Week 2: Part 1
Point-to-point communication: Remote Procedure Calls
Network Communications

- **Data Link Layer (2)**
  - Ethernet, Wi-Fi, DOCSIS, ATM, Frame Relay, …

- **Network Layer (3)**
  - Internet Protocol: IPv4, IPv6

- **Transport Layer (4)**
  - TCP, UDP

- **TCP**: Reliable, in-order byte stream
- **UDP**: Unreliable, message stream (order not guaranteed)
Is UDP that bad?

- Unreliable & out-of-order data?
  - Rare in many (most) environments
  - Data will arrive correctly … most of the time

- TCP requires storing & managing state
  - Sequence numbers
  - Buffering out-of-order data
  - Acknowledgements
  - Flow control
TCP Upsides & Downsides

• Upsides – huge!
  – In-order, reliable byte streams

• Downsides
  – Memory use with lots of connections
  – Recovery
    • All state lost if a system goes down – connections will need to be re-established
  – Increased latency
    • Session setup
    • Data may not be immediately transmitted or presented to the receiving app
UDP Upsides & Downsides

• Downsides
  – Delivery & message order not guaranteed

• Upsides
  – Fewer kernel resources
  – No setup overhead
  – Received data immediately sent & delivered to the application
  – No state recovery – traffic can be easily redirected to a standby system
Identifying Sessions: UDP

All traffic goes to a socket that reads from a host address & port
Identifying Sessions: TCP

Unique channels identified by

- Remote host, Remote port, Local host, Local port
- One socket for **listening** for new connections on a *local host, port*
- Separate communication socket for each “connection”
Software interaction model

• Socket API: all we get from the OS to access the network
• Socket = distinct end-to-end communication channels

read/write interface

• Line-oriented, text-based protocols common
  – Not efficient but easy to debug & use
Sample SMTP Interaction

$ telnet porthos.rutgers.edu 25
Trying 128.6.25.90...
Connected to porthos.rutgers.edu.
Escape character is '^]'.
220 porthos.cs.rutgers.edu ESMTP Postfix (Ubuntu)
HELO poopybrain.com
250 porthos.cs.rutgers.edu
MAIL FROM: <paul@poopybrain.com>
250 2.1.0 Ok
RCPT TO: <pxk@cs.rutgers.edu>
250 2.1.5 Ok
DATA
354 End data with <CR><LF>.<CR><LF>
From: Paul Krzyzanowski <myname@somewhere.edu>
Subject: test message
Date: Mon, 3 Feb 2021 17:00:16 -0500
To: Whomever <testuser@pk.org>

Hi,
This is a test
.
250 2.0.0 Ok: queued as 82D315F7C5
quit
221 2.0.0 Bye
Connection closed by foreign host.

This is the message body. Headers may define the structure of the message but are ignored for delivery.
Sample HTTP Interaction

$ telnet www.google.com 80
Trying 172.217.12.196...
Connected to www.google.com.
Escape character is '^]'.
GET /index.html HTTP/1.1
HOST: www.google.com
Accept: image/gif, image/jpeg, */*
Accept-Language: en-us
User-Agent: Mozilla/4.0

HTTP/1.1 200 OK
Date: Thu, 04 Feb 2021 22:58:25 GMT
Expires: -1
Cache-Control: private, max-age=0
Content-Type: text/html; charset=ISO-8859-1
...
Transfer-Encoding: chunked

5584
<!doctype html><html itemscope=""
itemtype="http://schema.org/WebPage"
lang="en"><head>
...
...
Problems with the sockets API

The **sockets** interface forces a read/write mechanism

Programming is often easier with a functional interface

To make distributed computing look more like centralized computing, I/O (read/write) is not the way to go
1984: Birrell & Nelson
- Mechanism to call procedures on other machines

Remote Procedure Call
Implementing RPC

No architectural support for remote procedure calls

*Simulate it* with tools we have (local procedure calls)

Simulation makes RPC a language-level construct

instead of an operating system construct

The OS gives us sockets

The compiler creates code to send messages to invoke remote functions
Implementing RPC

The trick:

Create stub functions to make it appear to the user that the call is local

On the client

The stub function (proxy) has the function’s interface

Packages parameters and calls the server

On the server

The stub function (skeleton) receives the request and calls the local function
1. Client calls stub (params on stack)

- Client calls client stub (proxy)
- Server calls server stub (skeleton)

Network routines

OS
2. Stub marshall params to network message

Marshalling = put parameters in a form suitable for transmission over a network (serialized)
3. Network message sent to server

client functions

client stub
(proxy)

network routines

server stub
(skeleton)

server functions

network routines

OS

OS
4. Receive message: send it to server stub
5. Unmarshal parameters, call server function
6. Return from server function

Stub functions

client functions

client stub (proxy)

network routines

server functions

server stub (skeleton)

network routines
7. Marshal return value and send message
8. Transfer message over network

Stub functions

Client functions

- Client stub (proxy)
- Network routines

Server functions

- Server stub (skeleton)
- Network routines
9. Receive message: client stub is receiver
10. **Unmarshal** return value(s), return to client code
A client proxy looks like the remote function

- Client stub has the same interface as the remote function
- Looks & feels like the remote function to the programmer
  - But its function is to
    - Marshal parameters
    - Send the message
    - Wait for a response from the server
    - Unmarshal the response & return the appropriate data
    - Generate exceptions if problems arise
A server stub contains two parts

1. **Dispatcher – the listener**
   - Receives client requests
   - Identifies appropriate function (method)

2. **Skeleton – the unmarshaller & caller**
   - Unmarshals parameters
   - Calls the local server procedure
   - Marshals the response & sends it back to the dispatcher

All this is invisible to the programmer
- The programmer doesn’t deal with any of this
- Dispatcher + Skeleton may be integrated
  - Depends on implementation
RPC Benefits

• RPC gives us a procedure call interface

• Writing applications is simplified
  – RPC hides all network code into stub functions
  – Application programmers don’t have to worry about details
    • Sockets, port numbers, byte ordering

• Where is RPC in the OSI model?
  – Layer 5: Session layer: Connection management
  – Layer 6: Presentation: Marshaling/data representation
  – Uses the transport layer (4) for communication (TCP/UDP)
RPC has challenges
RPC Issues

• Parameter passing
  – Pass by value or pass by reference?
  – Pointerless representation

• Service binding. How do we locate the server endpoint?
  – Central DB
  – DB of services per host

• Transport protocol
  – TCP? UDP? Both?

• When things go wrong
  – Opportunities for failure
When things go wrong

• **Semantics of remote procedure calls**
  – Local procedure call: *exactly once*

• Most RPC systems will offer either
  – *at least once* semantics
  – or *at most once* semantics

• Decide based on application
  – **idempotent** functions: may be run any number of times without harm
  – **non-idempotent** functions: those with side-effects

• Ideally – design your application to be idempotent
  – … and stateless
  – Not always easy!
  – Store transaction IDs, previous return data, etc.
More issues

**Performance**
- RPC is slower … a lot slower (why?)

**Security**
- messages may be visible over network – do we need to hide them?
- Authenticate client?
- Authenticate server?
Programming with RPC

Language support

- Many programming languages have no language-level concept of remote procedure calls (C, C++, Java <J2SE 5.0, ...)
  - These compilers will not automatically generate client and server stubs
- Some languages have support that enables RPC (Java, Python, Haskell, Go, Erlang)
  - But we may need to deal with heterogeneous environments (e.g., Java communicating with a Python service)

Common solution

- Interface Definition Language (IDL): describes remote procedures
- Separate compiler that generates stubs (pre-compiler)
Interface Definition Language (IDL)

- Allow programmer to specify remote procedure interfaces (names, parameters, return values)

- Pre-compiler can use this to generate client and server stubs
  - Marshaling code
  - Unmarshaling code
  - Network transport routines
  - Conform to defined interface

- An IDL looks similar to function prototypes
Sometimes called a protocol compiler
Writing the program

• Client code has to be modified
  – Initialize RPC-related options
    • Identify transport type
    • Locate server/service
  – Handle failure of remote procedure calls

• Server functions
  – Generally need little or no modification
The End