbered

- A TCP sending process divides the stream into a sequence of data segments and transmits them as IP packets

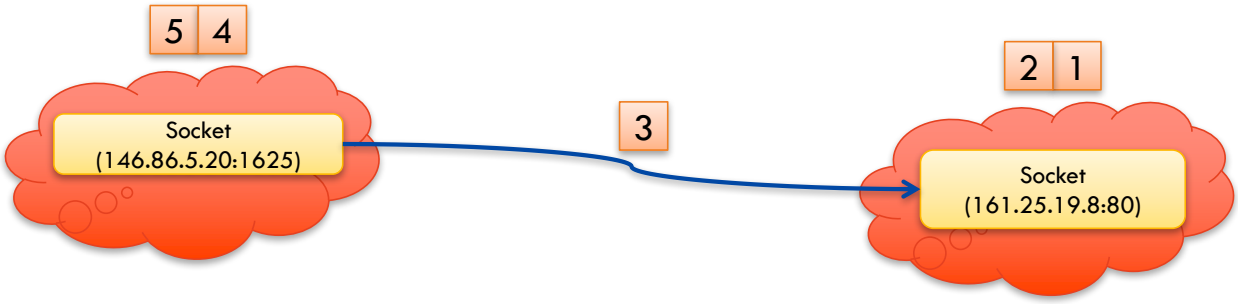


- A sequence number is attached to each TCP segment as its first byte
- A checksum is attached to the segment
- If a received segment does not match its checksum, the segment is dropped

TCP/IP

TCP segments are numbered

- A TCP sending process divides the stream into a sequence of data segments and transmit them as IP packets

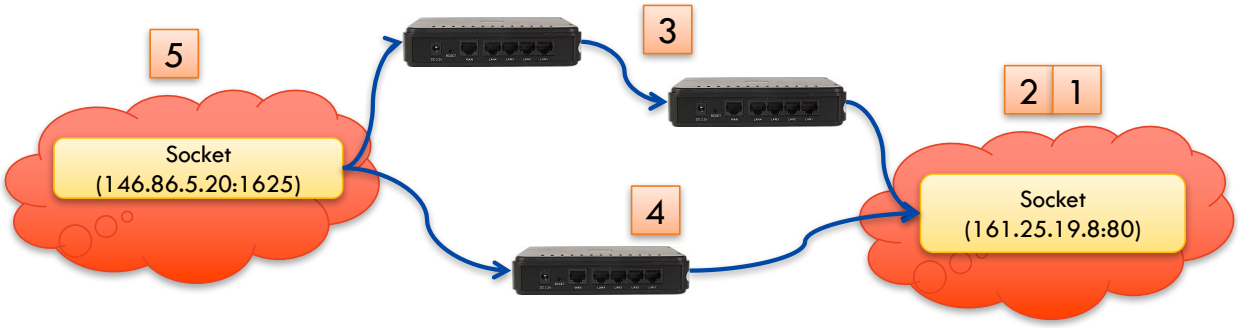


- A sequence number is attached to each TCP segment as its first byte

TCP/IP

Distinct routes per TCP connection

- Intermediate nodes have no knowledge of TCP connections

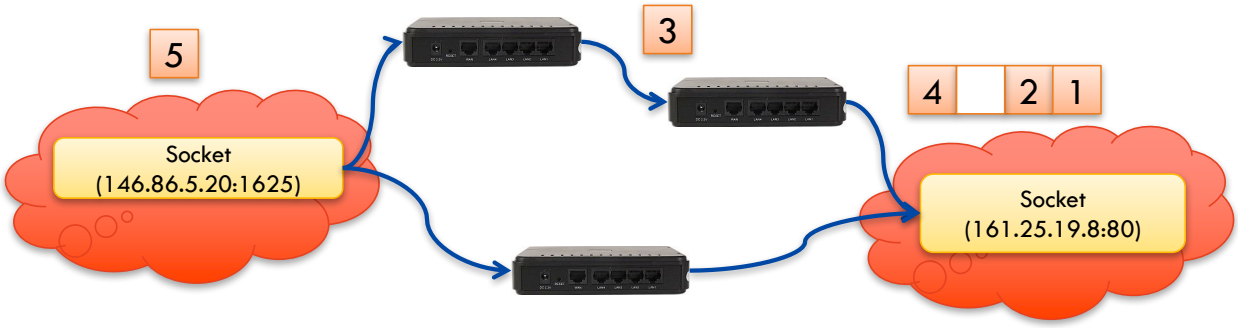


- The IP packets that transfer the data in a TCP transmission do not necessarily take all the same physical routes

TCP/IP

TCP guarantees ordered delivery

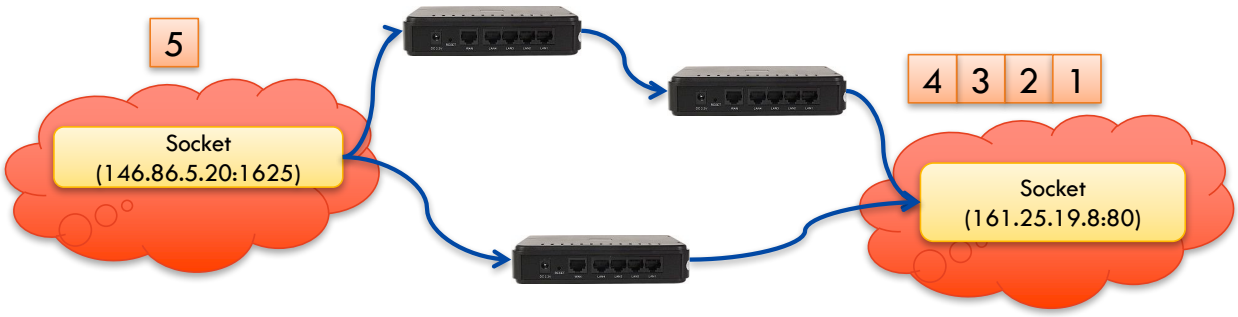
- If segments get re-ordered during the transmission



TCP/IP

TCP guarantees ordered delivery (con't)

