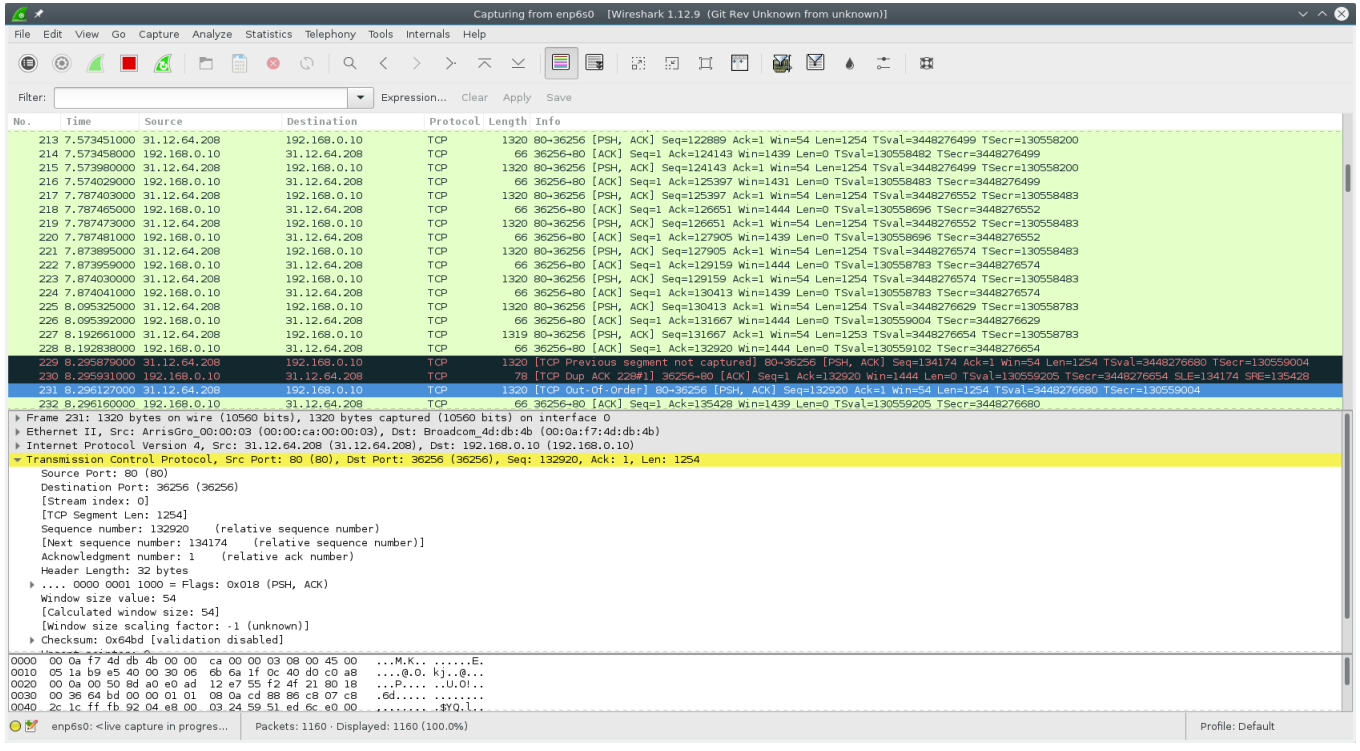
Networks and Network Programming



Wireshark screenshot of network traffic

Networking

- Hardware
- Protocols
- Software

The network is the computer. (John Gage)

