Distributed Systems

Data Networking &
Client-Server Communication

Paul Krzyzanowski
pxk@cs.rutgers.edu

Distributed systems

Independent machines work cooperatively without shared memory

They have to talk somehow

Interconnect is the network

Modes of connection

Circuit-switched

- dedicated path
- guaranteed (fixed) bandwidth
- [almost] constant latency

Packet-switched

- shared connection
- data is broken into chunks called packets
- each packet contains destination address
- available bandwidth ≤ channel capacity
- variable latency

What's in the data?

For effective communication

- same language, same conventions

For computers:

- electrical encoding of data
- where is the start of the packet?
- which bits contain the length?
- is there a checksum? where is it? how is it computed?
- what is the format of an address?
- byte ordering

Protocols

These instructions and conventions are known as **protocols**

Protocols

Exist at different levels

understand format of address and how to compute checksum	humans vs. whales *different wavelengths*
versus	
request web page	French vs. Hungarian

Layering

To ease software development and maximize flexibility:

- Network protocols are generally organized in layers
- Replace one layer without replacing surrounding layers
- Higher-level software does not have to know how to format an Ethernet packet

  … or even know that Ethernet is being used

Layering

Most popular model of guiding (not specifying) protocol layers is

OSI reference model

Adopted and created by ISO

7 layers of protocols

OSI Reference Model: Layer 1

Transmits and receives raw data to communication medium.

Does not care about contents.

voltage levels, speed, connectors

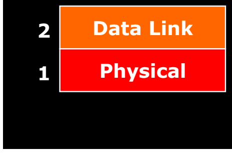
Examples: RS-232, 10BaseT

OSI Reference Model: Layer 2

Detects and corrects errors.

Organizes data into packets before passing it down. Sequences packets (if necessary).

Accepts acknowledgements from receiver.

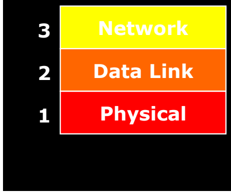


Examples: Ethernet MAC, PPP

OSI Reference Model: Layer 3

Relay and route information to destination.

Manage journey of packets and figure out intermediate hops (if needed).

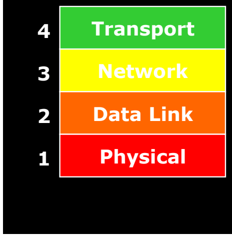


Examples: IP, X.25

OSI Reference Model: Layer 4

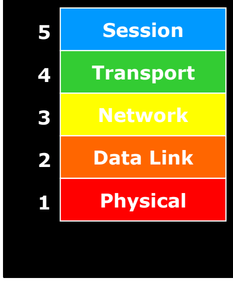
Provides a consistent interface for end-to-end (application-to-application) communication. Manages flow control.

Network interface is similar to a mailbox.



Examples: TCP, UDP

OSI Reference Model: Layer 5



5 Session
4 Transport
3 Network
2 Data Link
1 Physical

Services to coordinate dialogue and manage data exchange.

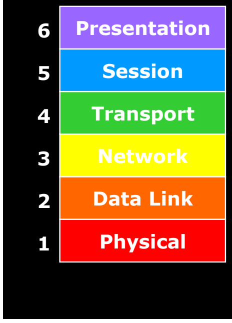
Software implemented switch.

Manage multiple logical connections.

Keep track of who is talking: establish & end communications.

Examples: HTTP 1.1, SSL, NetBIOS

OSI Reference Model: Layer 6



6 Presentation
5 Session
4 Transport
3 Network
2 Data Link
1 Physical

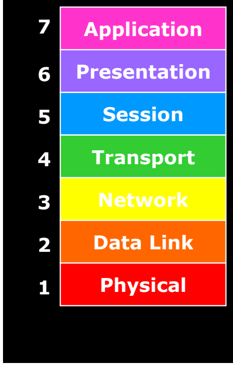
Data representation

Concerned with the meaning of data bits

Convert between machine representations

Examples: XDR, ASN.1, MIME, MIDI

OSI Reference Model: Layer 7



7 Application
6 Presentation
5 Session
4 Transport
3 Network
2 Data Link
1 Physical

Collection of application-specific protocols

Examples:
email (SMTP, POP, IMAP)
file transfer (FTP)
directory services (LDAP)

Some networking terminology

Local Area Network (LAN)

