Lecture 13
Networking

Where do we go from here?

- networking
- Java (CM)
- C++
- Go
- little languages
- exploratory software development (CM)
- legal issues in software
- ethical issues in software (CM)

- Guests:

Apr 4:	Molly Nacey '13,	startup, Google SWE, Area 120, consulting
Apr 11:	Clay Bavor '05,	VP, Augmented and Virtual Reality, Google
Apr 30:	mystery guest #2: don't miss it!	

Internet architecture

- **connects independent heterogeneous networks**
  - each network connects multiple computers
  - nearby computers connected by local area network

    often Ethernet but lots of other choices
- **networks connected by gateways/routers**
  - route packets from one network to next
  - gateways continuously exchange routing information
- **each packet passes through multiple gateways**
  - gateway passes packet to gateway that is closer to ultimate destination
  - usually operated by different companies
- **information travels through networks in packets**
  - each packet is independent of all others

    like individual envelopes through the mail
  - all packets have the same format

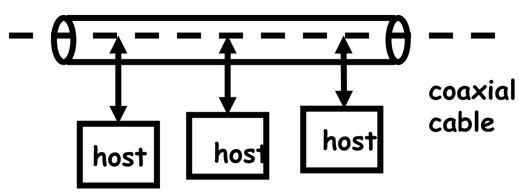
    but are carried on different physical transport media
- **no central control**
- **ICANN: central authority for resources that have to be unique**
  - IP addresses, domain names, country codes, ...

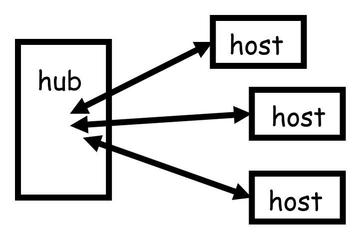
Internet mechanisms

- **names** for networks and computers
  - `www.cs.princeton.edu, de.licio.us`
  - hierarchical naming scheme
  - imposes logical structure, not physical or geographical
- **addresses** for identifying networks and computers
  - each has a unique 32-bit IP address (128 bits for IPv6)
  - ICANN assigns contiguous blocks of numbers to networks (icann.org)
  - network owner assigns host addresses within network
- **DNS** Domain Name System maps names /addresses
  - `www.princeton.edu = 128.112.136.12`
  - hierarchical distributed database
  - caching for efficiency, redundancy for safety
- **routing to** find paths from network to network
  - gateways/routers exchange routing info with nbrs
- **protocols** for packaging and transporting information, handling errors, ...
  - IP (Internet Protocol): a uniform transport mechanism
  - at IP level, all info is in a common packet format
  - different physical systems carry IP in different formats (e.g., Ethernet, wireless, fiber, phone,...)
  - higher-level protocols built on top of IP for exchanging info like web pages, mail, …

Local Area Networks; Ethernet

- a LAN connects computers ("hosts") in a small geographical area
- Ethernet is the most widely used LAN technology
  - developed by Bob Metcalfe & David Boggs (ELE '72) at Xerox PARC, 1973
  - each host has a unique 48-bit identification number
  - data sent in "packets" of 100-1500 bytes
    - packets include source and destination addresses, error checking
    - typical data rate 100-1000 Mbits/sec; maximum cable lengths
  - CSMA/CD: carrier sense multiple access with collision detection
    - sender broadcasts, but if detects someone else sending, stops, waits a random interval, tries again
  - hubs and wireless nets simulate cable behavior





packet:

hdr	src	dest		data	CRC
8	6	6	2	46-1500	4

Protocols

- precise rules that govern communication between two parties
- basic Internet protocols usually called TCP/IP
  - 1973 by Bob Kahn *64, Vint Cerf
- IP: Internet protocol (bottom level)
  - all packets shipped from network to network as IP packets
  - each physical network has own format for carrying IP packets (Ethernet, fiber, …)
  - no guarantees on quality of service or reliability: "best effort"
- TCP: transmission control protocol
  - reliable stream (circuit) transmission in 2 directions
  - most things we think of as "Internet" use TCP
- application-level protocols, mostly built from TCP
  - SSH, FTP, SMTP (mail), HTTP (web), …
- UDP: user datagram protocol
  - unreliable but simple, efficient datagram protocol
  - used for DNS, NFS, …
- ICMP: internet control message protocol
  - error and information messages
  - ping, traceroute