Networking Overview

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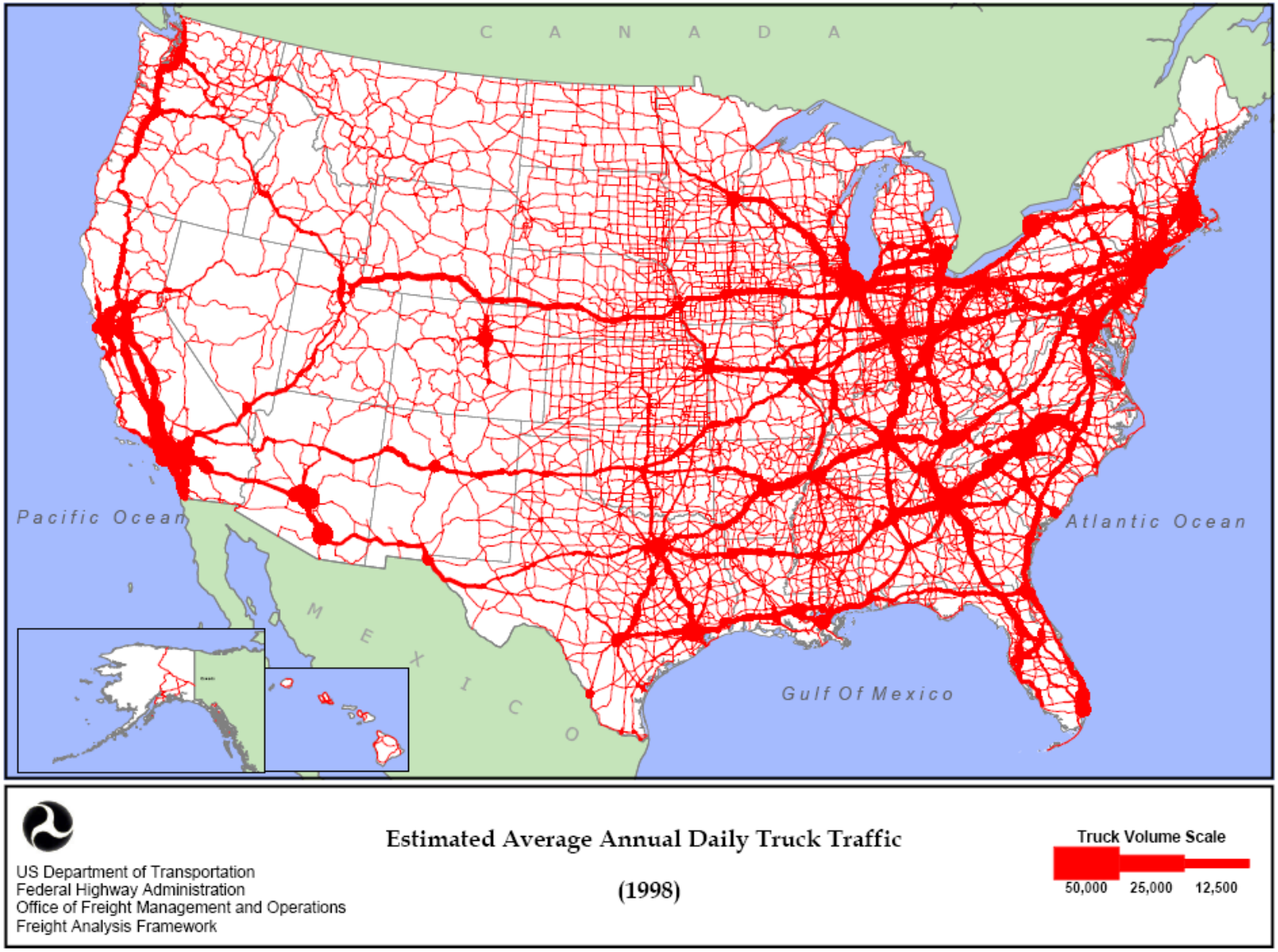
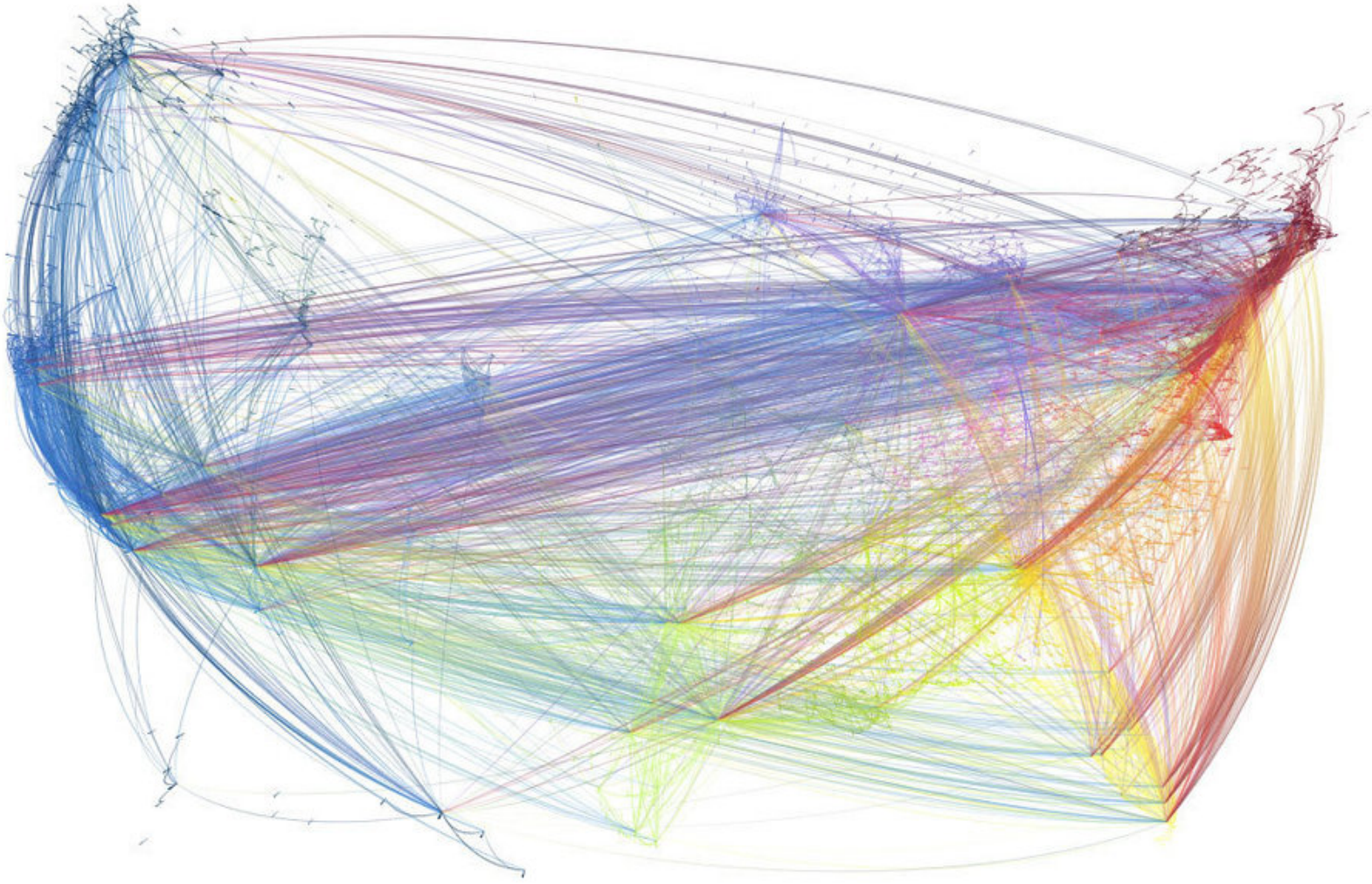

