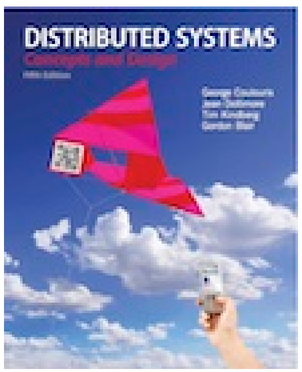
Slides for Chapter 4: Interprocess Communication



From Coulouris, Dollimore, Kindberg and Blair

Distributed Systems: Concepts and Design

Edition 5, © Addison-Wesley 2012

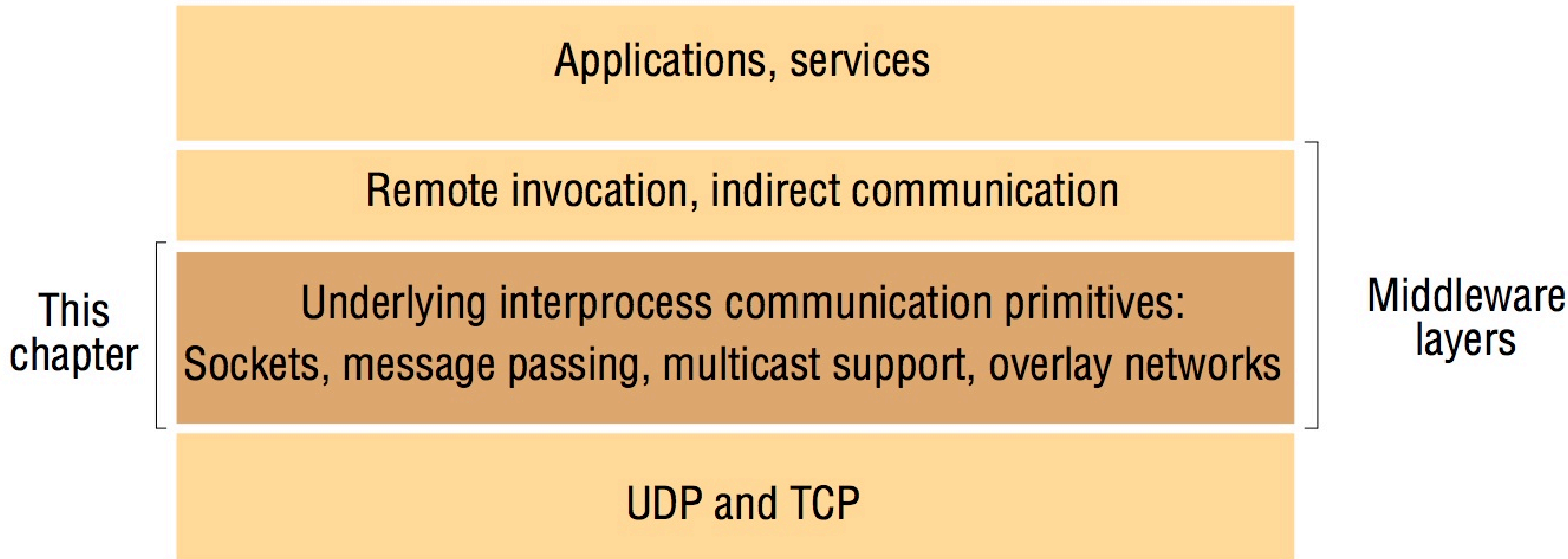
Next 2 Chapters: Communication Aspects of MW

- Chap 4: IPC
  - API for Internet protocols
  - External data representation and marshalling
  - Multicast communications
  - Network virtualization: overlay networks
  - Case Study: MPI
- Chapter 5: Remote invocation paradigms
  - Request-reply protocols
  - Remote procedure call
  - Remove method invocation
  - Case study: Java RMI

API for Internet Protocols [4.2]

- 4.2.1: How to implement send/receive of Sec 2.3.2
- 4.2.2: Sockets
- 4.2.3: UDP in Java
- 4.2.4: TCP in Java

Figure 4.1
Middleware layers



- APIs for Internet protocols
  - UDP: **message passing** abstraction (incl. multicast)
  - TCP: **stream processing**