Internet (IP) addresses

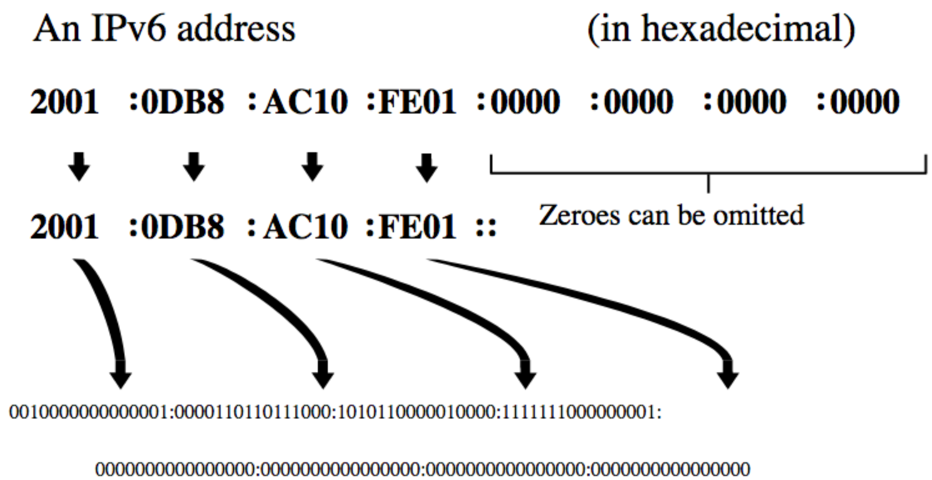
- **each network and each connected computer has an IP address**
- **IP address: a unique 32-bit number in IPv4 (IPv6 is 128 bits)**
  - 1st part is network id, assigned centrally in blocks
    (Internet Assigned Numbers Authority -> Internet Service Provider -> you)
  - 2nd part is host id within that network
    assigned locally, often dynamically

net part	host on that net

- **written in "dotted decimal" notation: each byte in decimal**
  - e.g., 128.112.128.81 = www.princeton.edu

128	112	128	81
10000000	01110000	10000000	01010001

IPv6



Fixed header format

<table>
<tr><th>Offsets</th><th>Octet</th><th colspan="8">0</th><th colspan="8">1</th><th colspan="8">2</th><th colspan="8">3</th></tr>
<tr><th>Octet</th><th>Bit</th><th>0</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14</th><th>15</th><th>16</th><th>17</th><th>18</th><th>19</th><th>20</th><th>21</th><th>22</th><th>23</th><th>24</th><th>25</th><th>26</th><th>27</th><th>28</th><th>29</th><th>30</th><th>31</th></tr>
<tr><th>0</th><th>0</th><td colspan="4">Version</td><td colspan="8">Traffic Class</td><td colspan="20">Flow Label</td></tr>
<tr><th>4</th><th>32</th><td colspan="16">Payload Length</td><td colspan="8">Next Header</td><td colspan="8">Hop Limit</td></tr>
<tr><th>8</th><th>64</th><td colspan="32" rowspan="4">Source Address</td></tr>
<tr><th>12</th><th>96</th></tr>
<tr><th>16</th><th>128</th></tr>
<tr><th>20</th><th>160</th></tr>
<tr><th>24</th><th>192</th><td colspan="32" rowspan="4">Destination Address</td></tr>
<tr><th>28</th><th>224</th></tr>
<tr><th>32</th><th>256</th></tr>
<tr><th>36</th><th>288</th></tr>
</table>