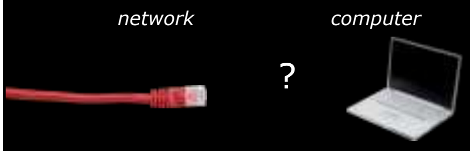
Communications network

- small area (building, set of buildings)
- same, sometimes shared, transmission medium
- high data rate (often): 1 Mbps – 1 Gbps
- Low latency
- devices are peers
  - any device can initiate a data transfer with any other device

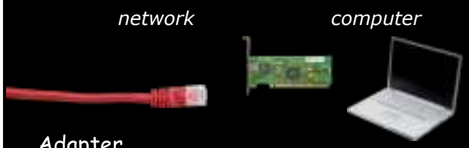
Most elements on a LAN are workstations

- endpoints on a LAN are called **nodes**

Connecting nodes to LANs



Connecting nodes to LANs



Adapter

- expansion slot (PCI, PC Card, USB dongle)
- usually integrated onto main board

Network adapters are referred to as **Network Interface Cards** (**NICs**) or adapters or **Network Interface Component**

Media

Wires (or RF, IR) connecting together the devices that make up a LAN

Twisted pair
- Most common:
  - STP: shielded twisted pair
  - UTP: unshielded twisted pair
    (e.g. Telephone cable, Ethernet 10BaseT)

Coaxial cable
- Thin (similar to TV cable)
- Thick (e.g., 10Base5, ThickNet)

Fiber

Wireless

Hubs, routers, bridges

Hub
- Device that acts as a central point for LAN cables
- Take incoming data from one port & send to all other ports

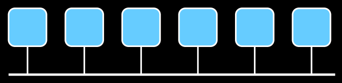
Switch
- Moves data from input to output port.
- Analyzes packet to determine destination port and makes a virtual connection between the ports.

Concentrator or **repeater**
- Regenerates data passing through it

Bridge
- Connects two LANs or two segments of a LAN
- Connection at data link layer (layer 2)

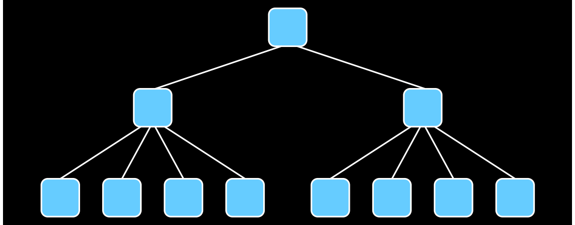
Router
- Determines the next network point to which a packet should be forwarded
- Connects different types of local and wide area networks at network layer (layer 3)

Networking Topology



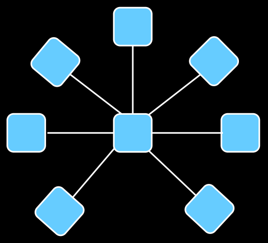
Bus Network

Networking Topology



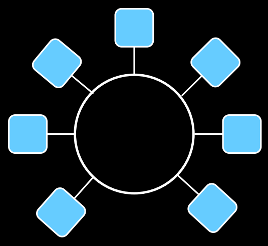
Tree Network

Networking Topology



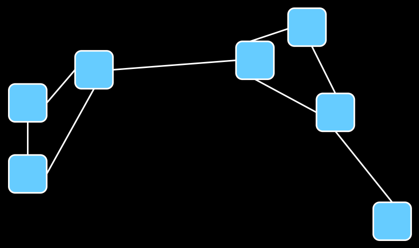
Star Network

Networking Topology



Ring Network

Networking Topology



Mesh Network

Transmission networks

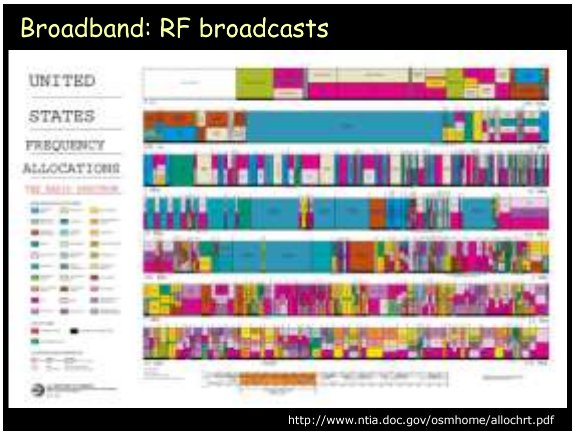
Baseband

- All nodes share access to network media on an equal basis
- Data uses entire bandwidth of media