Characteristics of IPC [4.2.1]

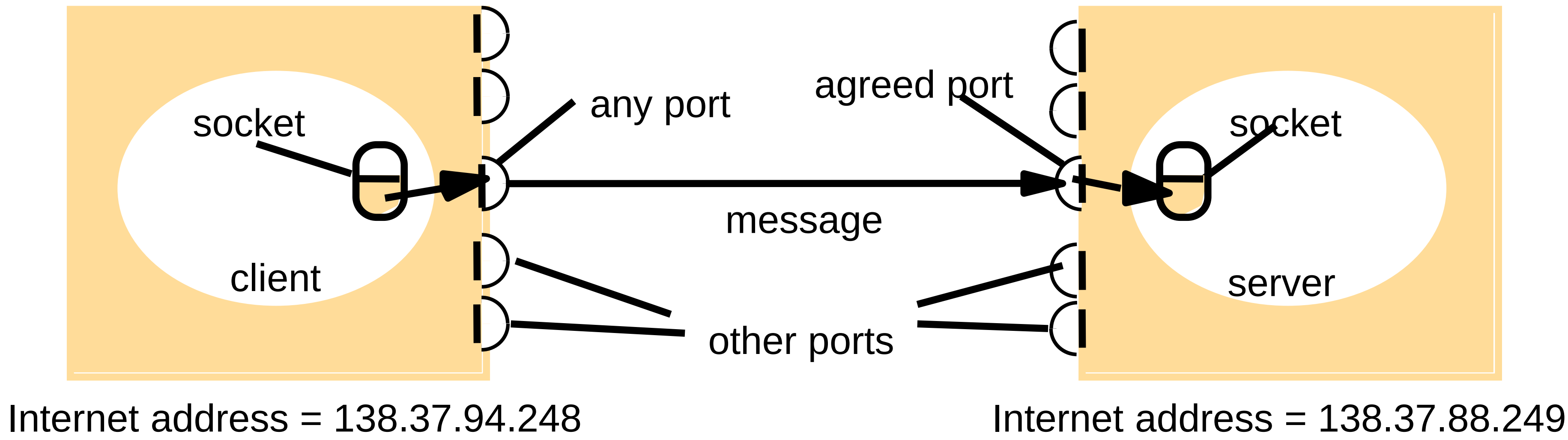
- Message passing supported by send+receive to endpoints ("message destination" in text)
- **Synchronous** and **asynchronous** communication
  - Associate a queue with each endpoint
    - Senders add msg to remote queue; Receivers remote msg from local queue
    - Send and receive both have synch. (blocking) and asynch. (non-blocking)
    - Non-blocking receive not always supported cause more complex for app
- Can combine in nice ways
  - SR Language from U. Arizona 1990s, http://www.cs.arizona.edu/sr/

		Receiver	
		Blocking wait	**Proc creation**
Sender	**Asynch call (non-blocking)**	Asynch. Msg passing	Dynamic proc creation
	Synch call (blocks)	Rendezvous	RPC

Characteristics of IPC (cont.)

- Message destinations
  - Endpoint on internet is (IP address, (remote) port #)
  - Local port created for both sides to access
  - One receiving process per port
  - Process can use multiple ports to receive messages
  - Transparency support: look up endpoint from name (Sec 5.4.2)
- Reliability
  - Reliable: msg delivered despite “reasonable” packets lost
  - Integrity support: msgs must be uncorrupted and no dups
    - More “above” too to verify sender etc
- Ordering
  - Some apps require sender order (FIFO)
  - Layer above UDP (if multicast), or with TCP

Figure 4.2
Sockets and ports



- Socket abstraction: hide steps in lower-level protocols etc
  - To receive: socket bound to local port
  - Can use same socket to both send and receive
  - “large number” (!!) of ports, 2^{16}
  - Anyone can send to a socket if know endpoint
  - Can not have multiple receivers (except for mulitcast ..)

