Last Class: Network Overview

- ⇒Processes in a distributed system all communicate via a message exchange.

Physical reality: packets	Abstraction: messages
limited size	arbitrary size
unordered (sometimes)	ordered
unreliable	reliable
machine to machine	process to process (routing)
asynchronous	synchronous
insecure	secure

- Unless otherwise stated, assume a reliable end-to-end message delivery.

Today: Distributed Systems

What gets harder when we move from a stand alone system to a distributed environment?

- resource sharing
- timing (e.g., synchronization)
- critical sections
- deadlock detection and recovery
- failure recovery

Resource Sharing

There are many mechanisms for sharing (hardware, software, data) resources.

- **Data Migration:** moving the data around
- **Computation Migration:** move the computation to the data
- **Job Migration:** moving the job (computation and data) or part of the job

⇒The fundamental tradeoff in resource sharing is to complete user instructions as fast and as cheaply as possible. (Fast and cheap are usually incompatible.)

Computation versus Communication

- If communication is fast and cheap, we can utilize all the resources in the distributed environment.
- If communication is slow and expensive, we should do most processing locally.
- Reality is usually in the middle somewhere.

⇒ we need a quantitative analysis to decide where the cutoffs are.

Data Migration

Data Migration may occur when process at site A accesses a file at site B

1. Copy file B to process A
   - Costly if the file is large.
   - Data must be converted to A's data format
   - Multiple copies can cause *consistency* problems
   - All subsequent accesses at A are local
2. Keep file at B, access file remotely from A
   - Saves file transfer cost
   - Converting the file from A's format to B's may be difficult to do in pieces
   - Single copy of file, so no consistency problems
   - Single "file service center" for file at B may be a performance bottleneck

Computation Migration

Computation Migration may occur when it is more efficient to transfer the computation itself rather than data.

Example: a small program which produces a short summary of a large file, say "wc" or a database query

- Remote Procedure Calls (**RPC**): suppose A wants to access file at site B. B provides a predefined process.

  A sends a message to the predefined process at B, which performs the requested action, and sends the result back to A.

Job Migration

- **Job Migration:** perform the job (or parts of the job) at remote sites by moving the data *and* computation.
  - **Load balancing:** even workload across the distributed system
  - **Computational speedup:** concurrent (parallel) execution of parts of the job.
  - **Hardware preference:** job may match a given piece of hardware somewhere in the system.
  - **Software preference:** job may require software only available on a specific site. For example, site specific license of expensive software.
  - **User interaction:** may want to hide migration from the user. For example, in load balancing. May want the user to specify migration (hardware/software preferences)

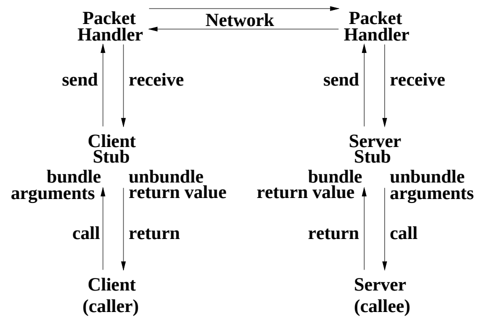
Client/Server Model

- One of the most common models for structuring distributed computation is by using the *client/server* paradigm.
  - A *server* is a process or collection of processes that provide a service, e.g., name service, file service, database service, etc.
  - The server may exist on one or more nodes.
  - A *client* is a program that uses the service.
  - A client first binds to the server, i.e., locates it in the network and establishes a connection.
  - The client then sends the server a request to perform some action. The server sends back a response.
  - RPC is one common way this structure is implemented.

Remote Procedure Call

Basic idea:

- Servers export procedures for some set of clients to call.
- To use the server, the client does a procedure call.
- OS manages the communication.



Remote Procedure Call: Implementation Issues

For each procedure on which we want to support RPC:

- The RPC mechanism uses the procedure *signature* (number and type of arguments and return value)
  1. to generate a client stub that bundles up the RPC arguments and sends it off to the server, and
  2. to generate the server stub that unpacks the message, and makes the procedure call.