Broadband

- Data takes segment of media by dividing media into channels (frequency bands)

Broadband: RF broadcasts

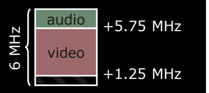


http://www.ntia.doc.gov/osmhome/allochrt.pdf

Broadband/Baseband: Cable TV

Broadband

55-552 MHz: analog channels 2-78
553-865 MHz: digital channels 79-136



Baseband within Broadband

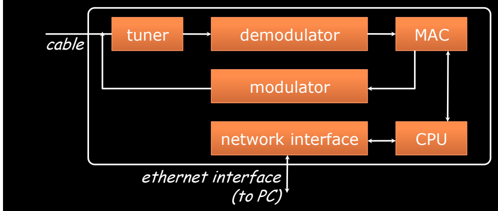
DOCSIS: Data Over Cable Service Interface Specification
(approved by ITU in 1998; DOCSIS 2.0 in 2001)

Downstream: 50-750 MHz range, 6 MHz bandwidth
- up to 38 Mbps
- received by all modems

Upstream: 5-42 MHz range
- 30.72 Mbps (10 Mbps in DOCSIS 1.0, 1.1)
- data delivered in timeslots (TDM)

DOCSIS 3.0 features channel bonding for greater bandwidth

DOCSIS Modem



Restrictions on upload/download rates set by transferring a configuration file to the modem via TFTP when it connects to the provider.

Baseband: Ethernet

Standardized by IEEE as 802.3 standard

Speeds: 100 Mbps - 1 Gbps typical today

- Ethernet: 10 Mbps
- Fast Ethernet: 100 Mbps
- Gigabit Ethernet: 1 Gbps
- 10 Gbps, 100 Gbps

Network access method is

Carrier Sense Multiple Access with Collision Detection (CSMA/CD)

- Node first listens to network to see if busy
- Send
- Sense if collision occurred
- Retransmit if collision

Ethernet media

Bus topology (original design)

- originally thick coax (max 500m): 10Base5
- then… thin coax (<200m): 10Base2
  - BNC connector

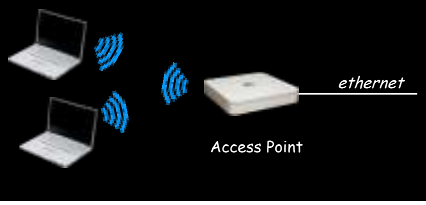
Star topology (central hub or switch)

- 8 pit RJ-45 connector, UTP cable, 100 meters range
- 10BaseT for 10 Mbps
- 100BaseT for 100 Mbps
- 1000BaseT for 1 Gbps
- Cables
  - CAT-5: unshielded twisted pair
  - CAT-5e: designed for 1 Gbps
  - CAT-6: 23 gauge conductor + separator for handling crosstalk better

Wireless Ethernet media

Wireless (star topology)

- 802.11 (1-2 Mbps)
- 802.11b (11 Mbps - 4-5 Mbps realized)
- 802.11a (54 Mbps - 22-28 Mbps realized)
- 802.11g (54 Mbps - 32 Mbps realized)
- 802.11n (108 Mbps - 30-47 Mbps realized)

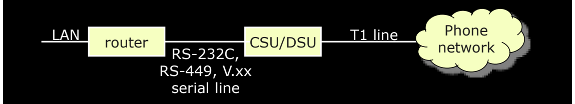


Connecting to the Internet

- DOCSIS modem via cable TV service
- DSL router
  - Ethernet converted to ATM data stream
  - Up to 20 Mbps up to ~ 2 km.
  - POTS limited to 300-3400 Hz
  - DSL operates > 3500 Hz
- Modem
  - Data modulated over voice spectrum (300-3400 Hz)
  - Serial interface to endpoint
  - V.92: 48 kbps downstream, near 56 kbps up
  - Use PPP or SLIP to bridge IP protocol

Connecting to the Internet

- Dedicated T1 or T3 line
  - T1 line: 1.544 Mbps
    (24 PCM TDMA speech lines @ 64 kbps)
  - T3 line: 44.736 Mbps (672 channels)
  - CSU/DSU at router presents serial interface
    - Channel Service Unit / Data Service Unit