IP: Internet Protocol

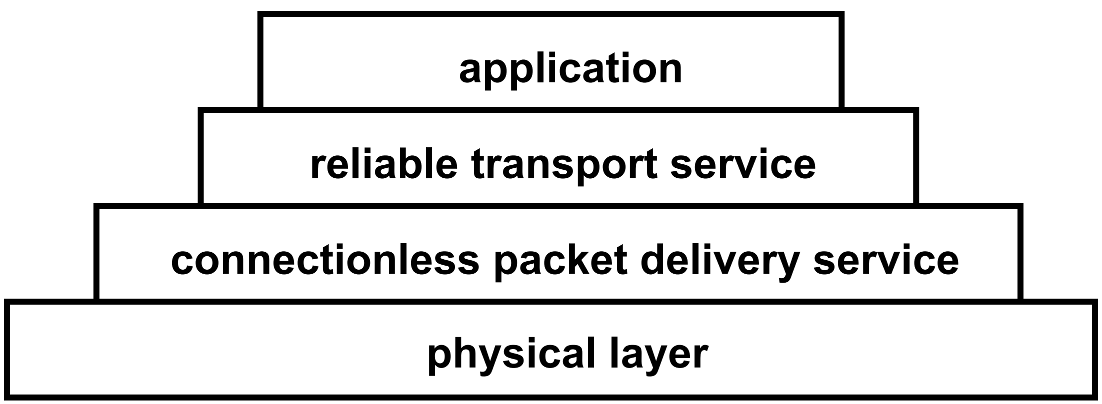
- **unreliable connectionless packet delivery service**
  - every packet has 20-40B header with
    - source & destination addresses,
    - time to live: maximum number of hops before packet is discarded (each gateway decreases this by 1)
    - checksum of header information (not of data itself)
  - up to 65 KB of actual data
- **IP packets are *datagrams*:**
  - individually addressed packages, like envelopes in mail
  - "connectionless": every packet is independent of all others
  - unreliable -- packets can be damaged, lost, duplicated, delivered out of order
  - packets can arrive too fast to be processed
  - stateless: no memory from one packet to next
  - limited size: long messages have to be fragmented and reassembled
- **higher level protocols synthesize error-free communication from IP packets**

TCP: Transmission Control Protocol

- **reliable connection-oriented 2-way byte stream**
  - no record boundaries
    - if needed, create your own by agreement
- **a message is broken into 1 or more packets**
- **each TCP packet has a header (20 bytes) + data**
  - header includes checksum for error detection,
  - sequence number for preserving proper order, detecting missing or duplicates
- **each TCP packet is wrapped in an IP packet**
  - has to be positively acknowledged to ensure that it arrived safely
    - otherwise, re-send it after a time interval
- **a TCP connection is established to a specific host**
  - **and a specific "port" at that host**
- **each port provides a specific service**
  - see /etc/services
  - FTP = 21, SSH = 22, SMTP = 25, HTTP = 80
- **TCP is basis of most higher-level protocols**

Higher level protocols:

- FTP: file transfer
- SSH: terminal session
- SMTP: mail transfer
- HTTP: hypertext transfer -> Web
- protocol layering:
  - a single protocol can't do everything
  - higher-level protocols build elaborate operations out of simpler ones
  - each layer uses only the services of the one directly below
  - and provides the services expected by the layer above
  - all communication is between peer levels: layer N destination receives exactly the object sent by layer N source



Network programming

- C: client, server, socket functions; based on processes & inetd
- Java: import java.net.* for Socket, ServerSocket; threads
- Python: import socket, SocketServer; threads
- underlying mechanism (pseudo-code):

server:

```
fd = socket(protocol)
bind(fd, port)
listen(fd)
fd2 = accept(fd, port)
while (...)
    read(fd2, buf, len)
    write(fd2, buf, len)
close(fd2)
```

client:

```
fd = socket(protocol)
connect(fd, server IP address, port)
while (...)
   write(fd, buf, len)
   read(fd, buf, len)
close(fd)
```

C TCP client

```
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <arpa/inet.h>
#include <netdb.h>

struct hostent *ptrh;        /* host table entry */
struct protoent *ptrp;       /* protocol table entry */
struct sockaddr_in sad;      /* server adr */
sad.sin_family = AF_INET;    /* internet */
sad.sin_port = htons((u_short) port);
ptrh = gethostbyname(host);  /* IP address of server /
memcpy(&sad.sin_addr, ptrh->h_addr, ptrh->h_length);
ptrp = getprotobyname("tcp");
fd = socket(PF_INET, SOCK_STREAM, ptrp->p_proto);
connect(sd, (struct sockaddr *) &sad, sizeof(sad));

while (...) {
   write(fd, buf, strlen(buf)); /* write to server */
   n = read(fd, buf, N);        /* read reply from server */
}
close(fd);
```