Remote Procedure Call: Implementation Issues

```
Client Stub:

  build message
  send message
  wait for response
  unpack reply
  return result
```

```
Server Stub:

  create threads
  loop
    wait for a command
    unpack request parameters
    call procedure with thread
    build reply with result(s)
    send reply
  end loop
```

Comparison between RPC and a regular procedure call

- Name of procedure
- Parameters
- Result
- Return address

Remote Procedure Call

- How does the client know the right port?
  - The binding can be static - fixed at compile time.
  - Or the binding can be dynamic - fixed at runtime.
- In most RPC systems, dynamic binding is performed using a name service.
  - When the server starts up, it exports its interface and identifies itself to a network name server
  - The client, before issuing any calls, asks the name service for the location of a server whose name it knows and then establishes a connection with the server.

Example: Remote Method Invocation (RMI) in Java

- Java provides the following classes/interfaces:
  - **Naming:** class that provides the calls to communicate with the remote object registry
  - `public static void bind(String name, Remote obj)` - Binds a server to a name.
  - `public static Remote lookup(String name)` - Returns the server object that corresponds to a name.
- **UnicastRemoteObject:** supports references to non-replicated remote objects using TCP, exports the interface automatically when the server object is constructed
- Java provides the following tools:
  - **rmiregistry** server-side name server
  - **rmic:** given the server interface, generates client and server stubs that create and interpret packets

Example: Server in Java

- **Server**
  - Defines an interface listing the signatures of methods the server will satisfy
  - Implements each of the methods in the interface
  - Main program for server:
    - Creates one or more server objects - normal constructor call where the object being constructed is a subclass of RemoteObject
    - Registers the objects with the remote object registry
- **Client**
  - Looks up the server in the remote object registry
  - Uses normal method call syntax for remote methods
  - Should handle RemoteException

Example: Hello World Server Interface

Declare the methods that the server provides:

```
package examples.hello;

// All servers must extend the Remote interface.
public interface Hello extends java.rmi.Remote {

  // Any remote method might throw RemoteException.
  // Indicates network failure.
  String sayHello() throws java.rmi.RemoteException;
}
```


Example: Hello World Server

```
package examples.hello;
import java.rmi.*;
import java.rmi.server.UnicastRemoteObject;

public class HelloImpl extends UnicastRemoteObject implements Hello
{
  public HelloImpl() throws RemoteException {
   // The superclass constrctor exports the interface and gets a port
    super();
  }

  public String sayHello() throws RemoteException {
    // This is the "service" provided.
    return  "Hello World!";
  }
```

Example: Hello World Server (contd)

```
  public static void main(String args[])
  {
    // Create and install a security manager
    System.setSecurityManager(new RMISecurityManager());

    // Construct the server object.
    HelloImpl obj = new HelloImpl();

    // Register the server with the name server.
    Naming.rebind("//myhost/HelloServer", obj);
  }
}
```


Example: Hello World Client

```
package examples.hello;

import java.awt.*;
import java.rmi.*;

public class HelloApplet extends java.applet.Applet {
  String message = "";

  // The init method begins the execution of the applet on the client
  // machine that is viewing the Web page containing the reference
  // to the applet.
  public void init() {
    try {
      // Looks up the server using the name server on the host that
      // the applet came from.
      Hello obj = (Hello)Naming.lookup(
                     "//" + getCodeBase().getHost() + "/HelloServer");
```

Example: Hello World Client (contd)

```
      // Calls the sayHello method on the remote object.
      message = obj.sayHello();
    } catch (RemoteException e) {
      System.out.println("HelloApplet RemoteException caught");
    }
  }

  public void paint(Graphics g) {
    // The applet will write the string returned by the remote method
    // call on the display.
    g.drawString(message, 25, 50);
  }
}
```


Summary

- Data, computation, job migration
- Client-Server Model
- Mechanism: RPC
  - Most common model for communications in distributed applications.
  - RPC is essentially language support for distributed programming.
  - Relies on a stub compiler to automatically produce client/server stubs from the signatures
  - RPC is commonly used *even on a single node* for communication between applications running in different address spaces.