Distributed Applications

Networking Basics

Georgia Tech

What is a "Network?"

- Depends on what level you're at
- One person's "network" is another person's "application"
- OSI Seven Layer Model
  - The physical wire itself
  - Ethernet, 802.11b
  - Routing protocols
  - ...

7. Application	FTP, HTTP, SMTP, etc.
6. Presentation	
5. Session	
4. Transport	TCP
3. Network	IP
2. Data Link	ARP, RARP
1. Physical	Ethernet

For Our Purposes: The Internet

- We're *application programmers*
- In terms of OSI, we're defining/using our own *application-layer protocol*
- Sits atop TCP/IP, the lingua franca of the Internet
- For almost every networked application you will ever want to build, this will be the lowest layer in the stack you'll need to care about

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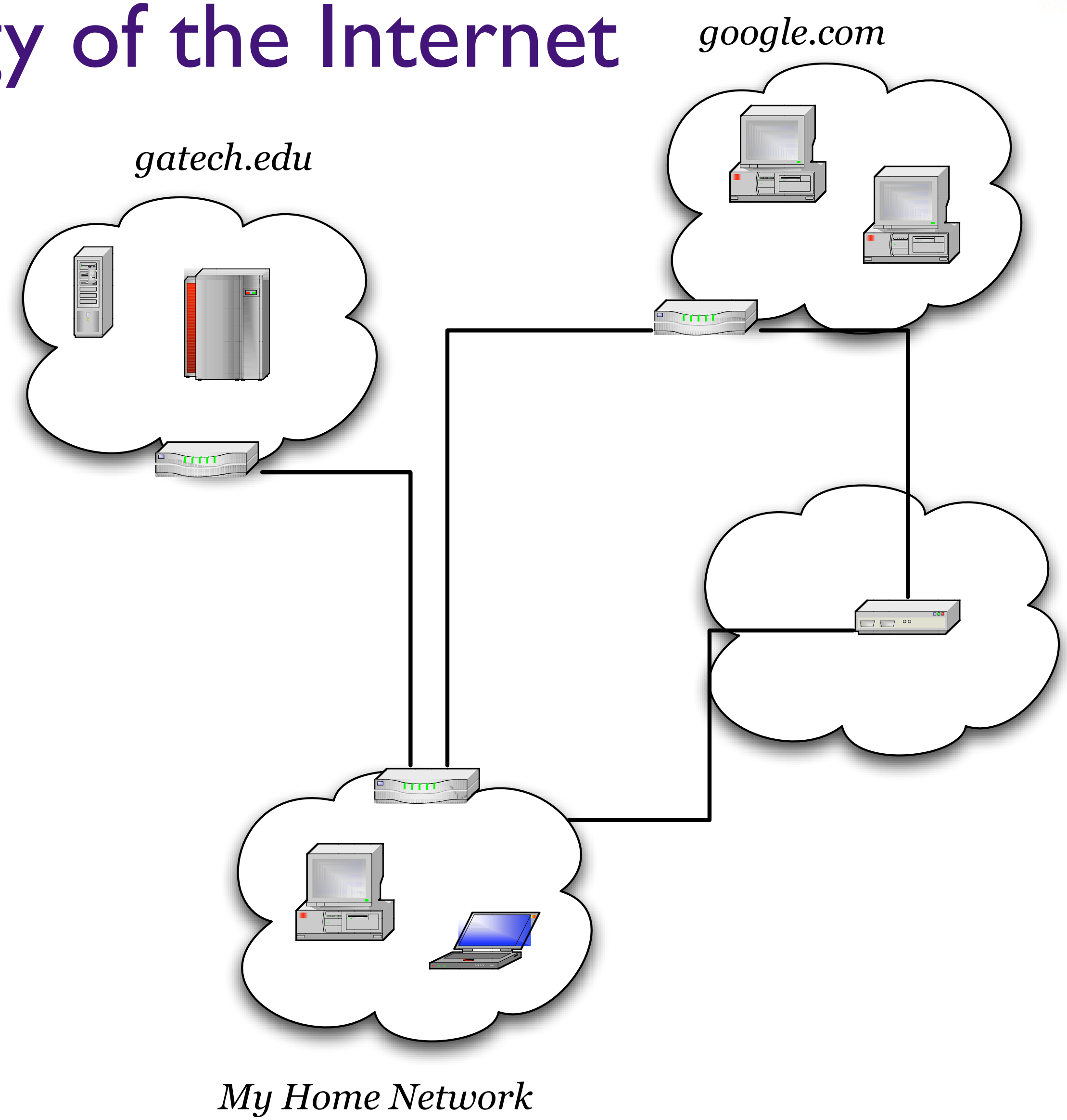
Topology of the Internet