C A N A D A
Pacific Ocean
Atlantic Ocean
M E X I C O
Gulf Of Mexico
US Department of Transportation
Federal Highway Administration
Office of Freight Management and Operations
Freight Analysis Framework
Estimated Average Annual Daily Truck Traffic
(1998)
Truck Volume Scale
50,000
25,000
12,500



Networking Options

Network type	maximum bandwidth (Mbits/second)	latency (microsecs)
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- Internet backbone uses specialized hardware and has speeds up to 500G/s. Experimental systems are available for much higher speeds.

Ethernet Protocol

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  - If packets collide, then the machines choose a random number from the interval $(0, k)$ and try again.
  - On subsequent collisions, the value k is doubled each time, making it a lot less likely that a collision would occur again. This is an example of an *exponential backoff protocol*.

Ethernet Packets

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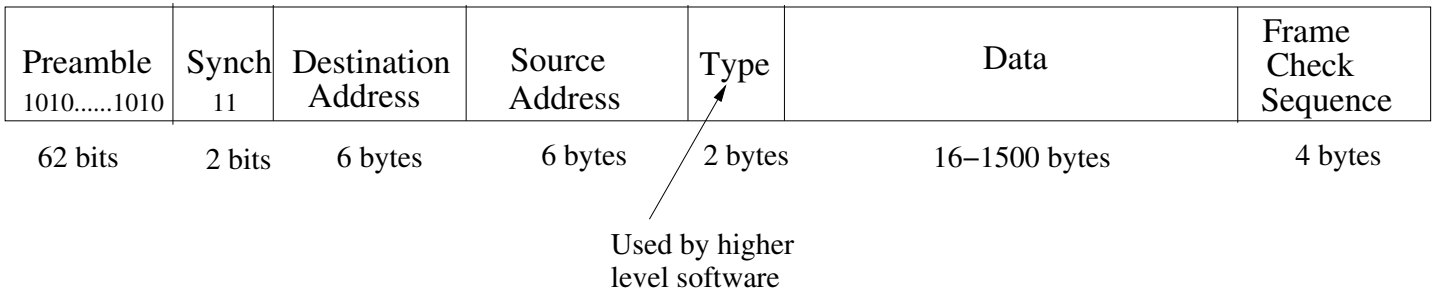

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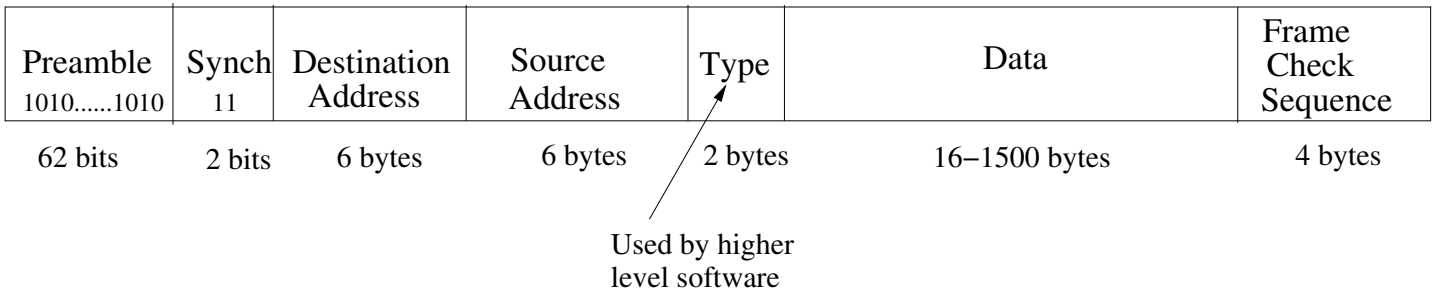

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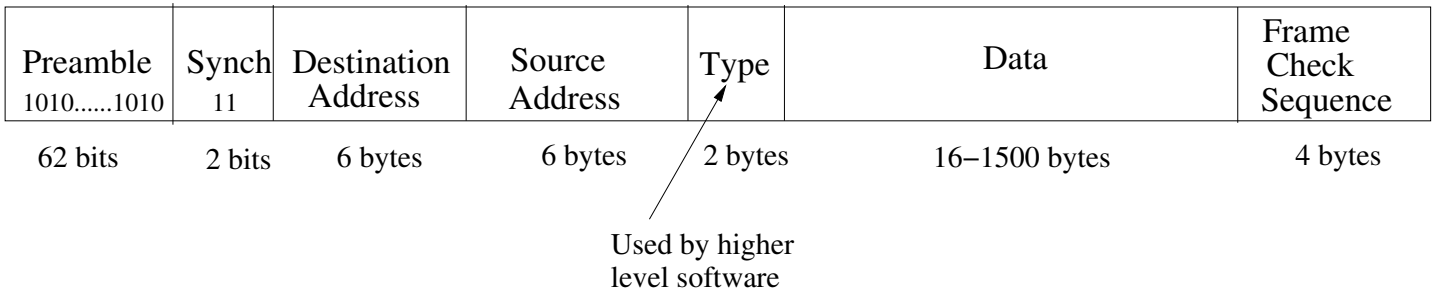