Connecting to the Internet

- Fiber to the Home, Fiber to the Curb
  - Ethernet interface
  - E.g., Verizon's FiOS – 30 Mbps to the home
- Long Reach Ethernet (LRE)
  - Ethernet performance up to 5,000 feet
- Wireless:
  - WiMax (seems to be dying – limited endorsement)
  - LTE (Long Term Evolution)
    - WiMax competitor, also known as 4G
    - Peak downstream rate: 326.5 Mbos; Peak upstream: 86.4 Mbps
    - Support from Verizon, AT&T, T-Mobile, France Télécom, …
  - EDGE (70-135 Kbps)
  - GPRS (<32 Kbps)

Client – Server Communication

Clients and Servers

- Send messages to *applications*
  - not just machines
- Client must get data to the desired *process*
  - server process must get data back to client process
- To offer a service, a server must get a **transport address** for a particular service
  - well-defined location

Machine address

versus

Transport address

Transport provider

Layer of software that accepts a network message and sends it to a remote machine

Two categories:

connection-oriented protocols

connectionless protocols

Connection-oriented Protocols

1. establish connection
2. [negotiate protocol]
3. exchange data
4. terminate connection

Connection-oriented Protocols

	analogous to phone call
1. establish connection	*dial phone number*
2. [negotiate protocol]	*[decide on a language]*
3. exchange data	*speak*
4. terminate connection	*hang up*

virtual circuit service

- provides illusion of having a dedicated circuit
- messages guaranteed to arrive in-order
- application does not have to address each message

vs. circuit-switched service

Connectionless Protocols

- no call setup
- send/receive data
  (each packet addressed)
- no termination

Connectionless Protocols

analogous to mailbox

- no call setup
- send/receive data — *drop letter in mailbox*
  (each packet addressed) — *(each letter addressed)*
- no termination

datagram service

- client is not positive whether message arrived at destination
- no state has to be maintained at client or server
- cheaper but less reliable than virtual circuit service

Ethernet

- Layers 1 & 2 of OSI model
  - Physical (1)
    - Cables: 10Base-T, 100Base-T, 1000Base-T, etc.
  - Data Link (2)
    - Ethernet bridging (via bridges)
    - Data frame parsing
    - Data frame transmission
    - Error detection
- Unreliable, connectionless communication

Ethernet

- 48-byte ethernet address
- Variable-length packet
  - 1518-byte MTU
    - 18-byte header, 1500 bytes data
- Jumbo packets for Gigabit ethernet
  - 9000-byte MTU

dest addr	src addr	frame type	data (payload)	CRC
6 bytes	6 bytes	2	46-1500 bytes	4

18 bytes + data

IP – Internet Protocol

Born in 1969 as a research network of 4 machines
Funded by DoD's ARPA

Goal:
build an efficient fault-tolerant network that could connect heterogeneous machines and link separately connected networks.

Internet Protocol

Connectionless protocol designed to handle the interconnection of a large number of local and wide-area networks that comprise the internet

IP can route from one physical network to another

IP Addressing

Each machine on an IP network is assigned a unique 32-bit number for each network interface:

- **IP address**, *not* machine address

A machine connected to several physical networks will have several IP addresses

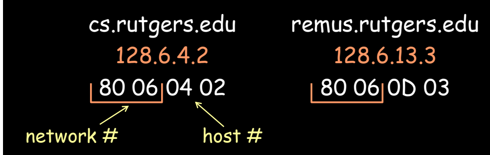
- One for each network

IP Address space

32-bit addresses → >4 billion addresses!

- Routers would need a table of 4 billion entries
- Design routing tables so one entry can match multiple addresses
  - hierarchy: addresses physically close will share a common prefix

IP Addressing: networks & hosts



- first 16 bits identify Rutgers
- external routers need only one entry
  - route 128.6.*.* to Rutgers

IP Addressing: networks & hosts

- IP address
  - **network #:** identifies network machine belongs to
  - **host #:** identifies host on the network
- use network number to route packet to correct network
- use host number to identify specific machine

IP Addressing

Expectation:

- a few big networks and many small ones
- create different **classes** of networks
- use leading bits to identify network

class	leading bits	bits for net #	bits for host
A	0	7 (128)	24 (16M)
B	10	14 (16K)	16 (64K)
C	110	21 (2M)	8 (256)

To allow additional networks within an organization:

use high bits of host number for a "network within a network" – **subnet**

IP Addressing

IBM: 9.0.0.0 – 9.255.255.255

```
00001001  xxxxxxxx xxxxxxxx xxxxxxxxx
network #             host #
 8 bits               24 bits
```