Some Terminology: Protocols

- **Protocols**: rules that facilitate information exchange among programs on a network
  - Example from human world: "roger" and "over" for radio geeks
- Similar to how you design the interfaces between objects in your program
  - A callback expects to get a certain set of parameters in a certain order
  - You need to know this in order to use the callback
- Likewise:
  - A networked program expects you to communicate with it in certain ways (using certain messages, in a known format)
  - You need to know this in order to use the program

Some Terminology: Servers

- **Server**: a (generally) long-lived program that sits around waiting for connections to it
  - Examples: web server, mail server, file server, IM server
- "Server" implies that it does something useful (delivers a *service*)
  - Web server: provides access to HTML documents
  - Mail server: allows retrieval, sending, organization of email messages
  - File server: provides remote access to files and directories
  - IM server: provides info about online users, passes messages between them

Some Terminology: Clients

- **Client**: a program that connects to a server to use whatever service it provides
  - Examples:
    - Web browser connects to web servers to access/view HTML documents
    - Mail client (Outlook, etc.) connects to mail servers for mail storage, transmission
    - IM clients connect to IM servers to access info about who is on, etc.
- Most servers can be connected to by multiple clients at the same time

Some Terminology: Host

- **Host**: Simply a machine that's connected to the network
- Generally running clients and/or servers
  - The machine "hosts" a server

The Next Phase of the Project

- We'll be building the networking part of the IM program
  - Enhancing the GUI code to talk to an an IM server on the network
- For the IM assignment:
  - I'll provide a sample IM server, and documentation on its protocol
- Important concept: understanding a protocol specification
  - Useful for when you want to write a program that talks to an existing server (and thus has its own existing, documented protocol)
  - Side concept: designing your *own* protocols
    - We'll talk about this, but won't do it for the project (unless you want to go nuts and get all fancy...)
- Should give you experience in using basic Internet-style networking, debugging, etc.

What Will You Have to Do?

1. Connect to the other machine(s)
   - Know how to refer to it: which machine do you want to connect to?
   - Know how to perform the connection
   - Know how to deal with errors (server is down, etc.)
2. Send messages to it (e.g., "I'm online now!")
   - Know how to "marshall" arguments
   - Know how to do the transmission
   - Know how to deal with errors (server crashed while sending, etc.)
3. Receive messages from it (e.g., list of online users)
   - Know how to "unmarshall" arguments
   - Know how to read data
   - Know how to deal with errors (e.g., got unexpected data from server, etc.)
4. Disconnect from it
   - This is the easy part!

Why All the Focus on Errors?

- Networking in inherently error-prone
- Different than single application programming
  - Errors generally result from a bug, and just crash entire program
- Networking: errors may be caused by reasons outside of your control
  - Network is down, server has crashed, server slow to respond, etc.
  - During a chat I could shut my laptop and walk away
  - Someone could trip over the power cord for an access point
  - Networks can't even guarantee that messages will get from A to B
- Good goal: *robustness*
  - Your program should survive the crash of another program on the network, receiving malformed data, etc
  - "Defensive programming"

Networking 101

Internet Addressing

- Every machine on the Internet has an *address*
- Internet addresses are sequences of 4 bytes
  - Usually written in "dotted quad" notation
  - Examples: 192.168.13.40, 13.2.117.14
- Addresses identify a particular machine on the Internet
  - Example: 64.223.161.104 is the machine www.google.com
- One special address
  - 127.0.0.1
  - *localhost*
  - Refers to the local machine always

Where do IP Addresses Come From?

- You can't just set your IP address to any random value and have it work
  - The rest of the Internet won't know how to reach you
  - You have to use values that are compatible with whatever network you're on
- In most cases a service called *DHCP* will take care of this for you
  - *Dynamic Host Configuration Protocol*
  - Assigns you a valid IP address when you boot your machine, wake your laptop, etc.
  - E.g., LAWN at Georgia Tech
  - IP address may change from time to time: in other words, don't count on this being your address forever
- If DHCP isn't available, you may have to set your IP address by hand, but only with a value provided by an administrator

Why Do You Need to Know This?

- First off: **don't change your IP address for this class!**
  - You can only do harm!
- Second: if you get an address from DHCP (which you probably do), you can't count on having this address forever
  - So don't hard-code it into any programs
- Third: if you want to debug clients and servers on the same machine, you can use the localhost address
  - But don't hardcode this either, since it would keep you from working when client and server are on *different* machines

Public Versus Private Addressing

- Not all IP addresses may be *reachable* from any given machine
- Simple case: machines behind a *firewall*
  - Example: my old machine at PARC was 13.1.0.128, but only reachable from within PARC
- More complex case:
  - Some IP addresses are *private* (also called *non-routable*)
  - Three blocks of addresses that cannot be connected to from the larger Internet
    - 10.0.0.0 - 10.255.255.255
    - 172.16.0.0 - 172.31.255.255
    - 192.168.0.1 - 192.168.255.255

Why Private Addresses?