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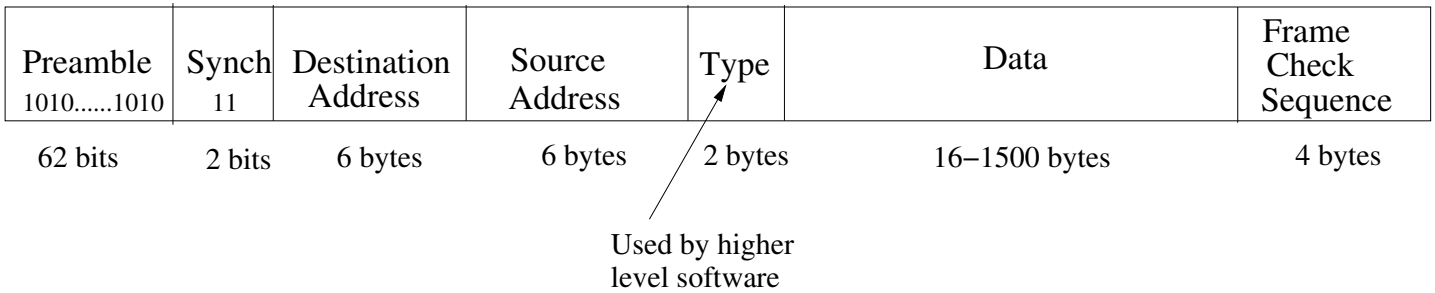

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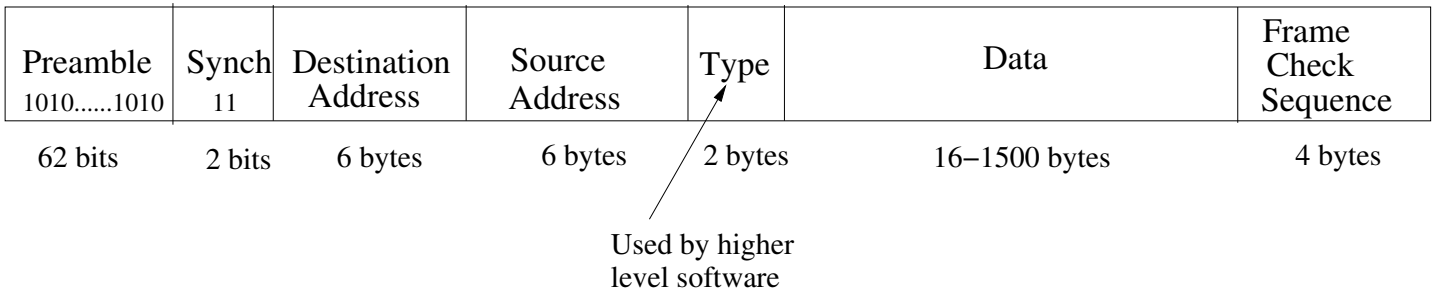

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Use the program `wireshark` to watch live Ethernet packets on your network!

Network Topology Design

Ranges of possibilities.

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Network Topology Options

Hubs and Switches.

- Direct wire. Two machines can be connected directly by a Ethernet cable (usually a Cat 5e cable) without needing a hub or a switch. With multiple NICs per machine, we can create networks but then we need to specify routing tables to allow packets to get through. The machines will end up doing double-duty as routers.