Subnet within IBM (internal routers only)

```
00001001 10101010 11  xxxxxx xxxxxxxxx
     network #            host #
      18 bits             14 bits
```

Running out of addresses

- Huge growth
- Wasteful allocation of networks
  - Lots of unused addresses
  - *Does IBM need 16.7M IP addresses?*
- Every machine connected to the internet needed a worldwide-unique IP address
- Solutions: CIDR, NAT, IPv6

Classless Inter-Domain Routing (CIDR)

Replace class A, B, C addresses:

- Explicitly specify # of bits for network number
- rather than 8 (A), 16 (B), 24 (C) bits

Better match for organizational needs

machine that needs 500 addresses:

- get a 23-bit network number (512 hosts) instead of a class B address (64K hosts)

Classless Inter-Domain Routing

How does a router determine # bits?

CIDR address specifies it:
32-bit-address/bits-for-network-prefix

- 128.6.13.3/16
- /27 : 1/8 of a class C (32 hosts)
- /24 : class C
- /16 : class B

managing CIDR addresses & prefixes can be a pain

IP Special Addresses

- All bits 0
  - Valid only as *source address*
  - "all addresses for this machine"
  - Not valid over network
- All host bits 1
  - Valid only as destination
  - Broadcast to network
- All bits 1
  - Broadcast to all directly connected networks
- Leading bits 1110
  - Class D network
- 127.0.0.0: reserved for local traffic
  - 127.0.0.1 usually assigned to *loopback device*

IPv6 vs. IPv4

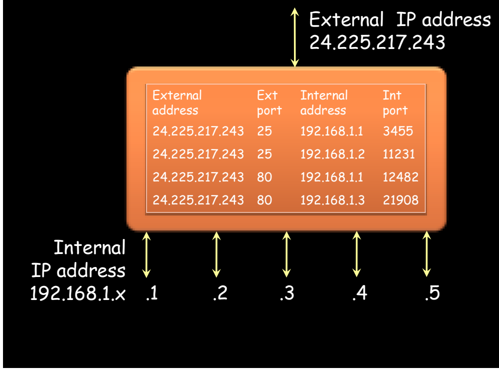
IPv4

- 4 byte (32 bit) addresses

IPv6:

- 16-byte (128 bit) addresses
  3.6×10^{38} possible addresses
  8×10^{28} times more addresses than IPv4
- 4-bit priority field
- Flow label (24-bits)

Network Address Translation (NAT)

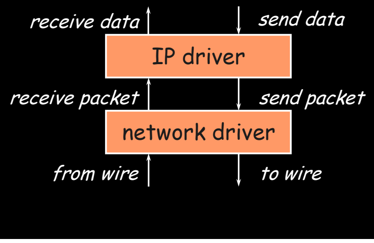


External address	Ext port	Internal address	Int port
24.225.217.243	25	192.168.1.1	3455
24.225.217.243	25	192.168.1.2	11231
24.225.217.243	80	192.168.1.1	12482
24.225.217.243	80	192.168.1.3	21908

Getting to the machine

IP is a logical network on top of multiple physical networks

OS support for IP: **IP driver**



IP driver responsibilities

- Get operating parameters from device driver
  - Maximum packet size (MTU)
  - Functions to initialize HW headers
  - Length of HW header
- Routing packets
  - From one physical network to another
- Fragmenting packets
- Send operations from higher-layers
- Receiving data from device driver
- Dropping bad/expired data

Device driver responsibilities

- Controls network interface card
  - Comparable to character driver
- Processes interrupts from network interface
  - Receive packets
  - Send them to IP driver

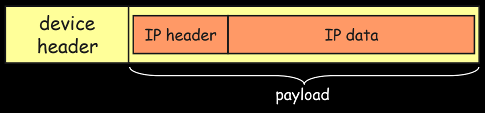
bottom half

- Get packets from IP driver
  - Send them to hardware
  - Ensure packet goes out without collision

top half

Network device

- Network card examines packets on wire
  - Compares destination addresses
- Before a packet is sent, it must be **enveloped** for the physical network