- Two reasons: IP address conservation and security
  - Public addresses *uniquely* define a given machine
    - There's a limited number of these, and they're running out
  - Private addresses can be reused (although not on the same network)
    - Probably hundreds of thousands of machines with 192.168.0.1 on private networks (corporation internal, homes, etc.)
  - Certain network configs let you *share* a single public IP address across multiple private machines
    - *Network Address Translation*
    - Built into most home routers
      - E.g., BellSouth gives me the address 68.211.58.142
      - My router gives my home machines 192.168 addresses
      - Connections *out* are translated so that it looks like they come from 68.211.58.142
      - Internal machines are "invisible" since they have non-routed addresses

Why Do You Need to Know This?

- Servers running on machines with private IP addresses are not reachable from machines not on that network
  - Ok if you're running your client and service on the same network
  - Ok if you're running your client and service on the same machine
  - **Not** ok if, e.g., your server is at home and you client is at Georgia Tech
- *Aside:* this is the reason that many people pay for an extra "static" IP address at home--so that they can run servers that have a fixed IP address that is visible throughout the Internet

Naming

- When you go to a web browser, you don't type in 64.223.161.104, you type in www.google.com
- The *Domain Name Service*
  - A big distributed database of all the machines on the Internet
  - Each organization manages its own little portion of it
  - Maps from host names to IP addresses
- Ultimately, the Internet runs on IP addresses. Names are a convenience for humans
  - When you type www.google.com, the browser *resolves* that name to an IP address by talking to a DNS server
  - If *name resolution* can't be done (DNS is down; you're not connected to the network), then browsing will fail

Naming Configuration

- Much like IP addressing, you may not have much control over the DNS name for your machine
  - In general, you *won't* have a name resolvable by DNS, even if your machine has a "local" name
  - In the CoC, CNS sets up DNS names for the machines they administer, mapping them to fixed IP addresses
    - If you were to take these machines to different networks (where they get different IP addresses), those names would no longer work
    - Resolve to the incorrect address
  - Personally owned machines, even if they get an IP address from DHCP, generally get sucky names, if they get a name at all
    - Example: lawn-199-77-214-212 on my laptop

Why Do You Need to Know This?

- General all-around erudition and cocktail party conversation :-)
- Even though we're used to using names to refer to machines on the Greater Internet, you'll probably be reduced to using IP addresses for this assignment
- We may be able to run a server on a well-known machine, administered by TSO, in which case you'd be able to specify it by name

Ports

- What if you've got multiple servers running on a single host?
  - E.g., a machine might have a web server, mail server, FTP server, ...
- When you tell a client to connect to a given machine, how does it know which server running on that machine to talk to?
- **Ports**: Let you address different servers running on the same machine
  - Think of IP addresses as the street address for an apartment building
  - Ports specify the individual apartments
- Ports are just numbers that range from 0-65,535

More On Ports

- Back to the question: when I type www.google.com into my browser...
  - It knows to go to 64.233.161.104
  - But how does it know which is the port for the google web server?
- *Well-known ports*: certain common Internet services use standard port numbers:
  - Web servers: port 80
  - FTP servers: port 21
- Terminology: we say that the FTP server *runs on* port 21, meaning that this is the port at which it is waiting for clients to connect to it
- *Reserved ports*: ports 0-1024 reserved for privileged programs
- Servers specify which port they run on when they start
- Clients specify *both* the IP address of the desired host, and the port number, when they connect to a server
- Clients outgoing connections *also* have a port, but generally you don't need to know what it is
- Only one client or service can run on a port at any given time

Why Do You Need to Know This?

- If you're writing a client for an existing service, you'll have to know what port is is running on in order to connect to it
- If you write a service, you'll need to run it on a port that will be known by its clients
  - Can be a fixed port number that you decide on, and tell your clients
  - Can let the system assign you a random one, but then you'll need some way to communicate this to clients
- You can't choose ports in the reserved range
- Good practice is to use relatively high numbers (e.g., 5,000 - 50,000)

Network Programming 101

Basic Network Programming

- One unified concept for dealing with the network at the Internet layer: **sockets**
- Basically similar across all platforms (Java, C, Python, etc.)
- De facto standard (slight differences across platforms, languages)
- So what's a socket?
  - An endpoint for communication
  - May be connected to another endpoint, in another program on the net
  - Lets you read from it and write to it, much like a file
  - Adds some additional operations specific to networking