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- Switches. Accepts packets, interprets destination address fields and send packets down only the segment that has the destination node. Allows half the machines to communicate directly with the other half (subject to bandwidth constraints of the switch hardware). Multiple switches can be connected in a tree or sometimes other schemes. The root switch can become a bottleneck. The root switch can be a higher bandwidth switch.

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- Stackable, high bandwidth switches. Stackable switches with special high bandwidth interconnect in-between the switches. For example, Cisco has 24-port Gigabit stackable switches with a 32 Gbits/sec interconnect. Up to 8 such switches can be stacked together. All the stacked switches can be controlled by one switch and managed as a single switch. If the controlling switch fails, the remaining switches hold an election and a new controlling switch is elected. Baystack also has stackable switches with a 40 Gbits/sec interconnect.

Network Interface Cards

- The Ethernet card, also known as the Network Interface Controller (NIC), contains the Data Link Layer and the Physical Layer (the two lowest layers of networking). Each Ethernet card has a unique hardware address that is know as its MAC address (MAC stands for Media Access Controller). The MAC address is usually printed on the Ethernet card.

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- Another issue to consider is that having multi-processor boards may cause more load on the network cards in each node. Certain network cards have multiple network processors in them, making them better candidates for multi-processor motherboards.

Networking Models

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- ISO Open System Interconnection (OSI). A reference model for networking prescribes seven layers of network protocols and strict methods of communication between them. Most systems implement simplified version of the OSI model. The ARPANET Reference Model (ARM) can be seen as a simplified OSI model.

Network Models (contd.)

ISO	ARM	4.2 BSD Layers	Example
application presentation	process applications	user programs/libraries	ssh
session		sockets	sock_stream
transport	host–host	protocols	TCP/IP
network	network interface	network interface	Ethernet driver
data link			
hardware	network hardware	network hardware	interlan controller

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  - Java Remote Method Invocation (`RMI`), Distributed Component Object Model (`DCOM`)

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- The address with all 0's in the host address, for example 192.168.1.0, is the network address and cannot be assigned to any machine. The address with all 1's in the host address, for example 192.168.1.255, is the network broadcast address.

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- These addresses are permanently unassigned, not forwarded by Internet backbone routers and thus do not conflict with publicly addressable IP addresses.

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Typical communication domains:

domain type	symbolic name	address format
Unix domain	`AF_Unix`	pathnames
Internet domain	`AF_INET`	Internet address and port number

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- *Raw sockets*. Allows access to TCP, IP or Ethernet protocol

Client-Server Setup Using Sockets

Server side	Client side
create a socket	
bind to an address	create a socket
listen for connections	connect to a server
accept a connection	
read/write to client	read/write to server
close	close or shutdown (input and/or output)

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  - port 21 is used by the `FTP` (File Transfer Protocol) client/server
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  - port 37 is reserved for getting the time from a system
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- The configuration directory `/etc/systemd.d/` contains several directories and files, one per service type, that control what is provided by the super-daemon `systemd` under Linux. The super-daemon invokes secondary daemons as needed.

TCP/IP and Linux/Unix Networking

- Port numbers in the range 1-255 are reserved in TCP/IP protocol for well known servers. In addition, Linux/Unix reserve the ports 1-1023 for superuser processes. Ports from 1024 to 65535 are available for user processes.
- The file `/etc/services` contains the port numbers for well known servers. For example:
  - port 7 is used for echoing the data sent by a client back
  - port 21 is used by the `FTP` (File Transfer Protocol) client/server
  - port 22 is used by `SSH` (Secure Shell Protocol) client/server
  - port 37 is reserved for getting the time from a system
  - port 80 is used by the `HTTP` (HyperText Transfer Protocol) daemon
  - port 443 is used by the `HTTP` over `TLS`/`SSL` (Transport Layer Security/Secure Sockets Layer for secure connections) (represented as the `https://` protocol)
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- Systemd subsumes `xinetd`, an older super daemon that was internet specific (`xinetd` stands for extended internet daemon).

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- A multi-threaded server accepts connections and passes them off to their own threads for processing.
- A multi-process server forks off a copy of itself after a connection to handle the client, while the original server process goes back to accept further connections.