Java API for IP Addresses

- Class `InetAddress` (both IPv4 and IPv6)
- `InetAddress aComputer =`
  `InetAddress.getByName("foo.bar.edu")`
- Can throw `UnknownHostException`

UDP datagram communication [4.2.3]

- Sent without ACKs or retries
- Issues
  - Message size: receiver gives fixed-sized buffer, if msg big trunc.
  - Blocking: `receive` blocks (unless timeout set), `send` rtns quickly
    - Receiver can get msg later if not blocked (queued)
  - Timeouts: can set, choosing really hard
  - Receive from any: no origin (sender) specified, endpoint in header
- Failure model: omissions, ordering
- Uses of UDP
  - DNS
  - VOIP and other video/audio
  - Higher-level multicast with stronger properties

Java API for UDP datagrams

- `DatagramPacket` class
  - Sending constructor takes array of bytes, length, endpoint
  - Another constructor for receiving msgs: array of bytes, length
  - `DatagramPacket.getData`: receiver gets buffer
- `DatagramSocket` class
  - Constructor: port (also no-port: choose any free local port)
  - `Send()` and `receive()`
  - `setSoTimeout`: for receive, if times out throws `InterruptedIOException`
  - `Connect`: connect to remote endpoint

Figure 4.3
UDP client sends a message to the server and gets a reply

```
import java.net.*;
import java.io.*;
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,  m.length(), aHost, serverPort);
                aSocket.send(request); // send message to the remote endpoint
                byte[] buffer = new byte[1000];
                DatagramPacket reply = new DatagramPacket(buffer, buffer.length);
                aSocket.receive(reply); // blocking wait for 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();}
    }
}
```

Figure 4.4 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){  // typical infinite server waiting loop: get request, send reply
			   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();}
    }
}
```

TCP stream communication [4.2.4]

- Hides many details beyhind socket abstraction
  - Message sizes: sender chooses how much data to read or write
    - Underlying impl decides when to send packets
    - Can flush/synch to force a send (why need?)
  - Lost packets
  - Flow control
  - Packet duplication and ordering
  - Message destinations (once socket set up)
    - Server creates listening socket
    - Client calls `connect(...)`
    - Server calls `accept(...)`

TCP stream communication (cont)

- API
  - Assumes for setup one side client other server
  - After that bidirectional with no distinction (both input and output stream in socket)
  - Listening socket maintains queue of `connect` requests
- Issues with TCP (and stream communication)
  - Matching data items: need to agree on data types (UDP too)
  - Blocking: like UDP
  - Threads: server usually forks new process for each client (why?)

TCP stream communication (cont)

- Failure model
  - Checksums detects and rejects corrupted packets
  - Sequence numbers: detect and reject duplicate packets
  - If too many lost packets, socket declared to be closed
    - I.e., not (very) reliable communication
  - Uses of TCP (lots): HTTP, FTP, Telnet, SMTP

Java API for TCP streams

- `ServerSocket` class: for listening to `connect` requests
  - Method `accept` gets `connect` request or blocks if none queued
    - Returns a `Socket` object to communication with the client
- `Socket`: for pair to communicate with
  - Client uses constructor to create a given endpoint
  - Can throw `UnknownHostexception` or `IOException`
  - `getInputStream` and `getOutputStream` to access streams

Figure 4.5: TCP client makes connection to server, sends request and receives reply

```
import java.net.*;
import java.io.*;
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());}}
        }
}
```

Figure 4.6

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
```

Figure 4.6 continued

```
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*/}}
        }
}
```

External data representation and marshalling [4.3]

- Procedures/methods called with params, msgs take buffers
- Marshalling does this translation, unmarshalling reverses
- External data representations describe how
  - Endian-ness, ASCI or Unicode text, etc
- Two main techniques
  - Neutral format
  - Sender's format ("receiver makes right")

Approaches to marshalling and external data representation

1. CORBA's common data rep. (CDR): structs, primitives
2. Java serialization: object or tree of objects
3. XML: textual description of data

- Comparisons
  - CDR, Java: middleware layer, XML more for hand coding in app
  - CDR, Java: binary form, XML text
  - CDR: only values (sort of), Java, XML: type info
  - XML larger, more error prone than automatic marshalling by middleware compiler
- Other possibilities (more "lightweight")
  - Google protocol buffers (20.4.1): describe stored&transmitted data
  - JavaScript Object Notation (JSON)