Network Programming from the Client's Perspective

1. *Create* a socket
2. *Bind* it to an address on a client machine
   - Both endpoints of a communication have addresses, including ports
3. *Connect* it to the server, by specifying its address and port
   - This call blocks until the connection is successful, or times out
4. *Read* and *write* to and from the socket, to get and send data
5. *Close* the socket when you're done with it

Network Programming from the Server's Perspective

1. *Create* a socket
2. *Bind* it to an address on the server machine
   - This sets the port for the socket
3. *Listen* for incoming connections
4. *Accept* any connection that comes in.
   - This call *blocks* until a new connection comes in
   - This produces a **new** socket, paired with the client, and just for communication with that client
   - This socket can be read, written, and closed independently from the socket used for any other client
   - Meanwhile, original listening socket can go back to listening
   - Allows you to have multiple ongoing client connections at one time
5. *Close* the listening socket when you're done accepting connections

Example: Basic Socket Programming in Jython

Need to import the socket module before doing anything:

import socket

How to create a socket (for both clients and servers):

s = socket.socket(socket.AF_INET, socket.SOCK_STREAM)

How to connect to a server (if you're a client):

s.connect((”192.168.2.54”, 45235))

Note *double parentheses!*
This is because connect() takes a single tuple as an argument; this tuple contains the address and port. (The inner set of parentheses wraps the arguments in a tuple.)

How to bind to an address, listen for connections and accept them (if you're a server):

s.bind((“”, 45235))

Note *double parentheses!*
Same with bind()

s.listen(5)

newSock, clientAddress = s.accept()

How to send and receive data (both clients and servers):

s.send(”hello world”)

reply = sa.recv(1024)

How to close a socket (both clients and servers):

s.close()

Writing a Simple Server

(All of this code is on the web site, as net-sampler.py)

```
import socket
import sys

class SimpleServer:
    def __init__(self, port):
        self.sock = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
        self.sock.setsockopt(socket.SOL_SOCKET, socket.SO_REUSEADDR, 1)
        self.sock.bind(('', port))
        self.sock.listen(5)
        while 1:
            requestSock, peerAddress = self.sock.accept()
            print "Accepted connection from", peerAddress
            while 1:
                input = requestSock.recv(1024)
                if not input:
                    print "Peer closed connection"
                    break
                requestSock.send(input)

            requestSock.close()

if __name__ == "__main__":
    port = 7777
    if len(sys.argv) > 1:
        port = sys.argv[1]
    server=SimpleServer(port)
```

Writing a Simple Client

```
import socket
import sys

class SimpleClient:
    def __init__(self, serverAddr, serverPort):
        self.sock = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
        self.sock.connect((serverAddr, serverPort))

    def sendToServer(self, message):
        self.sock.send(message)
        return self.sock.recv(1024)

    def close(self):
        self.sock.close()

if __name__ == "__main__":
    if len(sys.argv) != 3:
        sys.exit(1)
    else:
        client = SimpleClient(sys.argv[1], int(sys.argv[2]))

    while 1:
        string = sys.stdin.readline()
        if string == "close\n":
            client.close()
            sys.exit(0)
        else:
            response = client.sendToServer(string)
            print "Server replied '", response,  "'"
```

Extra Useful Tricks

- Figuring out what you're connected to:
  - s.getpeername() returns a tuple of (address, port) indicating what you're connected to (or what has connected to you)
- Figuring out your local address:
  - s.getsockname() returns a tuple of (address, port) indicating your local address. Useful when you need to know what port your service is on
- Making life easier:
  - s.setsockopt(socket.SOL_SOCKET, socket.SO_REUSEADDR, 1)
  - Tells the OS that it's ok to reuse a port number
  - Example: you find a bug, kill your server, fix it, and restart
  - Without this call, OS may prevent the port from being reused until some timeout expires

Multi-threaded Servers

- Problem with previous simple server:
  - While it's processing requests from one client, every other client must queue up
  - Only when first client dies does the next one in the queue get handled
- Bad, since most servers should support connections by multiple clients at the same time
- Common approach: multi-threaded servers
  - One thread to hang around waiting for clients to appear
  - One thread to handle each client; terminates when client is done

Multi-Threaded Server Example

```
import socket
import sys
import threading

class MTServer:
	def __init__(self, port):
		self.sock = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
		self.sock.setsockopt(socket.SOL_SOCKET, socket.SO_REUSEADDR, 1)
		self.sock.bind(('', port))
		self.sock.listen(1)
		while 1:
			requestSock, peerAddress = self.sock.accept()
			handler = Handler(requestSock)

class Handler:
	def __init__(self, requestSock):
		self.requestSock = requestSock
		self.thread = threading.Thread(target=self.handle)
		self.thread.start()

	def handle(self):
		while 1:
			input = self.requestSock.recv(1024)
			if not input:
				break
			self.requestSock.send(input)
		self.requestSock.close()

if __name__ == "__main__":
	port = 7777
	if len(sys.argv) > 1:
		port = sys.argv[1]
	server=MTServer(port)
```