- If segments get re-ordered during the transmission

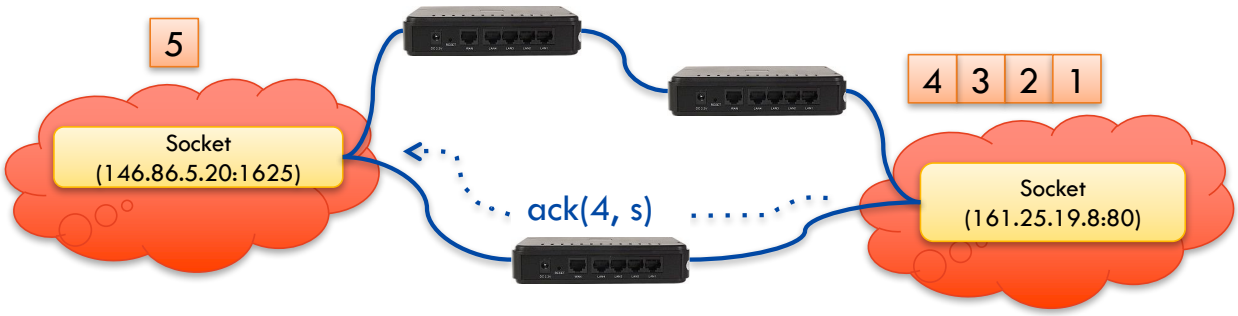


- The receiver exploits the sequence numbers to reorder segments before delivery at its higher layers

TCP/IP

TCP controls the flow

- The sender takes care not to overwhelm the receiver

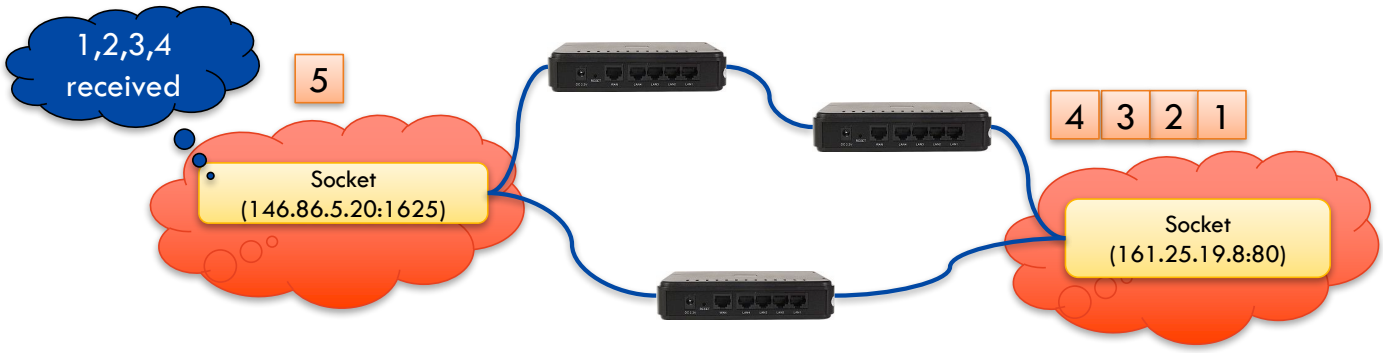


- Whenever the receiver receives a segment it records its number
- The receiver sends acknowledgments to the sender with
  - the highest number seen and
  - a window size, indicating the amount of data the sender can send before waiting for the next acknowledgment

TCP/IP

TCP ensures retransmission

- The sender records the sequence numbers of the segments it has sent



- Upon reception of an acknowledgment it notes the successful receipts and deletes the appropriate numbers
- If any segment is not acknowledged within a timeout, then the sender retransmits it

Multithreaded TCP Server in Java

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TCP/IP

TCP in Java

- A socket class provides a getInputStream and a getOutputStream for accessing the two streams associated with a socket.
- The returned abstract classes InputStream and OutputStream define the methods for reading and writing bytes

- Let's implement a client that passes data to a server that writes it on the standard output
- We will use DataOutputStream and DataInputStream to allow binary representations of primitive data types to be read and written in a machine independent manner.

TCP/IP

Example: a client/multithreaded server

- The client: creates a new socket with specified address and port

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

public class TCPClient {
   public static void main (String args[]) {
      // arguments supply message and hostname of destination  (e.g., java TCPClient msg 127.0.0.1)
      Socket s = null;
      try {
         int serverPort = 7896;
         s = new Socket(args[1], serverPort);
         DataInputStream in = new DataInputStream(s.getInputStream()); // for reading from socket
         DataOutputStream out = new DataOutputStream(s.getOutputStream()); // for writing to it
         out.writeUTF(args[0]); // UTF is a string encoding
         String data = in.readUTF();
         System.out.println("Received:" + data);
      } catch(Exception e) { System.out.println(e.getMessage());
      } finally { if (s!=null) try {s.close();} catch (IOException e) { /* close failed */ }
      }
   }
}
```

TCP/IP

Example: a client/multithreaded server

- The client: declares an input stream and an output stream

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

public class TCPClient {
   public static void main (String args[]) {
      // arguments supply message and hostname of destination  (e.g., java TCPClient msg 127.0.0.1)
      Socket s = null;
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         DataInputStream in = new DataInputStream(s.getInputStream()); // for reading from socket
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      }
   }
}
```

TCP/IP

Example: a client/multithreaded server

- The client: reads (receives) and writes (sends) from these streams

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

public class TCPClient {
   public static void main (String args[]) {
      // arguments supply message and hostname of destination  (e.g., java TCPClient msg 127.0.0.1)
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      } finally { if (s!=null) try {s.close();} catch (IOException e) { /* close failed */ }
      }
   }
}
```

TCP/IP

Example: a client/multithreaded server

- The client: catches exception in case of unreachable server or network issue

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

public class TCPClient {
   public static void main (String args[]) {
      // arguments supply message and hostname of destination  (e.g., java TCPClient msg 127.0.0.1)
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      try {
         int serverPort = 7896;
         s = new Socket(args[1], serverPort);
         DataInputStream in = new DataInputStream(s.getInputStream()); // for reading from socket
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      } finally { if (s!=null) try {s.close();} catch (IOException e) { /* close failed */ }
      }
   }
}
```

TCP/IP

Example: a client/multithreaded server

- The client: in any case closes the connection at the end

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

public class TCPClient {
   public static void main (String args[]) {
      // arguments supply message and hostname of destination  (e.g., java TCPClient msg 127.0.0.1)
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      } catch(Exception e) { System.out.println(e.getMessage());
      } finally { if (s!=null) try {s.close();} catch (IOException e) { /* close failed */ }
      }
   }
}
```

TCP/IP

Example: a client/multithreaded server (con't)

- The server: creates a socket with port number (no address required)

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

public class TCPServer {
   public TCPServer() {
      try {
         int serverPort = 7896;
         ServerSocket listenSocket = new ServerSocket(serverPort);
         while (true) {
            Socket clientSocket = listenSocket.accept();                // accept client connection
            Thread t = new Thread(new Connection(clientSocket)); // one thread per connection
            t.start();
         }
      } catch (IOException e) { System.out.println(e.getMessage()); }
   }

   public static void main (String args[]) { TCPServer srv = new TCPServer(); }
}
```