CORBA's Common Data Representation (CDR) [4.3.1]

- All 15 primitive types: `short`, `long`, `boolean`, … `any`
  - Defn's for both big- and little-endian (sent in sender's order; tag)
  - Other types straightforward: IEEE floats, chars agreed between client and server
- Constructed/composite types (Fig 4.7, next)
  - Primitive types that make them up added in a byte sequence in a given order
- Marshalling generated automatically from IDL

Figure 4.7
CORBA CDR for constructed types

Type	*Representation*
sequence	length (unsigned long) followed by elements in order
string	length (unsigned long) followed by characters in order (can also can have wide characters)
array	array elements in order (no length specified because it is fixed)
struct	in the order of declaration of the components
enumerated	unsigned long (the values are specified by the order declared)
union	type tag followed by the selected member

Figure 4.8
CORBA CDR message

index in sequence of bytes	← 4 bytes →	*notes on representation*
0–3	5	*length of string*
4–7	"Smit"	*'Smith'*
8–11	"h___"	
12–15	6	*length of string*
16–19	"Lond"	*'London'*
20-23	"on__"	
24–27	1984	*unsigned long*

```
struct Person
{
 string name;
 string place;
 unsigned long
               year;
};
```

The flattened form represents a *Person* struct with value: {'Smith', 'London', 1984}

Java Object Serialization [4.3.2]

- Java **`class`** equivalent to CORBA Person **`struct`**:

```
public class Person implements Serializable {
 private String name;
 private String place;
 private int year;
 public Person(String aName, String aPlace, int aYear) {
     name = aName;
     place = aPlace;
     year = aYear;
 }
 // followed by methods for accessing the instance vars
}// class Person
```

Java Serialization (cont.)

- **Handles**: serialized references to other objects
- Reflection:used by serialization to find class name of object to be serialized, when deserialized to create class
- (Read rest of details in text, not covering)

Figure 4.9
Indication of Java serialized form

Serialized values				*Explanation*
Person	8-byte version number		h0	*class name, version number*
3	int year	java.lang.String name:	java.lang.String place:	*number, type and name of instance variables*
1984	5 Smith	6 London	h1	*values of instance variables*

The true serialized form contains additional type markers; h0 and h1 are handles

Extensible Markup Language (XML) [4.3.3]

- Markup language: encodes both text and its structure
  - HTML: for web pages
  - XML: for structured documents for web
  - Both: derived from (very complext) SGML
- XML namespaces: provided for scoping names (avoid name collisions)
- XML schemas: define elements and attributes for a doc, nesting, order and number of elements, etc
- Overview in this lecture, read details in text
  - Gory details not testable (don't memorize minutia)
  - But should really have intuition into difference from CORBA and Java: purpose, why design decisions made, efficiency, readability, other comparisons

Figure 4.10 XML definition of the Person structure

```xml
<person id="123456789">
        <name>Smith</name>
        <place>London</place>
        <year>1984</year>
        <!-- a comment -->
</person >
```

Figure 4.11 Illustration of the use of a namespace in the *Person* structure

```
<person pers:id="123456789" xmlns:pers = "http://www.cdk5.net/person">
        <pers:name> Smith </pers:name>
        <pers:place> London </pers:place >
        <pers:year> 1984 </pers:year>
</person>
```

Figure 4.12 An XML schema for the *Person* structure

```
<xsd:schema  xmlns:xsd = URL of XML schema definitions      >
        <xsd:element name= "person" type ="personType" />
                <xsd:complexType name="personType">
                        <xsd:sequence>
                                <xsd:element name = "name"  type="xs:string"/>
                                <xsd:element name = "place"  type="xs:string"/>
                                <xsd:element name = "year"  type="xs:positiveInteger"/>
                        </xsd:sequence>
                        <xsd:attribute name= "id"   type = "xs:positiveInteger"/>
                </xsd:complexType>
</xsd:schema>
```

Remote object references [4.3.4]

- (Only applies to CORBA &Java: distributed object model)
- NOT XML
- **Remote object reference**: identifier valid thru a DS
- Generated so unique over space and time
  - Lots of processes in a DS!
  - Must not reuse