C TCP server

```
struct protoent *ptrp;       /* protocol table entry */
struct sockaddr_in sad;      /* server adr */
struct sockaddr_in cad;      /* client adr */
memset((char *) &sad, 0, sizeof(sad));
sad.sin_family = AF_INET;    /* internet */
sad.sin_addr.s_addr = INADDR_ANY; /* local IP adr */

sad.sin_port = htons((u_short) port);
ptrp = getprotobyname("tcp");
fd = socket(PF_INET, SOCK_STREAM, ptrp->p_proto);
bind(fd, (struct sockaddr *) &sad, sizeof(sad));
listen(fd, QLEN);

while (1) {
   fd2 = accept(sd, (struct sockaddr *) &cad, &alen));
   while (1) {
      read(fd2, buf, N);
      write(fd2, buf, N);
   }
   close(fd2);
}
```

Serving multiple requests simultaneously

- **how can we serve more than one client at a time?**
- **in C/Unix, usually start a new process for each conversation**
  - fork & exec: process is entirely separate entity
  - usually shares nothing with other processes
  - operating system manages scheduling
  - alternative: use a threads package (e.g., pthreads)
- **in Java, use threads**
  - threads all run in the same process and address space
  - process itself controls allocation of time (JVM)
  - threads have to cooperate (JVM doesn't enforce this)
  - threads must not interfere with each other's data and use of time
- **Thread class defines two primary methods**
  - start start a new thread
  - run run this thread
- **a class that wants multiple threads must**
  - extend Thread
  - implement run()
  - call start() when ready, e.g., in constructor
- **Python is very similar**

Inetd: use processes to avoid blocking

- how do we arrange that a server can dispatch requests to the right processes without blocking?
- one solution: a daemon process that accepts connection requests, and forks a new process for each request

```
for (;;) {
  int alen = sizeof(cad), sd2;
  if ((sd2 = accept(sd, (struct sockaddr *) &cad, &alen)) < 0)
    exit(1);      /* accept failed */
  if (fork() == 0) {
    close(sd);      /* child does this */
    runsrv(sd2);
    exit(0);
  }
  close(sd2); /* parent does this */
}
```

Java client: copy stdin to server, read reply

- uses Socket class for TCP connection between client & server

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

public class cli {

static String host = "localhost";  //  or 127.0.0.1
static String port = "33333";

public static void main(String[] argv) {
    if (argv.length > 0)
        host = argv[0];
    if (argv.length > 1)
        port = argv[1];
    new cli(host, port);
}
```

- (continued…)

Java client: part 2

```
cli(String host, String port) { // tcp/ip version
   try {
      BufferedReader stdin = new BufferedReader(
            new InputStreamReader(System.in));
      Socket sock = new Socket(host, Integer.parseInt(port));
      System.err.println("client socket " + sock);
      BufferedReader sin = new BufferedReader(
            new InputStreamReader(sock.getInputStream()));
      BufferedWriter sout = new BufferedWriter(
            new OutputStreamWriter(sock.getOutputStream()));
      String s;
      while ((s = stdin.readLine()) != null) { // read cmd
         sout.write(s);  // write to socket
         sout.newLine();
         sout.flush();   // needed
         String r = sin.readLine(); // read reply
         System.out.println(host + " got [" + r + "]");
         if (s.equals("exit"))
            break;
      }
      sock.close();
   } catch (IOException e) {
        e.printStackTrace();
   }
}
```

Multi-threaded Java server

```
public class multisrv {
  static String port = "33333";

  public static void main(String[] argv) {
     if (argv.length == 0)
         multisrv(port);
     else
         multisrv(argv[0]);
  }
  public static void multisrv(String port) { // tcp/ip version
     try {
         ServerSocket ss =
             new ServerSocket(Integer.parseInt(port));
         while (true) {
             Socket sock = ss.accept();
             System.err.println("multiserver " + sock);
             new echo1(sock);
         }
     } catch (IOException e) {
         e.printStackTrace();
     }
  }
}
```

Thread part...