Message Formatting

- Any messages you send to a server must be parseable by it
  - Recipient must be able to decipher what you sent it
  - Must know when it has reached the end of the message
- There are many ways of encoding messages

The Joy of ASCII

- Many protocols use a simple text-based encoding
  - Example: HTTP

    GET /index.html HTTP/1.0
  - Example: SMTP

    HELO rutabaga.cc.gatech.edu

    MAIL From: Keith Edwards <keith@cc>

    DATA

    Hello there!

    .
- Parameters and commands encoded using simple, regular format
- *Marshalling*: the process of gathering parameters and encoding them for transmission
- *Unmarshalling*: the process of unpacking the received data for use by your program
- Goal should be *machine* parseability for ease of implementation; *human* parseability for ease of debugging

More Complex Data

- What about very complex data?
- Example: marshalling an arbitrary Jython dictionary
  - {"name":"keith,"location": (2.425, 1.783, 0.892),"info": {"email": "keith@cc","phone": 56783},"buddies":"[ralph","fred","betty"] }
- You *could* create a string representation that is parseable and "rebuildable" on the other end
- Sometimes called *flattening* the dictionary to a string
- Parsing at the recipient can be very difficult
- Need to account for *arbitrary* objects that might be stored in dictionaries (including custom-defined objects)

Is There an Easier Way?

- Most “standard” services just bite the bullet and use ASCII
  - Perhaps with more complex formatting atop it, such as XML
  - ASCII--since it’s universal--lets you program a client in any language that speaks the necessary protocol
- The marshalling/unmarshalling of complicated parameters can be a significant part of the complexity in dealing with a given service
- **But:** If you *know* you’ll only be working with clients in a particular language, you can take some short cuts

Serialization

- *Serialization* is the process of automatically creating a representation of complex data that can be shipped over the wire
- Generally *built in* to the programming language itself
  - So: can work with custom-defined data types without special work by the programmer
  - Present in Java, Python, Jython, ...
- *Opaque*: with most of these systems, you don't care what the on-the-wire representation is
  - Generally complex; generally non-ASCII
  - System takes care of the chores of generating it, and parsing it
- Terminology: a serialization system is one approach to simplifying the marshalling and unmarshalling of arguments

Serialization in Jython/Python

- Serialization provided by the *pickle* library
  - You "pickle" objects for transmission over the wire
- Works for any Jython data type, including custom-defined objects
  - However: some objects may "depickle" with data intact, but not behave as expected
  - Classic example: swing widgets

Sending Dictionaries Using Pickle

- On the sending side:

  import pickle

  dict = {"name":"keith, "location": (2.425, 1.783, 0.892), "info": {"email": "keith@cc", "phone": 56783}, "buddies": "[ralph", "fred", "betty"] }

  data = pickle.dumps(dict)

  s.send(data)

- On the receiving side:

  data = s.recv(1024)

  dict = pickle.loads(data)

Combining Pickling with Other Techniques

- Pickled objects are *opaque*--you can't easily parse the data yourself

  But you generally don't want/need to. Just unpickle it!

- Common approach is to create a data structure that represents the entire message and pickle it
  - Sender:

    ```
    s.send(pickle.dumps((”Hello”, dict)))
    ```

  - Receiver:

    ```
    pickle.loads(s.recv(1024))
    ```

Instant Messaging Assignment

- Turn the GUI front end into a working network-ified program
- Grab the server off the class web page
- Understand the protocol it speaks
- Integrate it into your client
  - Connect to the server
  - Send messages to it in response to starting up, user events (such as new chats), etc.
  - Be prepared to receive messages from it
    - Asynchronous notifications of online users: *necessitates having a thread to listen for messages!*
    - Responses to client-initiated messages (invitations, etc.)