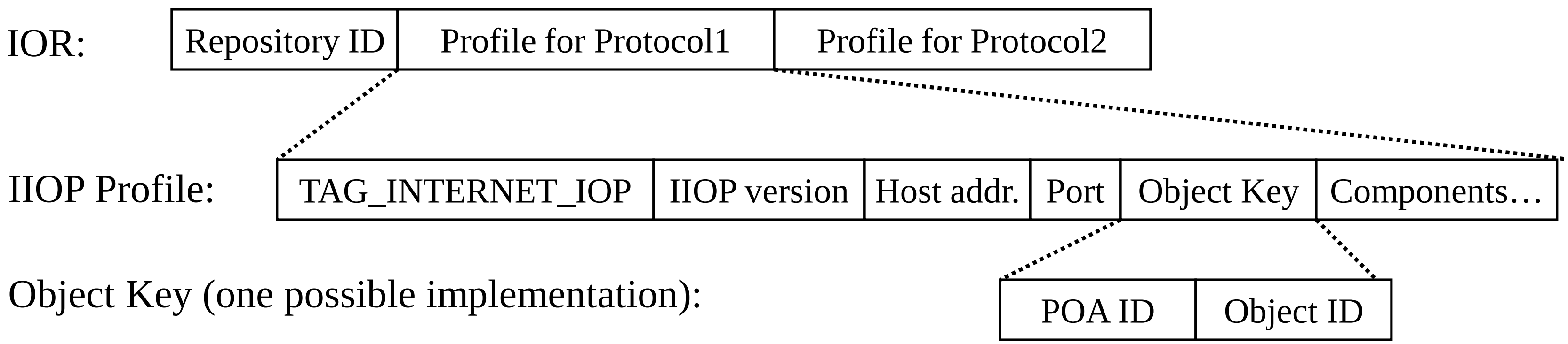
Figure 4.13
Representation of a remote object reference

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

CORBA Object References (not in texbook)

- Object reference
  - Opaque handle for client to use
  - Identifies exactly one CORBA object
  - <u>IOR</u> == “Interoperable Object Reference”
- References may be passed among processes on different hosts
  - As parameters, return values, or “stringified”
  - ORB will marshall
  - ORB on receiver side unmarshalling will
    - create a proxy
    - return a pointer to it
  - Basically functions as a remote “pointer” that works across heterogeneity in language, OS, net, vendor, …

CORBA Object References (cont.)



- Object Key
  - Opaque to client
  - ORB-specific
- Object ID
  - Can be created by user or POA
- Components: Optional data
  - e.g., alternate endpoint, info for security policies, etc

Multicast Communication [4.4]

- Point-to-point communications not great for process groups
- Multicast: 1:many communications, many uses
  - Fault-tolerance based on replicated services
  - Discovering services in spontaneous networking
  - Better performance through replicated data (multicast updates)
  - Propagation of event notices (Facebook, implement pub-sub)

IP Multicast (IPMC) [4.4.1]

- One implementation of multicast, using UDP not TCP
  - Use normal sockets to join (receiving) group
- Multicast routers: can send to multiple LANs (use its mcast)
- Multicast addresses
  - Permanent: assigned by IANA, exist even if no members
  - Temporary: come and go dynamically
- Failure model:
  - Same as UDP (omission)
  - Some group members may receive, others not
  - AKA **unreliable multicast** (reliable multicast in Chapter 15, for 562)

Java API for IP Multicast

- Class `MulticastSocket`
  - Subclass of `DatagramSocket`
  - `joinGroup(…)`
  - `leaveGroup(…)`

Figure 4.14: Multicast peer joins a group and sends and receives datagrams

```
import java.net.*;
import java.io.*;
public class MulticastPeer{
        public static void main(String args[]){
         // args give message contents & destination multicast group (e.g. "228.5.6.7")
        MulticastSocket s =null;
         try {
                InetAddress group = InetAddress.getByName(args[1]);
                s = new MulticastSocket(6789);
                s.joinGroup(group);
                byte [] m = args[0].getBytes();
                DatagramPacket messageOut =
                        new DatagramPacket(m, m.length, group, 6789);
                s.send(messageOut);


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

Figure 4.14 continued