TCP/IP

Example: a client/multithreaded server (con't)

- The server: spawns a new thread to treat the request concurrently

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

public class TCPServer {
   public TCPServer() {
      try {
         int serverPort = 7896;
         ServerSocket listenSocket = new ServerSocket(serverPort);
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       } catch (IOException e) { System.out.println(e.getMessage()); }
   }

   public static void main (String args[]) { TCPServer srv = new TCPServer(); }
}
```

TCP/IP

Example: a client/multithreaded server (con't)

- A thread: inits streams

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

class Connection implements Runnable {
        DataInputStream in;
        DataOutputStream out;
        Socket clientSocket;

        public Connection(Socket aClientSocket) {
          try {
                clientSocket = aClientSocket;
                in = new DataInputStream(clientSocket.getInputStream()); // for reading from socket
                out = new DataOutputStream(clientSocket.getOutputStream()); // for writing to it
          } catch (IOException e) { System.out.println(e.getMessage()); }
        }

        public void run() {
          try {
                String data = in.readUTF();
                out.writeUTF(data);
          } catch (Exception e) { System.out.println(e.getMessage());
          } finally { if (clientSocket!=null) try {clientSocket.close();} catch (IOException e) { /* close failed */ }
          }
        }
}
```

TCP/IP

Example: a client/multithreaded server (con't)

- A thread: reads/writes

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

class Connection implements Runnable {
        DataInputStream in;
        DataOutputStream out;
        Socket clientSocket;

        public Connection(Socket aClientSocket) {
          try {
                clientSocket = aClientSocket;
                in = new DataInputStream(clientSocket.getInputStream()); // for reading from socket
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          } catch (IOException e) { System.out.println(e.getMessage()); }
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        public void run() {
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          } catch (Exception e) { System.out.println(e.getMessage());
          } finally { if (clientSocket!=null) try {clientSocket.close();} catch (IOException e) { /* close failed */ }
          }
        }
}
```

Remote Procedure Call (RPC)

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Conventional procedure call

Conventional Procedure Call

- Call-by-value: a value is simply an initialized local variable. Potential modifications within the called procedure do not affect the value outside the procedure scope.

- Call-by-reference: a reference is a *pointer* (i.e., address) of a variable. If the called procedure modifies the value located at the memory address pointed by the reference, then this change will be visible outside the scope of the procedure (e.g., from the caller).

- Call-by-copy/restore: the variable is copied to the stack by the caller, as in call-by-value, and then copied back after the call, overwriting the caller's original value. The value is not propagated immediately but upon return.

Conventional procedure call

Conventional Procedure Call (con't)

- Example: (a) a combination of call-by-reference and call-by-value in C
  - Integer i is passed by value
  - Character c is passed by reference