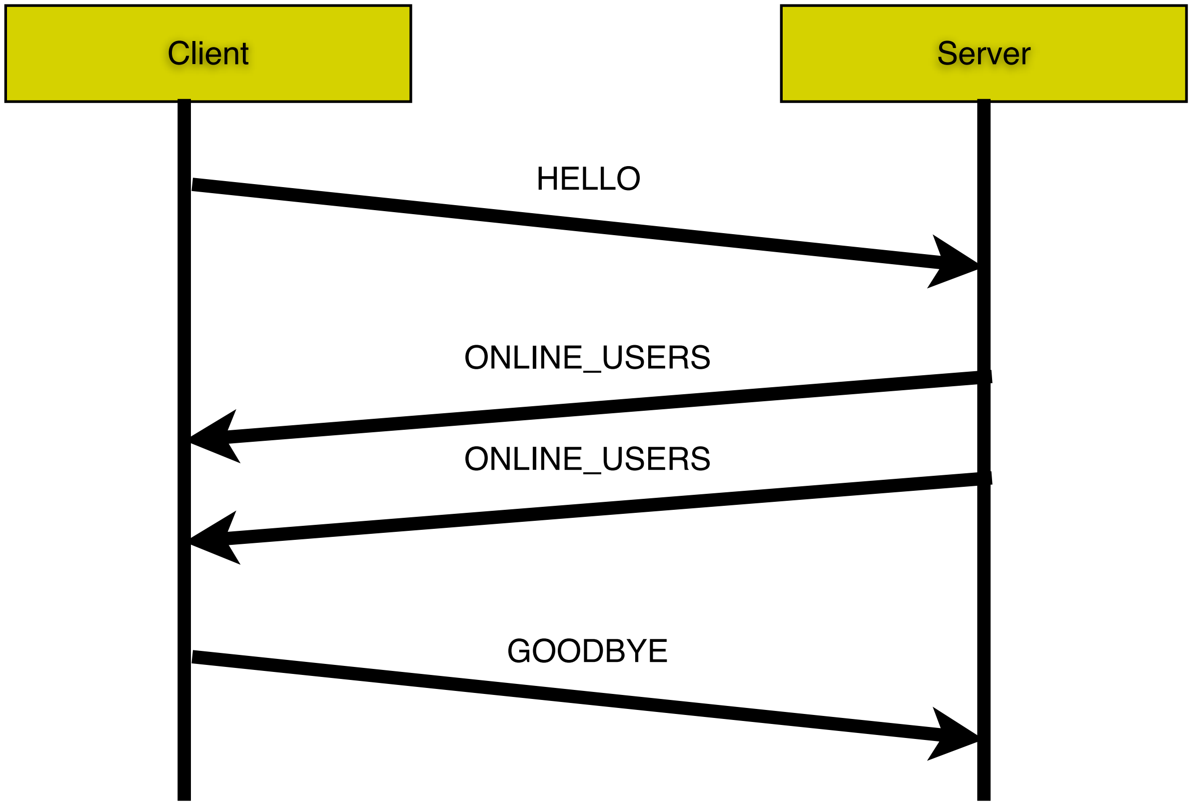
Getting Started

- Get code off the web site: server.py
- Running the server
  - jython server.py
  - Will run on port 6666
  - Generates a lot of debugging messages (don't run under JES though)
  - Look at the *handle* messages in the server if you need to see what it's doing
- Create a client to connect to this port
  - Start small! Create a new file net.py
  - Generate a message to tell the server that you're online
  - Next, make the online user list "real": thread to listen for incoming messages
  - Debug by running multiple instances of the client (as different users)
  - Pay attention to server debugging messages!
  - Iron out the connection, messaging issues *then* integrate it