```
        // get 3 messages from others in group
            byte[] buffer = new byte[1000];
            for(int i=0; i< 3; i++) {
                DatagramPacket messageIn =
                        new DatagramPacket(buffer, buffer.length);
                s.receive(messageIn);
                System.out.println("Received:" + new String(messageIn.getData()));
            }
            s.leaveGroup(group);
        }catch (SocketException e){System.out.println("Socket: " + e.getMessage());
        }catch (IOException e){System.out.println("IO: " + e.getMessage());}
        }finally {if(s != null) s.close();}
    }
}
```

Reliability and ordering of multicast [4.4.2]

- IPMC: dropped msgs, partial delivery to group, no ordering
- Effects on different apps?
  - Fault-tolerance based on replicated services
    - E.g., keep replicas with same state, multicast requests
    - What happens with failures above?
  - Discovering services in spontaneous networking
    - What happens with failures above?
  - Better performance through replicated data (multicast updates)
    - What happens with failures above?
  - Propagation of event notices (Facebook, implement pub-sub)
    - What happens with failures above?

Network virtualization: overlay networks [4.4]

- Some applications need (much) more advanced delivery services than Internet protocols provide
  - End-to-end argument says to not push functions down here
- Network virtualization: construct many different virtual networks over Internet
  - Support specific services needed
  - Answers end-to-end argument: app-specific virtual network

Overlay networks [4.5.1]

- Overlay network: virtual network consisting of topology of virtual nodes and virtual links (above underlay network's)
  - Tailor services to specific app (e.g., multimedia content)
  - More efficient in some network environments (ad hoc)
  - Add more features: multicast, secure communications, …
- Can redefine addressing, protocols, routing
- Advantages
  - Add services without having to change (and standardize) underlay
  - Encourage experimentation
  - Can exist with other overlays (same kind or different)

Overlay networks (cont)

- Disadvantages:
  - extra level of indirection
    - Placement (overlay→underlay) is key for efficiency
  - add to complexity
- Examples in book
  - Skype next
  - Chap 10: P2P file sharing, distributed hash tables
  - Chap 19: mobile/ubiquitous: ad hoc and disruption-tolerant
  - Chap 20: multimedia streaming

Figure 4.15
Types of overlay

Motivation	*Type*	*Description*