Addressing The Device

Translate: IP address → ethernet address

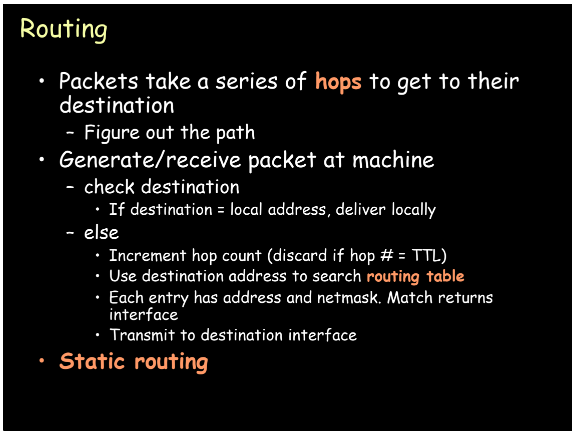
Address Resolution Protocol (ARP)

1. Check local ARP cache
2. Send broadcast message requesting ethernet address of machine with certain IP address
3. Wait for response (with timeout)

Routing

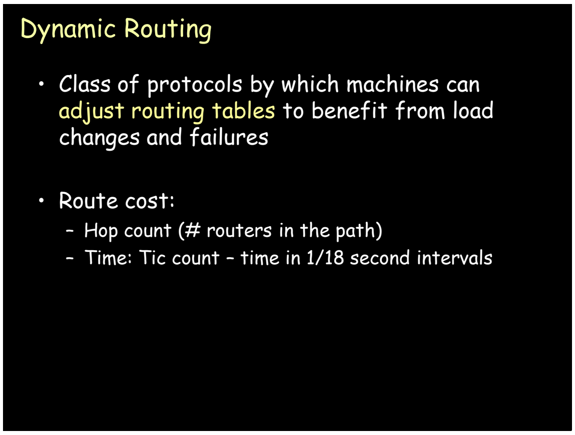
Router

- Switching element that connects two or more transmission lines (e.g., Ethernet)
- Routes packets from one network to another (OSI layer 3 – Network Layer)
- Special-purpose hardware or a general-purpose computer with two or more network interfaces



Routing

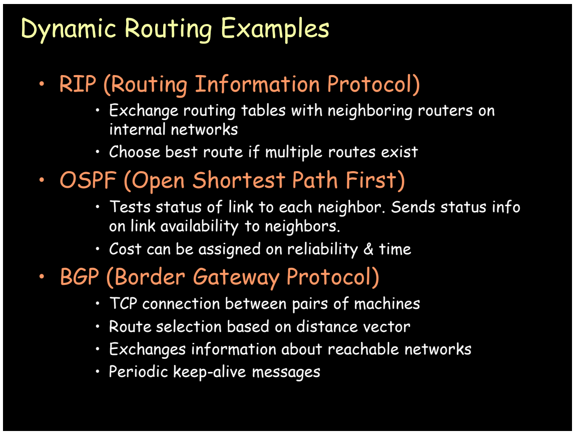
- Packets take a series of **hops** to get to their destination
  - Figure out the path
- Generate/receive packet at machine
  - check destination
    - If destination = local address, deliver locally
  - else
    - Increment hop count (discard if hop # = TTL)
    - Use destination address to search **routing table**
    - Each entry has address and netmask. Match returns interface
    - Transmit to destination interface
- **Static routing**



Dynamic Routing

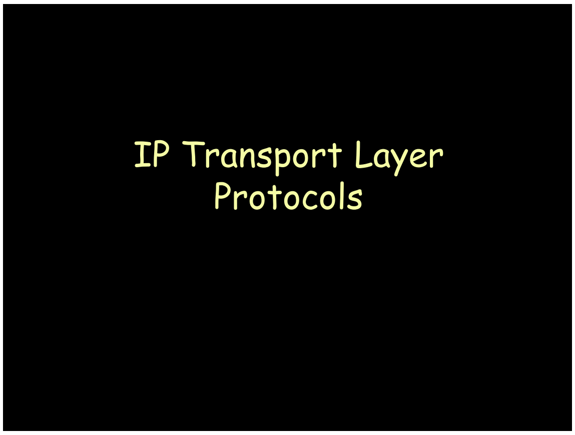
- Class of protocols by which machines can adjust routing tables to benefit from load changes and failures

- Route cost:
  - Hop count (# routers in the path)
  - Time: Tic count – time in 1/18 second intervals