```
class echo1 extends Thread {
  echo1(Socket sock) {
    this.sock = sock; start();
  }
  public void run() {
    try {
        BufferedReader in = new BufferedReader(new
             InputStreamReader(sock.getInputStream()));
        BufferedWriter out = new BufferedWriter(new
          OutputStreamWriter(sock.getOutputStream()));
        String s;
        while ((s = in.readLine()) != null) {
            out.write(s);
            out.newLine();
            out.flush();
            System.err.println(sock.getInetAddress() + " " + s);
            if (s.equals("exit"))     // end this conversation
                break;
        }
        sock.close();
    } catch (IOException e) {
        System.err.println("server exception " + e);
    }
 }
```

Multi-threaded Python server

```
#!/usr/bin/python

import SocketServer
import socket
import string

class Srv(SocketServer.StreamRequestHandler):
  def handle(self):
    print "Python server called by %s" % (self.client_address,)
    while 1:
      line = self.rfile.readline()
      print "server got " + line.strip()
      self.wfile.write(line)
      if line.strip() == "exit":
        break

srv = SocketServer.ThreadingTCPServer(("",33333), Srv)
srv.serve_forever()
```

Node.js server

```
var net = require('net');
var os = require('os');
var server = net.createServer(function(c) {
                                  //'connection' listener
  console.log('server connected');
  c.on('data', function(d) {
    process.stdout.write(d);
    console.log("Javascript srv got [%s] from %s",
                      d.toString().trim(), os.hostname());
  });
  c.on('end', function() {
    console.log('server disconnected');
  });
  c.pipe(c);
});
server.listen(33333, function() { //'listening' listener
  console.log('Javascript srv listening');
});
```

Multi-threaded client: web crawler

- want to crawl a bunch of web pages to do something
  - e.g., figure out how big they are
- problem: network communication takes relatively long time
  - program does nothing useful while waiting for a response
- solution: access pages in parallel
  - send requests asynchronously
  - display results as they arrive
  - needs some kind of threading or other parallel process mechanism
- takes less time than doing them sequentially

Python version, no parallelism

```
import urllib2, time, sys

def main():
    start = time.time()
    for url in sys.argv[1:]:
        count("http://" + url)
    dt = time.time() - start
    print "\ntotal: %.2fs" % (dt)

def count(url):
    start = time.time()
    n = len(urllib2.urlopen(url).read())
    dt = time.time() - start
    print "%6d  %6.2fs   %s" % (n, dt, url)

main()
```

Python version, with threads

```
import urllib2, time, sys, threading

global_lock = threading.Lock()

class Counter(threading.Thread):
  def __init__(self, url):
    super(Counter, self).__init__()
    self.url = url

  def count(self, url):
    start = time.time()
    n = len(urllib2.urlopen(url).read())
    dt = time.time() - start
    with global_lock:
      print "%6d  %6.2fs   %s" % (n, dt, url)

  def run(self):
    self.count(self.url)

def main():
  threads = []
  start = time.time()
  for url in sys.argv[1:]:  # one thread each
    w = Counter("http://" + url)
    threads.append(w)
    w.start()

  for w in threads:
    w.join()
  dt = time.time() - start
  print "\ntotal: %.2fs" % (dt)

main()
```

Python version, with threads (main)

```
def main():
  threads = []
  start = time.time()
  for url in sys.argv[1:]:  # one thread each
    w = Counter("http://" + url)
    threads.append(w)
    w.start()

  for w in threads:
    w.join()
  dt = time.time() - start
  print "\ntotal: %.2fs" % (dt)

main()
```

Python version, with threads (count)

```
import urllib2, time, sys, threading

global_lock = threading.Lock()

class Counter(threading.Thread):
  def __init__(self, url):
    super(Counter, self).__init__()
    self.url = url

  def count(self, url):
    start = time.time()
    n = len(urllib2.urlopen(url).read())
    dt = time.time() - start
    with global_lock:
      print "%6d  %6.2fs   %s" % (n, dt, url)

  def run(self):
    self.count(self.url)
```