Tailored for application needs	Distributed hash tables	One of the most prominent classes of overlay network, offering a service that manages a mapping from keys to values across a potentially large number of nodes in a completely decentralized manner (similar to a standard hash table but in a networked environment).
	Peer-to-peer file sharing	Overlay structures that focus on constructing tailored addressing and routing mechanisms to support the cooperative discovery and use (for example, download) of files.
	Content distribution networks	Overlays that subsume a range of replication, caching and placement strategies to provide improved performance in terms of content delivery to web users; used for web acceleration and to offer the required real-time performance for video streaming [www.kontiki.com].

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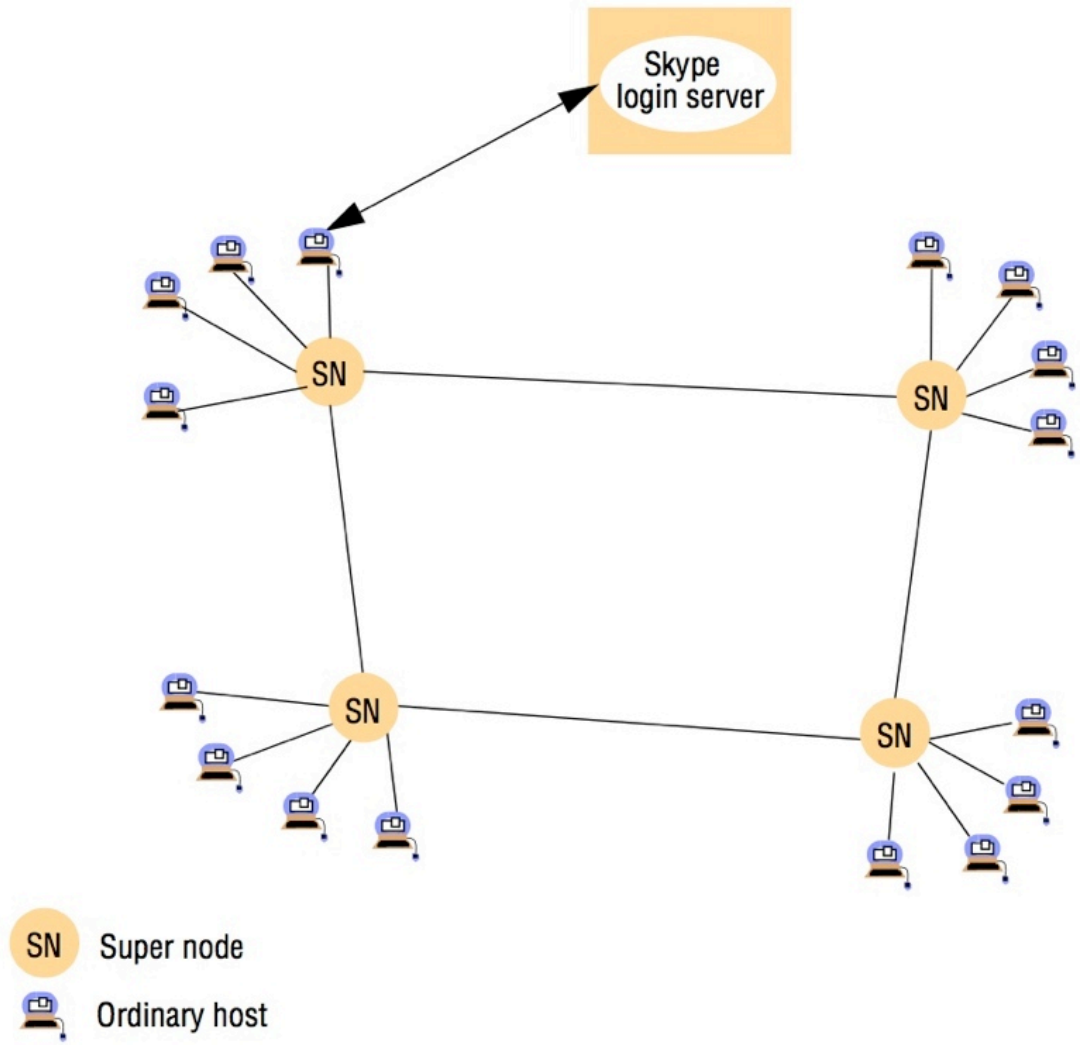
Figure 4.15 (continued)
Types of overlay

Tailored for network style	Wireless ad hoc networks	Network overlays that provide customized routing protocols for wireless ad hoc networks, including proactive schemes that effectively construct a routing topology on top of the underlying nodes and reactive schemes that establish routes on demand typically supported by flooding.
	Disruption-tolerant networks	Overlays designed to operate in hostile environments that suffer significant node or link failure and potentially high delays.
Offering additional features	Multicast	One of the earliest uses of overlay networks in the Internet, providing access to multicast services where multicast routers are not available; builds on the work by Van Jacobsen, Deering and Casner with their implementation of the MBone (or Multicast Backbone) [mbone].
	Resilience	Overlay networks that seek an order of magnitude improvement in robustness and availability of Internet paths [nms.csail.mit.edu].
	Security	Overlay networks that offer enhanced security over the underling IP network, including virtual private networks, for example, as discussed in Section 3.4.8.

Skype [4.5.2]

- P2P VOIP overlay network (instant msgs, video, telephony)
- Addresses: skype username or phone number
- Original architecture: P2P
  - Ordinary user machines “hosts”
  - Well enabled/connected hosts: super node
- Authenticate users over well-known login server, gives them super node
- Supernodes goal: search for users efficiently
- Direct voice connection between two parties
  - Signalling: TCP
  - Call: UDP or TCP (latter only to circumvent firewalls)
- Codecs key: optimized for ≥ 32 kbps

Figure 4.16
Skype overlay architecture (pre-cloud)



Case Study: MPI [4.6]

- Started in grid computing (and influenced it)
- NOT Covering: required for 564 (not for 464)