```
void procedure(int i, char *c) {
   i = 1;  c[0]='A';
}

int main(int argc, char *argv[])  {
   int i = 0;
   printf("Before call: i=%d, argv[0][0]=%c\n", i, argv[0][0]);
   procedure(i, argv[0]);
   printf("After call: i=%d, argv[0][0]=%c\n", i, argv[0][0]);
   return 0;
}
```

(a) Code of proc.c

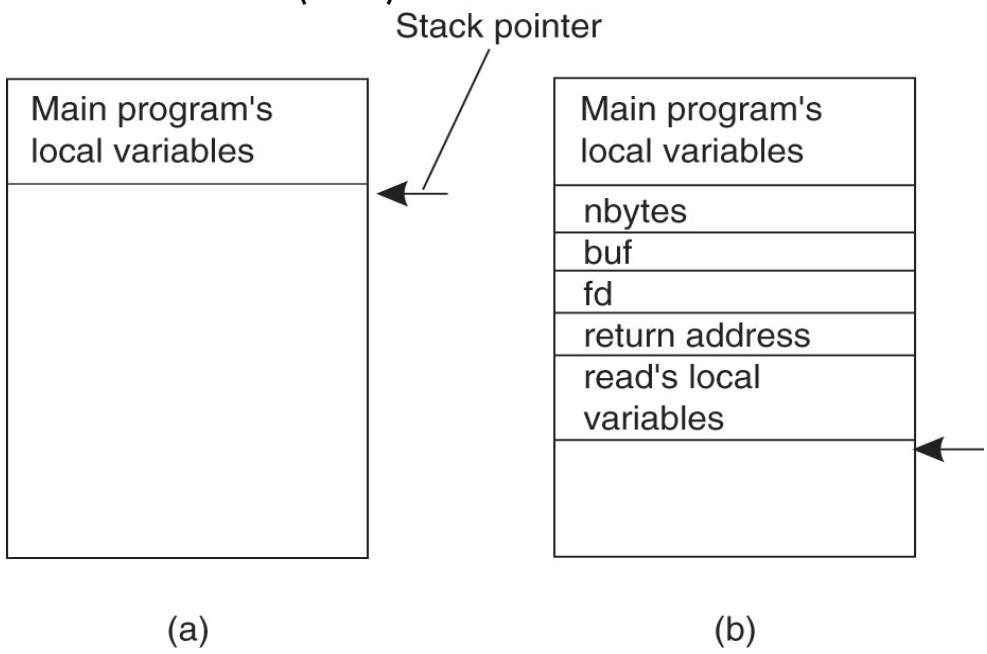
```
> gcc –o proc proc.c
> ./proc
Before call: i=0, argv[0][0]=.
After call: i=0, argv[0][0]=A
```

(b) Execution of proc.c

- (b) Changes to 'c' are visible outside the procedure, changes to i are not.

Conventional procedure call

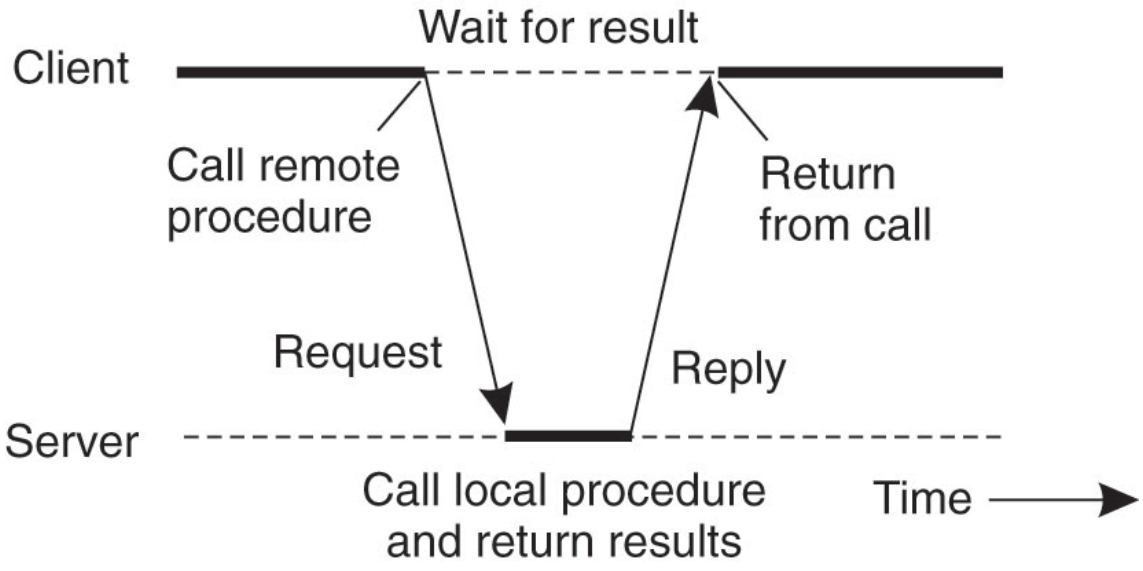
Conventional Procedure Call (con't)



- (a) The stack before the call to the read procedure
- (b) The stack while the called procedure is active

RPC

Client and server interaction



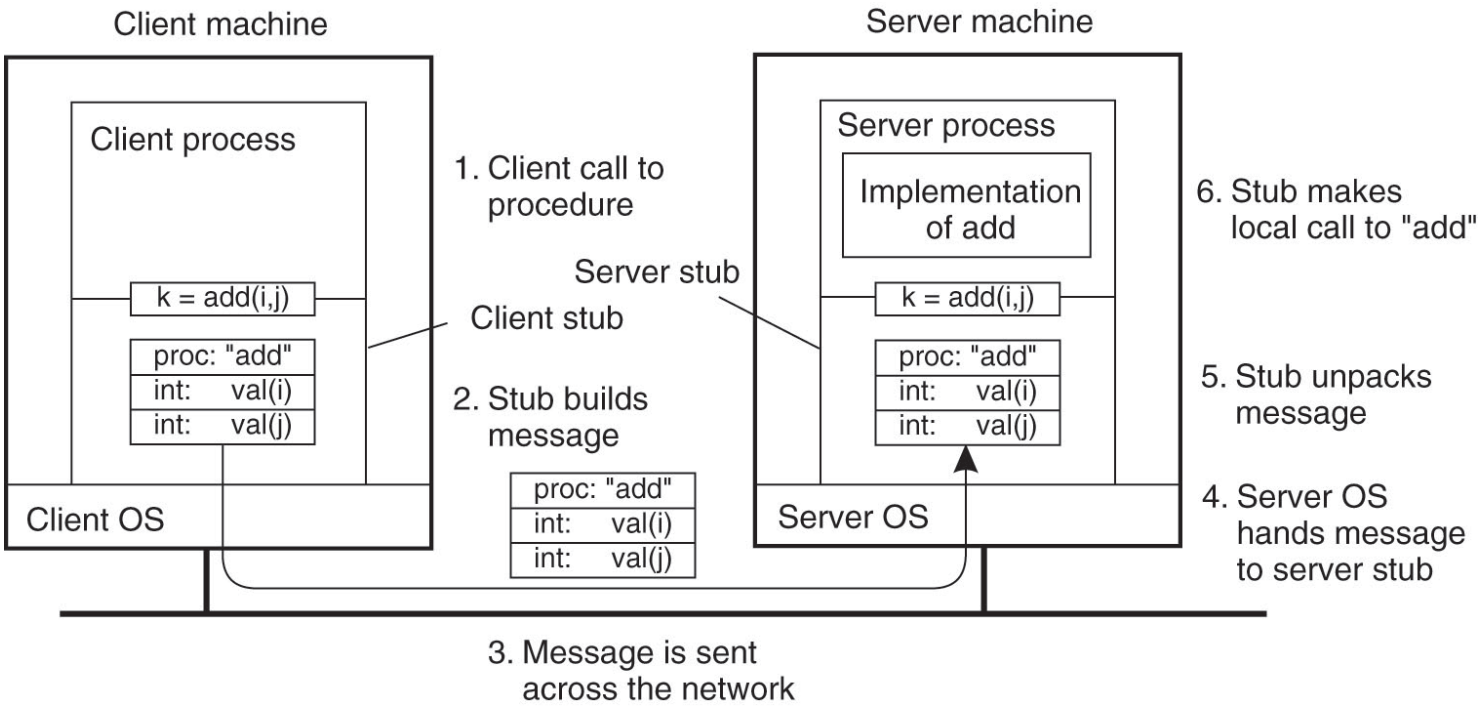
RPC

A remote procedure call occurs in the following steps:

1. The client procedure calls the client stub in the normal way.
2. The client stub builds a message and calls the local operating system.
3. The client's OS sends the message to the remote OS.
4. The remote OS gives the message to the server stub.
5. The server stub unpacks the parameters and calls the server.
6. The server does the work and returns the result to the stub.
7. The server stub packs it in a message and calls its local OS.
8. The server's OS sends the message to the client's OS.
9. The client's OS gives the message to the client stub.
10. The stub unpacks the result and returns to the client.

Passing parameters

Remote procedure call example: add(int i, int j) which sums up 2 integers, i+j.