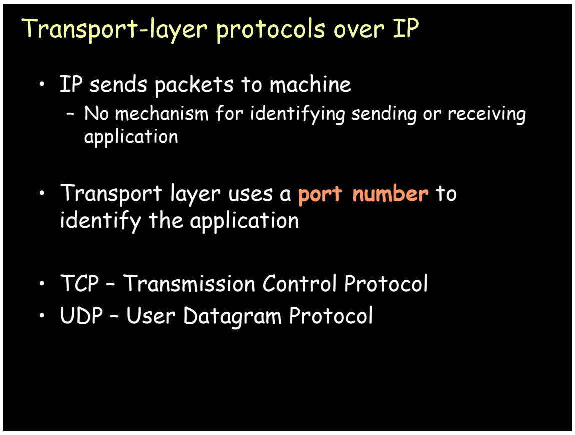


Dynamic Routing Examples

- RIP (Routing Information Protocol)
  - Exchange routing tables with neighboring routers on internal networks
  - Choose best route if multiple routes exist
- OSPF (Open Shortest Path First)
  - Tests status of link to each neighbor. Sends status info on link availability to neighbors.
  - Cost can be assigned on reliability & time
- BGP (Border Gateway Protocol)
  - TCP connection between pairs of machines
  - Route selection based on distance vector
  - Exchanges information about reachable networks
  - Periodic keep-alive messages



IP Transport Layer Protocols

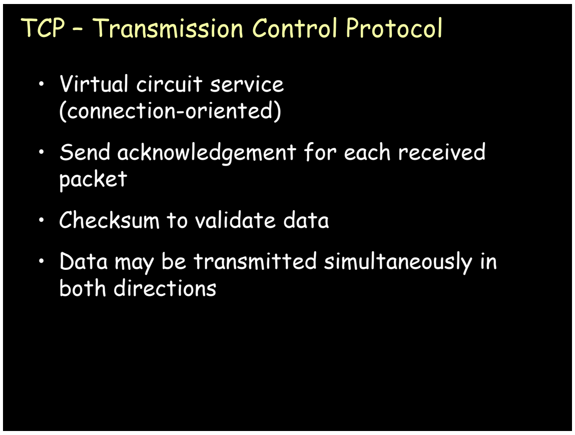


Transport-layer protocols over IP

- IP sends packets to machine
  - No mechanism for identifying sending or receiving application

- Transport layer uses a **port number** to identify the application

- TCP – Transmission Control Protocol
- UDP – User Datagram Protocol



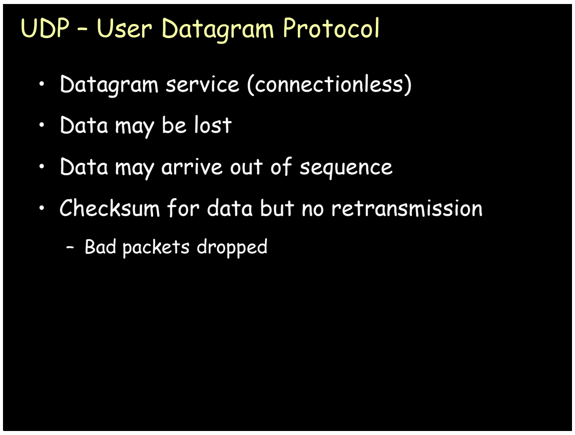
TCP – Transmission Control Protocol

- Virtual circuit service (connection-oriented)