Java ServerSocket Constructors and methods

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- `ServerSocket(int port, int backlog, InetAddress bindAddr)`: Create a server with the specified port, listen backlog, and local IP address to bind to.
- `accept()`: Listen for a connection to be made and accept it. Blocking call.
- See Java docs for other methods.

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- `Socket(String host, int port)`: Creates a stream socket and connects it to the specified port number on the named host.
- `ServerSocket(int port)`: Creates a server socket, bound to the specified port.
- Commonly used methods: `connect()`, `getOutputStream()`, `getInputStream()`, `close()`, `bind()` etc
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Client/Server Communication Using Sockets in Java

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- Now the server and the client can read/write to the streams associated with the sockets.
- Always open `OutputStream` before `InputStream` on a socket to avoid deadlock and synchronization problems.

Client Example (Java)

```
try {
    Socket server = new Socket("www.party.com",1234);
    OutputStream out = server.getOutputStream();
    InputStream in = server.getInputStream();

    out.write(42); //write a byte

    //write a newline or carriage return delimited string
    PrintWriter pout = new PrintWriter(out, true);
    pout.println("Hello!");

    //read a byte
    Byte response = in.read();

    //read a newline or carriage return delimited string
    BufferedReader bin = new BufferedReader (
        new InputStreamReader(in));
    String answer = bin.readLine();

    //send a serialized Java object
    ObjectOutputStream oout = new ObjectOutputStream(out);
    oout.writeObject(new java.util.Date());
    oout.flush();

    server.close();
} catch (IOException e) {System.err.println(e);}
```

Server Example (Java)

```
try {//meanwhile, on www.party.com...
    ServerSocket listener = new ServerSocket(1234);
    while (!finished) {
        Socket client = listener.accept();
        OutputStream out = client.getOutputStream();
        InputStream in = client.getInputStream();

        Byte someByte = in.read(); //read a byte

        //read a newline/carriage return delimited string
        BufferedReader bin =
            new BufferedReader(new InputStreamReader(in));
        String someString = bin.readLine();

        out.write(42); //write a byte
        PrintWriter pout = new PrintWriter(out, true);
        pout.println("Goodbye!");

        //read a serialized Java object
        ObjectInputStream oin = new ObjectInputStream(in);
        Date date = (Date) oin.readObject();

        client.close();
        //...
    }
    listener.close();
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- Thus, all the data coming into a specific network interface gets handed off to an appropriate connection.

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See the folder and subfolders in `sockets`.

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- Server implemented using an Executor: TimeServerExecutor.java

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- Use `wireshark` to watch network packets in real time! You will need superuser access to be able to use `wireshark` fully.

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- A sample work request class: MyCalculation.java

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- The Server.java, Client.java classes that tie it all together.

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- It is possible to overcome this restriction with the help of reflection? (More on this later...)

Socket and ServerSocket Options

- `ServerSocket` and `Socket` classes have several useful options.
- For example: we can set a timeout on a socket, we can set the receive buffer sizes, etc.
- See examples ServerSocketOptions.java and ClientSocketOptions.java in the package `tcp.socketoptions`.

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- Sketch the setup for two servers that act as both server and client with each other.
- A servent style time server example!
  TimeServent.java

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- Domain Name Service (`DNS`) and Network File System (`NFS`) use UDP.
- Example: UdpServer1.java and UdpClient1.java in package `tcp.udp`.
- This example also illustrates shutdown hooks, which is a method that is called asynchronously when a server receives a terminate signal (such as with `Ctrl-c`).

Example Network Applications

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- How to implement a web server?
- A server could run a proxy that lets the application communicate indirectly with anyone the server likes and allows. *How would you design a proxy server?*

The HTTP Protocol and Web Servers

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- Requests/Methods in the HTTP Protocol:

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GET <pathname> HTTP/x.y  (e.g. GET /sample.html HTTP/1.0)
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        (useful for running server side scripts)
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- Response from server:

```
HTTP-Version status-code reason-phrase <CR><LF>
```

Selected status codes in the HTTP Protocol

Status codes:

```
200 OK
201 Created

301 Moved permanently
305 Use Proxy
307 Temporary redirect

400 Bad request (bad syntax)
401 Unauthorized
402 Payment required
403 Forbidden
404 Not found

500 Internal server error
501 Not implemented
503 Service unavailable
505 HTTP version not supported
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- Then use a web browser and point to `localhost:5005` or use the provided client program.
  `java tinyhttpd.Client localhost 5005`

A Tiny Web Server

- Example: TinyHttpd.java, Client.java
- To run the server, go to the folder `sockets` folder and run the following command:
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- Then use a web browser and point to `localhost:5005` or use the provided client program.
  `java tinyhttpd.Client localhost 5005`
- Warning! This web server will serve files without any protection from a system!

Using the Built-In Security Manager

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- Recompile and run the server as follows.

```
java -Djava.security.manager
-Djava.security.policy=mysecurity.policy TinyHttpd 5005
```

Adding a Custom Security Manager to TinyHttpd

```
class TinyHttpdSecurityManager extends SecurityManager {
  public void checkAccess(Thread g) {};
  public void checkListen(int port) {};
  public void checkLink(String lib) {};
  public void checkPropertyAccess(String key) {};
  public void checkAccept(String host, int port) {};
  public void checkWrite(FileDescriptor fd) {};
  public void checkRead(FileDescriptor fd ) {};

  public void checkRead(String s) {
    if (new File(s).isAbsolute() || (s.indexOf("..") != -1))
      throw new SecurityException("Access to file: " + s
                                  + " denied.");
  }
}
//add the following to the TinyHttpd at the start of the
//main method but after creating the ServerSocket

System.setSecurityManager(new TinyHttpdSecurityManager());
```

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66.249.69.87 - - [28/Jan/2016:23:16:04 -0700]
 "GET /~amit/teaching/555/cs455-555.html HTTP/1.1" 200 7343 "-"
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Scalable I/O with java.nio package

- Nonblocking and selectable network communications are used to create services that can handle high volumes of simultaneous client requests.
- Starting one thread per client request can consume a lot of resources. One strategy is to use nonblocking I/O operations to manage a lot of communications from a single thread. The second strategy is to use a configurable pool of threads, taking advantage of machines with many processors.
- The `java.nio` package provides selectable channels. A selectable channel allows for the registration of a special kind of listener called a selector that can check the readiness of the channel for operations such as reading and writing or accepting or creating network connections.

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- The possible values of interest ops are: OP_READ, OP_WRITE, OP_CONNECT and OP_ACCEPT. These values can be OR'd together to express interest in one or more operations.
- Once one or more channels are registered with the Selector, we can perform a select operations by using one of the select() methods.

```
int readyCount = selector.select(); //block until a channel is ready
int readyCount = selector.selectNow(); //returns immediately
int readyCount = selector.select(50); //timeout of 50 millisecs

while (selector.select(50) == 0);
```

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```
Set readySet = selector.selectedKeys();
for (Iterator itr = readySet.iterator(); itr.hasNext();) {
    SelectionKey key = (SelectionKey) itr.next();
    itr.remove(); //remove the key from the ready set
    //use the key in the application
}
```

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- Example: LargerHttpd.java, HttpdConnection.java, ClientQueue.java.
- A single thread executes the main loop that accepts new connections and checks the readiness of existing client connections for reading or writing.
- Whenever a client needs attention, it places the job in a queue where threads from our thread pool wait to service it.
- Run it as follows (on one line!):

```
java -Djava.security.manager
     -Djava.security.policy=mysecurity.policy
      LargerHttpd <port> <maxthreads>
```

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- Write a Ping Pong program (two processes) using sockets and an object to represent the ping-pong ball. (Homework 1)
- Write a singlethreaded port scanner. The program is a client program that attempts to connect with all ports in the range 1-65535 and reports on the ones that are found open. Then write a multithreaded version and test to see how much faster it is than the singlethreaded version.