Passing parameters

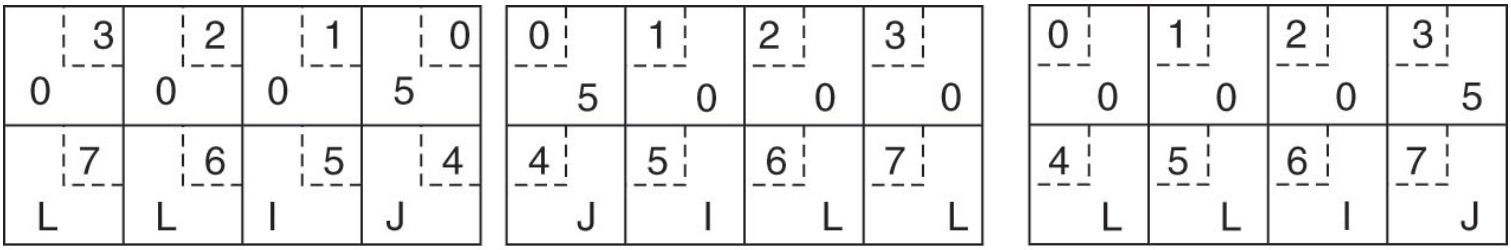
Parameter marshalling: packing parameters into a message.

1. The client stub marshals the following into a message before sending it:
   - The two parameters, i and j,
   - The identifier (name or number) of the procedure 'add' to be called.
2. The server stub unmarshals the message and calls the procedure on the server
3. Once done, the server stub marshals the result i+j to send it back
4. The client stub unmarshals this message and returns to the client

Passing parameters

Why the type (e.g., integer, string) information must be sent

- Different architectures may have different data representations:
  - SPARC (<v9) uses the *big endian* format to number bytes (numbered from left to right)
  - x86 uses the *little endian* format to number bytes (numbered from right to left)



(a) (b) (c)

- (a) original message sent from the Intel Pentium (x86) reads 5 and "JILL"
- (b) message after reception on the SPARC: it reads $5*2^{24}$ and "JILL"
- (c) message after inversion is still incorrect: it reads 5 and "LLIJ"
- Hence the need for specifying types (integer or string).

Passing parameters

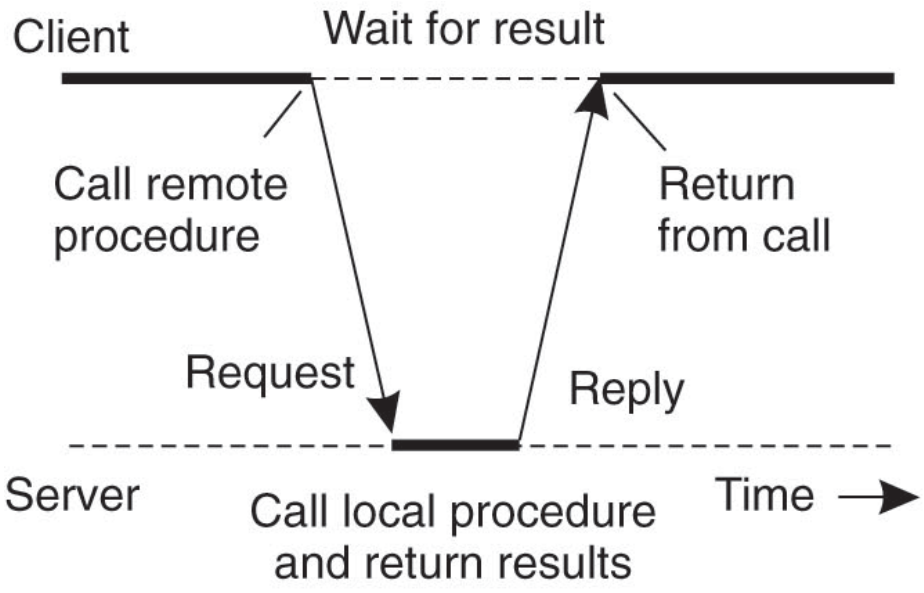
Passing reference parameters in a RPC

- Reference is only meaningful within a given address space
- Different processes have different address spaces
  - on the client, address 1000 may points the argv[0][0] while
  - on the server, address 1000 may point to somewhere in the program text
- The solution is to call-by-copy/restore instead of call-by-reference
  - The client stub marshalls the pointer and the value it points to into the message