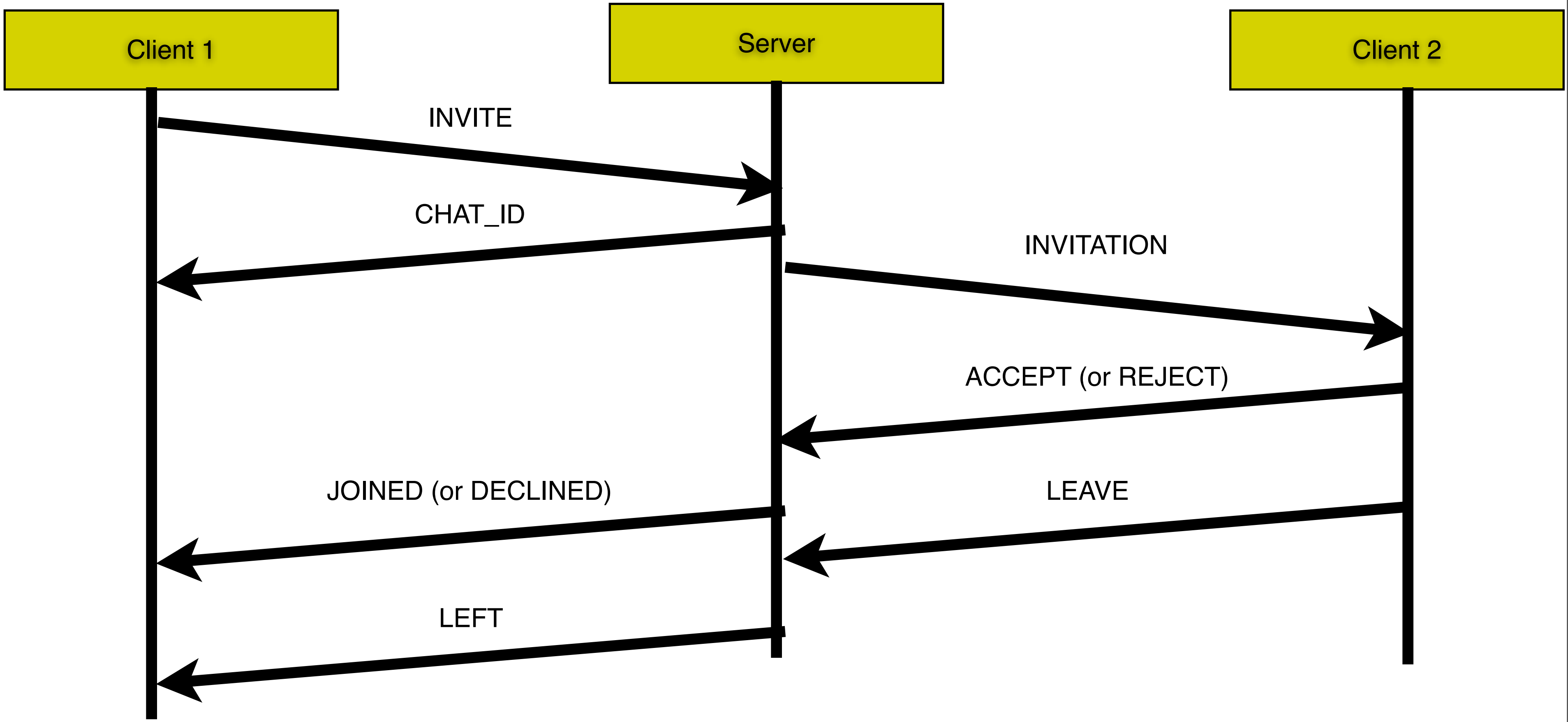
The IM Server Protocol

- Uses the "pickled argument list" approach
  - Every message is a pickled list; first item is the "command"
- Clients announce themselves when they first start; server periodically sends updated online user status
- Each chat has a unique ID *that the server generates*
- Clients only communicate with server, not each other
  - Tell the server to *invite*, specifying desired users
  - Server creates a chat, giving it a unique *chat ID*, and sending this ID back to the initiator
  - Server sends *invitations* to all clients, indicating the chat ID
  - Clients *accept* or *reject* the invitation, providing the specified chat ID
  - Clients tell server to send message to parties in a chat, by specifying both the message and the chat ID
  - Server propagates message to all members of the chat
  - Clients can leave chats by specifying their ID

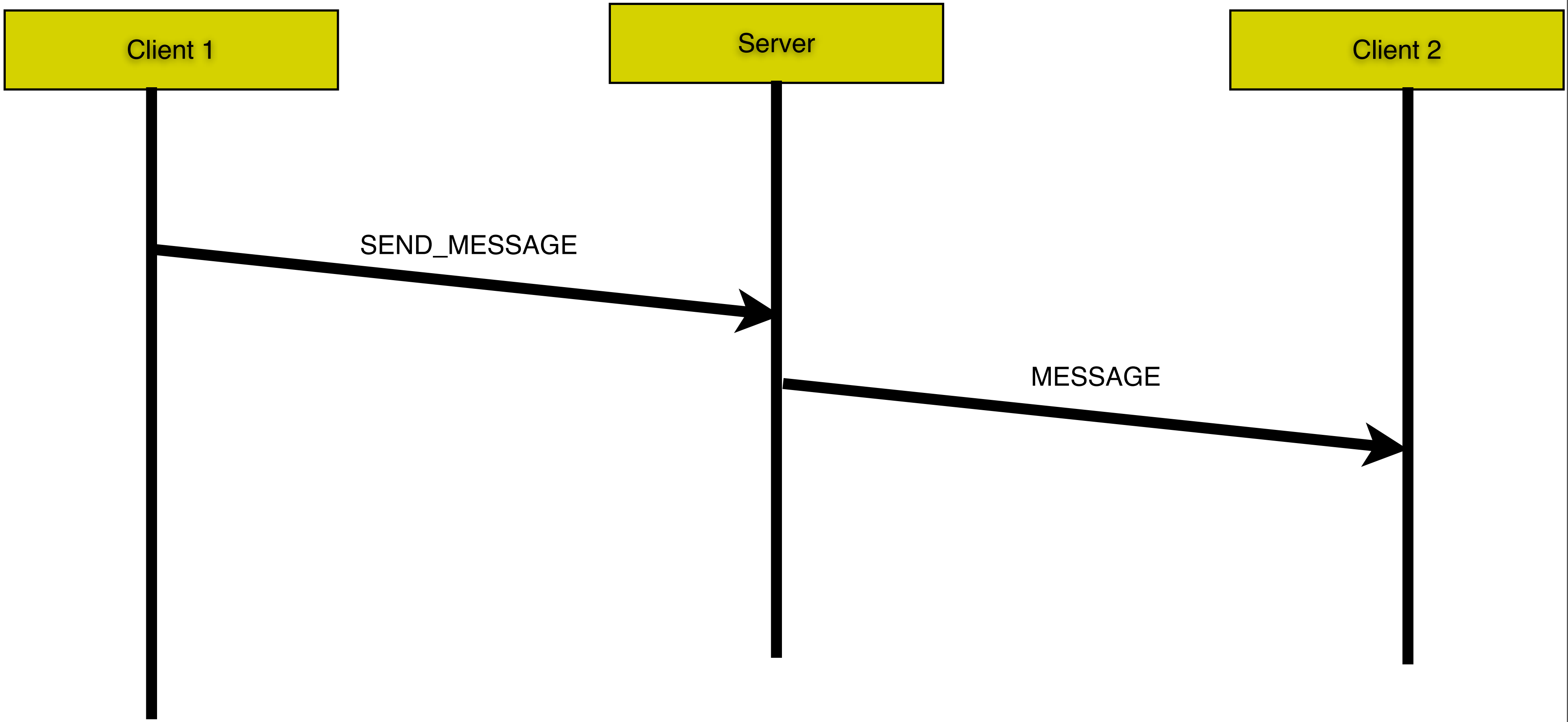
The IM Server protocol: Basic status info