  - The server stub unmarshalls the message determines the pointer that points to this value (which may be different) and call the procedure on the server
  - If the server modified the value located at this pointer, then the modifications are visible from the stub
  - Once the result message is sent back to the client stub, it is copied to the client

Synchronous RPC

Synchronous RPC

- Interaction between client and server in a normal (synchronous) RPC

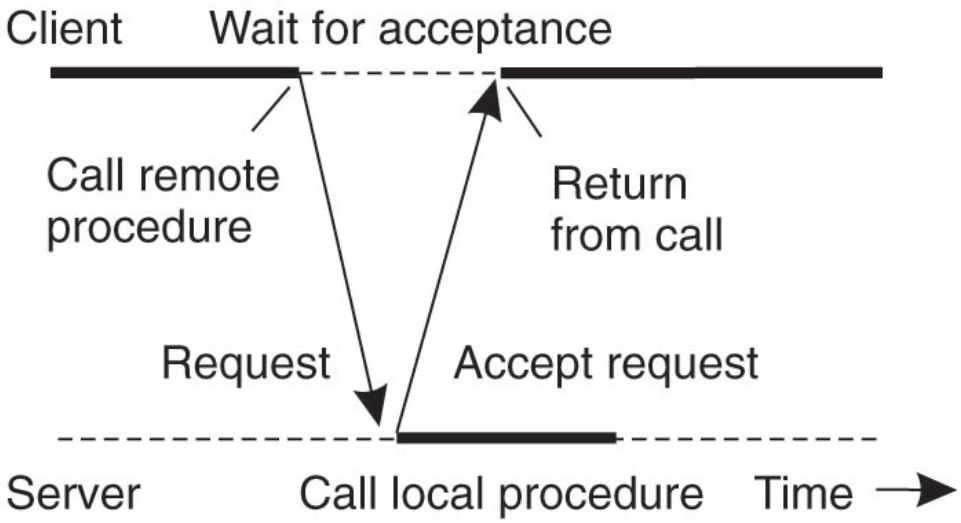


(a)

Asynchronous RPC

Asynchronous RPC

- Interaction with an asynchronous RPC: e.g., when no result is returned

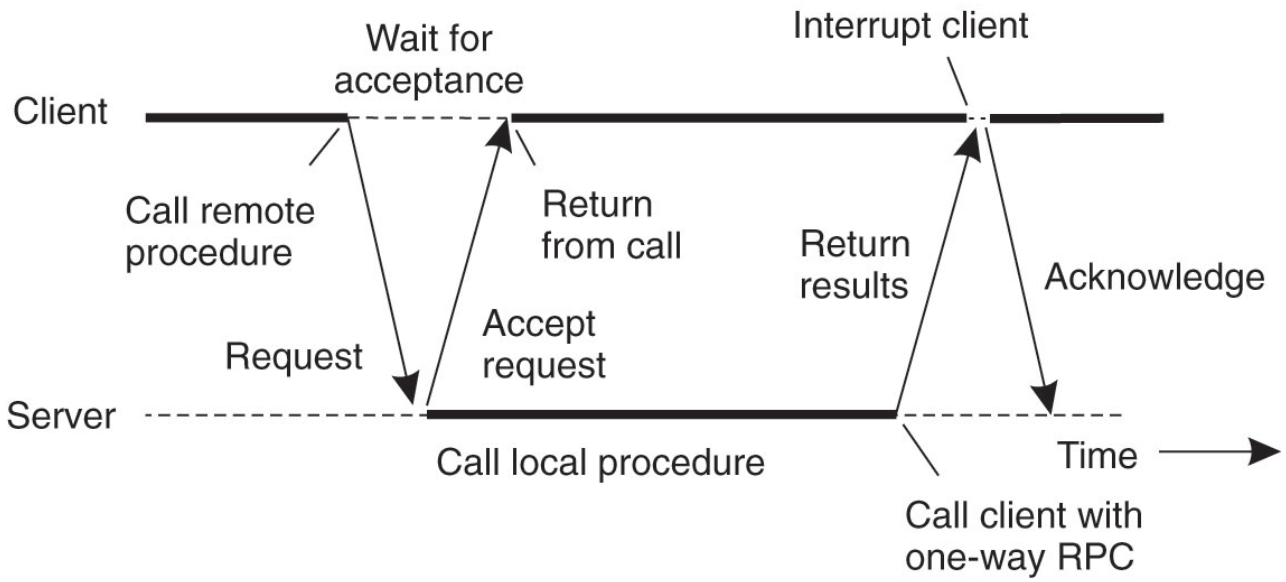


(b)

Asynchronous RPC

Asynchronous RPC

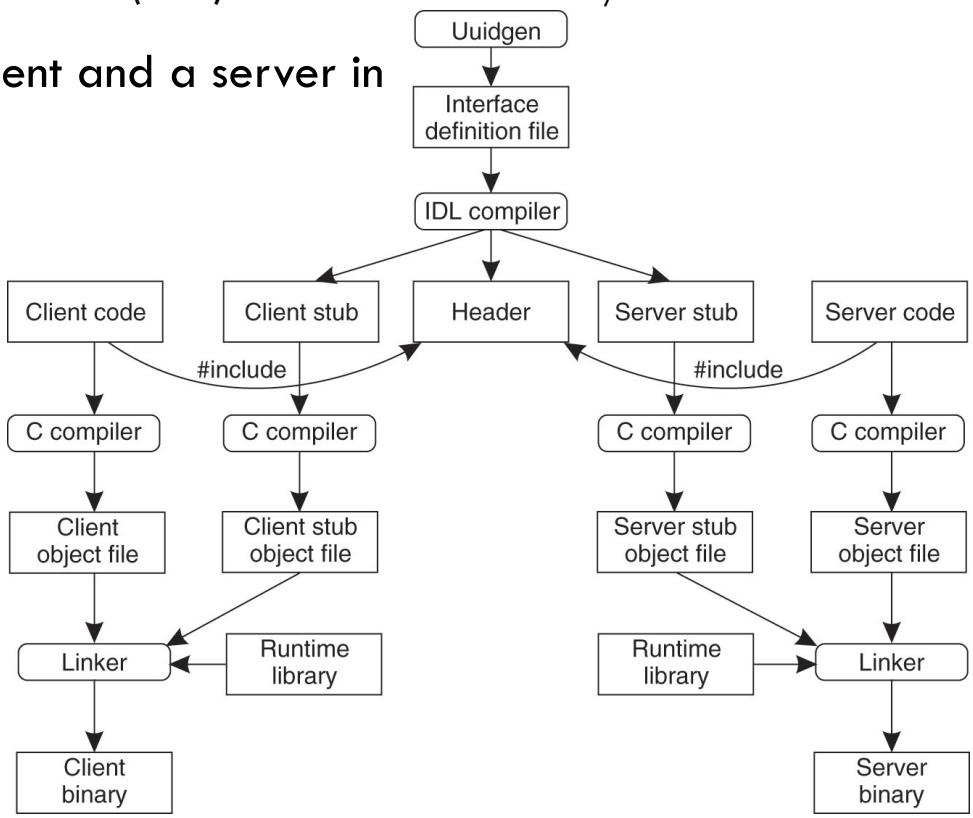
- Interaction through two asynchronous RPCs: with deferred returned result



Distributed Computing Environment

Distributed Computing Environment (DCE): middleware for UNIX/Windows…

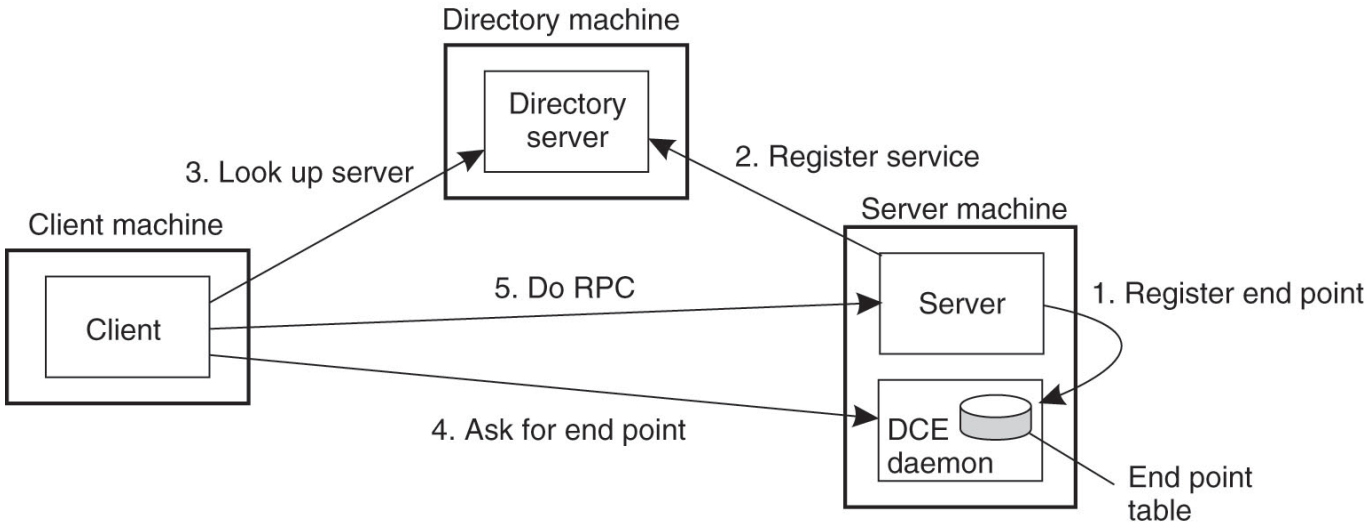
- Steps in writing a client and a server in DCE/RPC



Distributed Computing Environment

Distributed Computing Environment (DCE)

- Client and server binding:
  - Locate server: using a directory machine indicating which server runs the service



Remote Method Invocation (RMI)

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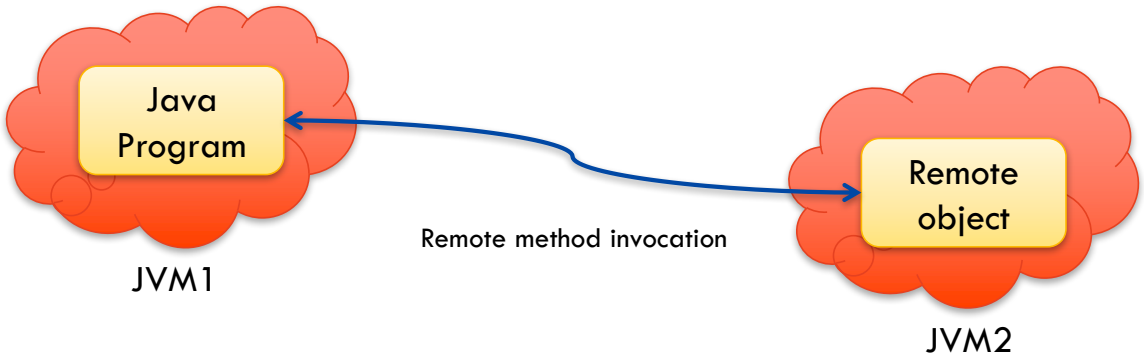
RMI

RMI: A Java feature similar to RPC

- An RMI allows a thread to invoke a method on a remote object
- A *remote object* is an object residing in a different Java Virtual Machine (JVM)



RMI

Two main differences between RMI and RPC