The IM Server protocol: Basic chat setup



The IM Server protocol: Sending text



The IM Server Protocol

Messages from Server to Client	Messages from Client to Server
["ONLINE_USERS", {user1: status1, user2: status2, ...}] Sent by the server every 5 seconds to all clients to indicate what users are online and their status. The parameter is a dict.	["HELLO", username, status] Sent by client when it first starts; username and status are both strings
["CHAT_ID", chatID, [invitee1, invitee2, ...]] Sent in response to an invite, providing the initiating client with the chatID. The invitees list allows the client to tell which chat this ID is for.	["GOODBYE"] Sent by client when it shuts down
["INVITATION", invitor, [invitee1, invitee2, ...], chatID] Sent by the server to invitees to a new chat. Invitor is a string that indicates who started the chat; the invitees list indicates the other invitees; chatID is an integer that identifies the new chat.	["INVITE", [user1, user2, ...]] Sent by client to ask the server to invite a list of users to a new chat. Each user name should be a string.
["JOINED", chatID, userName] Sent to all members of a chat when an invitee (indicated by the userName string) joins. chatID indicates the chat.	["ACCEPT", chatID] Used to accept an invitation to chat. The client should provide the chatID it is accepting; this is an integer.
["DECLINED", chatID, userName] Sent to all members of a chat when an invitee (indicated by userName) declines an invitation. chatID indicates the chat.	["REJECT", chatID] Used to reject an invitation to chat. The client should provide the chatID it is rejecting; this is an integer.
["MESSAGE", chatID, userName, message] Sent to all members of a chat when a user sends a message. chatID indicates the chat; userName indicates the sender; and the message string is the message itself.	["SEND_MESSAGE", chatID, message] Used to send a text message to the members in a chat. chatID is an integer and message is the text to be sent.
["LEFT", chatID, userName] Sent to all members of a chat when a member (userName) leaves.	["LEAVE", chatID] Used by a client when it wishes to leave the chat indicated by the chatID.
	["CHANGE_STATUS", newStatus] (*optional!)* Change the status message associated with the client. newStatus is a string.

A Few Tips

- Write some utility methods for common operations
  - Example: receiving variable-length replies:

```
def receive(self, sock):
    reply = “”
    while 1:
        data = sock.recv(1024)        # read up to 1024 bytes
        if not data:                  # no data means connection closed
            break
        elif len(data) == 1024:       # read the data, there may be more; keep going
            reply = reply + data
        else:                         # read less than 1024, so that’s the end of the msg
            reply = reply + data
            break
    return reply
```

More Tips

- Remember: messages from the server may come *at any time* (asynchronously!)
    - Invitations to chat, updated user list, a new message, etc.
- Create your socket and connect it to the server
- Whenever you need to *write* to the server, you can do it pretty much anywhere
- But for *reading*, start a new thread that'll always be hanging out, waiting for messages to show up (like the Handler class we saw before):

```
class Handler:
    def __init__(self, sock):
        self.thread = threading.Thread(target=self.handle)
        self.thread.start()

    def handle(self):
        input = self.sock.recv(1024)
        # deal with the message you just read from the server here
        ....
```