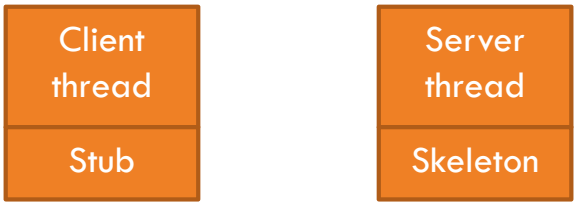
1. Procedure vs. method
   - RPC is procedural: only functions or procedures may be called
   - RMI is object-based: invocation of methods on remote objects

2. Data structures vs. primitive data types
   - RPC parameters are generally data structures
   - RMI parameters can be primitive data types (e.g., int, boolean) as well as objects

RMI

RMI steps

- *Stub*: a proxy for the remote object that resides at the client
- *Skeleton:* responsible for unmarshalling the message on the server-side
- *Parcel:* the name of the method and the marshalled parameters



1. The client-side stub creates the parcel, sends it to the server
2. The skeleton unmarshals the parameters and invokes the desired method on the server
3. The skeleton marshals the return value (or the exception, if any) into a parcel and returns this parcel
4. The stub unmarshals the return value and passes it to the client

RMI

Passing parameters

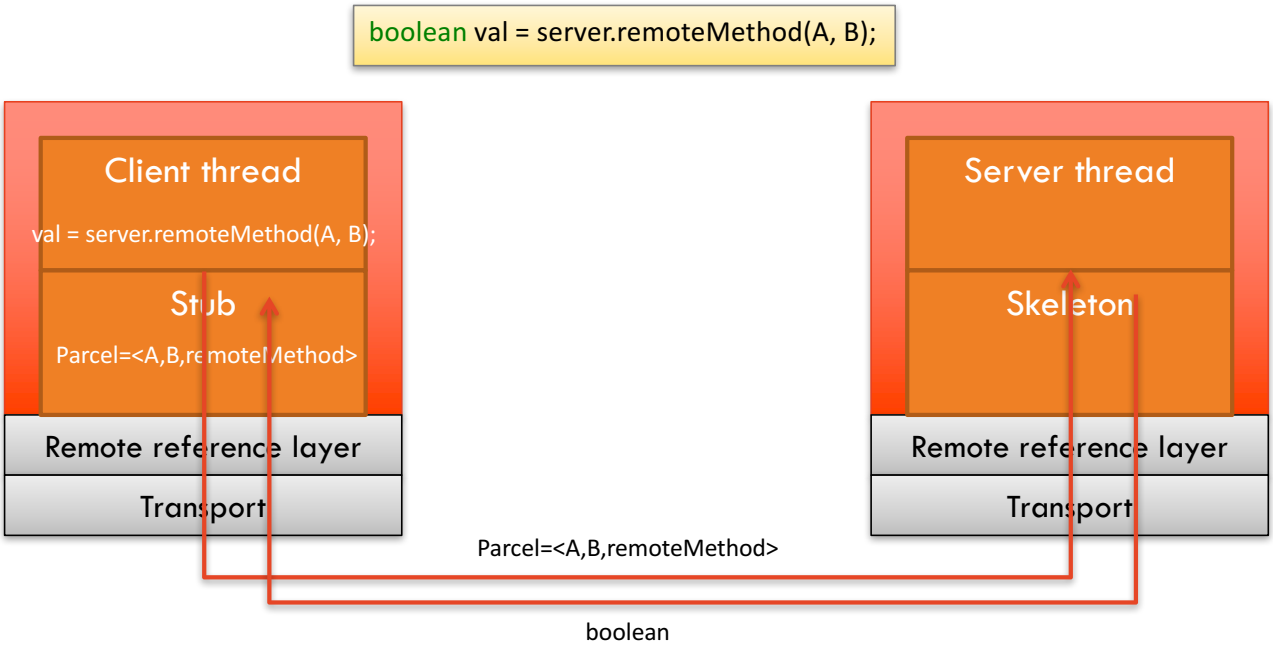
- Call-by-copy/restore:
  - Local (or non-remote) objects are passed by copy using object serialization
  - The local object must implements the java.io.serializable interface (most of them do)

- Call-by-reference:
  - Remote objects are passed by reference
  - It allows the receiver to alter the state of the remote object as well as invokes its remote methods

RMI

Example: a client invokes remoteMethod(Object, Object) returning a boolean

- Client executes the following statement:



RMI

Example: a date server program using RMI

- The RemoteDate interface: specifies the methods that can be invoked remotely.

```
import java.rmi.*;
import java.util.Date;

public interface RemoteDate extends Remote {
   public Date getDate() throws RemoteException;
}
```

- In our example, only the method getDate() can be called remotely
- All methods declared in the interface must throw the exception java.rmi.RemoteException
- The class that defines the remote object must implement the remote interface

RMI

Example: a date server program using RMI (con't)

- Implementation of the RemoteDate interface: the class must extend the UnicastRemoteObject for listening to request using RMI default sockets

```
import java.rmi.*;
import java.rmi.server.UnicastRemoteObject
import java.util.Date;

public class RemoteDateImpl extends UnicastRemoteObject implements RemoteDate {
  public RemoteDateImp() throws RemoteException { }

  public Date getDate() throws RemoteException {
    return new Date();
  }

  public static void main(String args[]) {
    try {
      RemoteDate dateServer = new RemoteDateImpl();
      // Bind this object instance to the name "RMIDateObject"
       Naming.rebind("RMIDateObject", dateServer);
    } catch (Exception e) { System.err.println(e); }
  }
}
```

RMI

Example: a date server program using RMI (con't)

- The main method creates an instance of the object and registers with the RMI registry running on the server via rebind() method

```
import java.rmi.*;
import java.rmi.server.UnicastRemoteObject
import java.util.Date;

public class RemoteDateImpl extends UnicastRemoteObject implements RemoteDate  {
   public RemoteDateImp() throws RemoteException { }

   public Date getDate() throws RemoteException {
     return new Date();
   }

   public static void main(String args[]) {
      try {
         RemoteDate dateServer = new RemoteDateImpl();
         // Bind this object instance to the name "RMIDateObject"
          Naming.rebind("RMIDateObject", dateServer);
      } catch (Exception e) { System.err.println(e); }
   }
}
```

RMI

Example: a date server program using RMI (con't)

- A default constructor must be created, it throws a RemoteException if a communication problem prevents the remote object from being exported

```
import java.rmi.*;
import java.rmi.server.UnicastRemoteObject
import java.util.Date;

public class RemoteDateImpl extends UnicastRemoteObject implements RemoteDate  {
  public RemoteDateImp() throws RemoteException { }

  public Date getDate() throws RemoteException {
    return new Date();
  }

  public static void main(String args[]) {
    try {
      RemoteDate dateServer = new RemoteDateImpl();
      // Bind this object instance to the name "RMIDateObject"
       Naming.rebind("RMIDateObject", dateServer);
    } catch (Exception e) { System.err.println(e); }
  }
}
```

RMI

Example: a date server program using RMI (con't)

- The RMI client: gets a proxy reference to the (rebound) object from the RMI registry running on the server with a URL lookup scheme

```
import java.rmi.*;

public class RMIClient {
  static final String server = "127.0.0.1";

  public static void main(String args[]) {
    try {
      String host = "rmi://" + server + "/RMIDateObject";

      RemoteDate dateServer = (RemoteDate)Naming.lookup(host);
      System.out.println(dateServer.getDate());
    }
    catch (Exception e) {
      System.err.println(e);
    }
  }
}
```

RMI

Example: a date server program using RMI (con't)

- The RMI client: once it has the proxy reference of the object, it invokes the remote method getDate(); lookup and remote method may throw exception

```
import java.rmi.*;

public class RMIClient {
   static final String server = "127.0.0.1";

   public static void main(String args[]) {
      try {
         String host = "rmi://" + server + "/RMIDateObject";

         RemoteDate dateServer = (RemoteDate)Naming.lookup(host);
         System.out.println(dateServer.getDate());
      }
      catch (Exception e) {
        System.err.println(e);
      }
   }
}
```

RMI

Example: a date server program using RMI (con't)

- Executing on the same machine:
  - The registry should be started and run in the background using
    - rmiregistry & (on unix-like machines)
    - start rmiregistry (on windows)
- An instance of the remote object has now to be created using
    - java RemoteDateImpl
- Start the client that will get a proxy reference to the remote object
    - java RMIClient

```
> rmiregistry &
> java RemoteDateImpl
> java RMIClient
```

Backup

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RPC-like Techniques

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RPC-like techniques

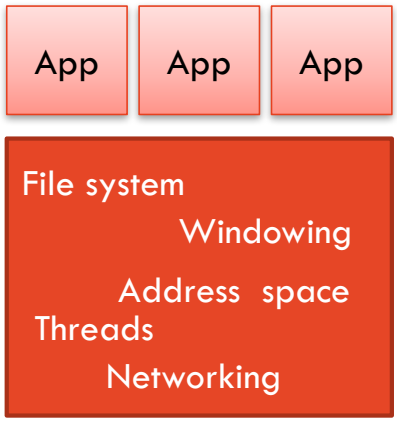
RPC-like techniques vs. Sockets

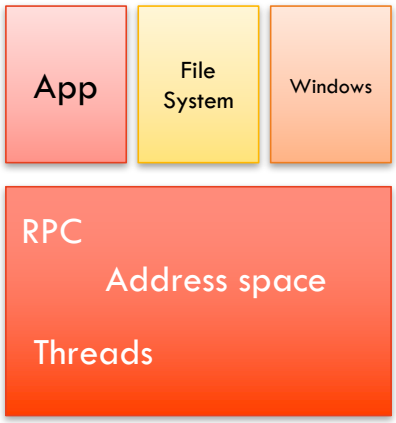
- Sockets must manage the socket connection, including opening and closing the socket and establishing an InputStream and OutputStream to read from and write to the socket
- The design of the client using RMI is much simpler, it must simply get a proxy for the remote object, to invoke the remote method as it would invoke an ordinary local method

- Other RPC-like techniques (besides RPC and RMI)
  - CORBA (Common Object Request Broker Architecture)
  - DCOM (Distributed COM)

RPC-like techniques

Application: Microkernel operating system





- Monolithic structure
  - 2 Levels: lots of stuff running in kernel mode (Windowing in kernel in Windows for perf reason)
  - Applications running in user mode
  - One faulty component crashes the system

- Microkernel structure
  - Thread package, address space, RPC mechanisms run in kernel mode
  - File system runs at user level
  - Bugs are isolated
  - Clean API: components can be migrated

Conclusion

- Message losses can have dramatic consequences
- TCP/IP protocol suite hides these losses from the application level
- Socket, RPC, RMI use TCP/IP
  - Sockets are complex
  - RPC and RMI are more transparent for the client