- Send acknowledgement for each received packet

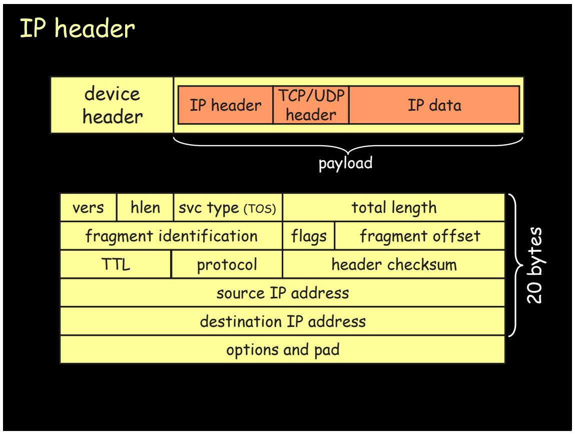
- Checksum to validate data

- Data may be transmitted simultaneously in both directions



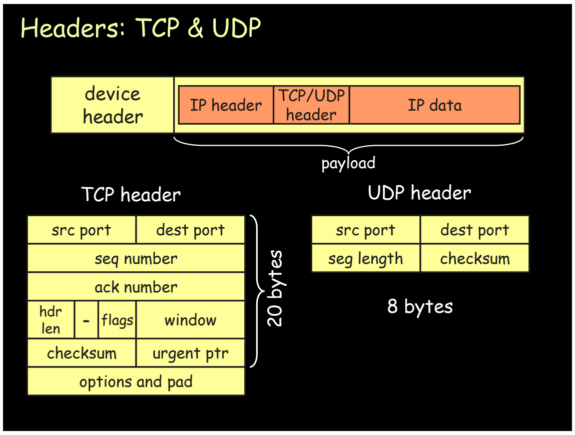
UDP – User Datagram Protocol

- Datagram service (connectionless)
- Data may be lost
- Data may arrive out of sequence
- Checksum for data but no retransmission
  - Bad packets dropped



IP header

vers	hlen	svc type (TOS)	total length
fragment identification		flags	fragment offset
TTL	protocol	header checksum	
source IP address			
destination IP address			
options and pad			



Headers: TCP & UDP

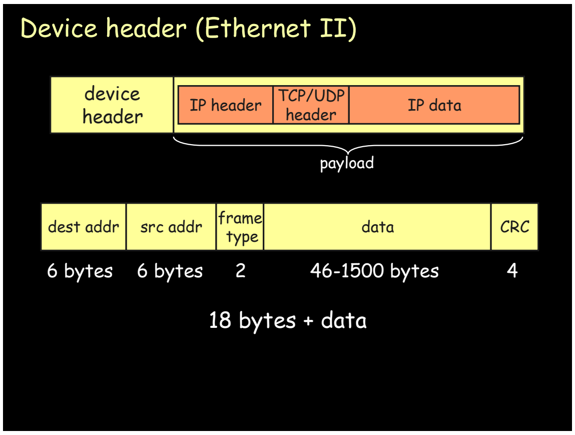
TCP header

src port			dest port
seq number			
ack number			
hdr len	-	flags	window
checksum			urgent ptr
options and pad			

UDP header

src port	dest port
seg length	checksum

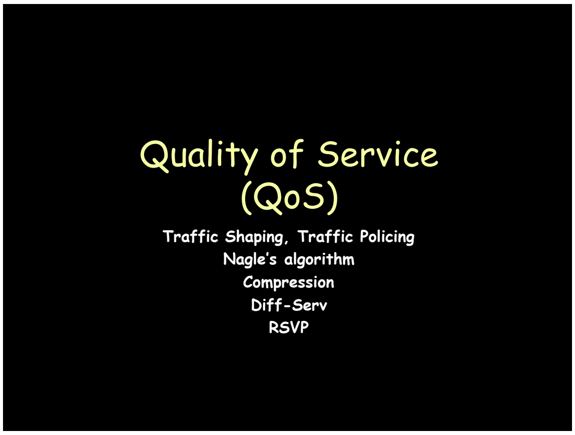
8 bytes



Device header (Ethernet II)

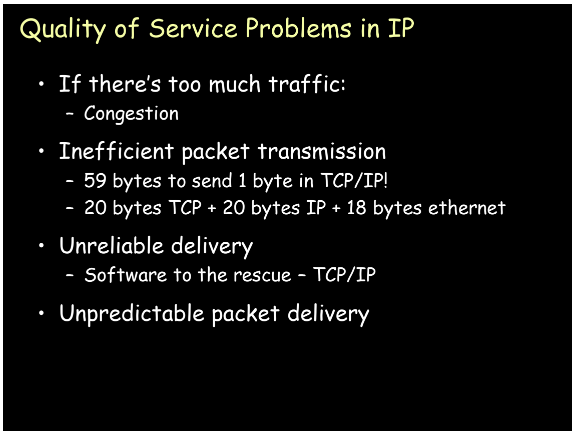
dest addr	src addr	frame type	data	CRC
6 bytes	6 bytes	2	46-1500 bytes	4

18 bytes + data



Quality of Service (QoS)

Traffic Shaping, Traffic Policing
Nagle's algorithm
Compression
Diff-Serv
RSVP



Quality of Service Problems in IP

- If there's too much traffic:
  - Congestion
- Inefficient packet transmission
  - 59 bytes to send 1 byte in TCP/IP!
  - 20 bytes TCP + 20 bytes IP + 18 bytes ethernet
- Unreliable delivery
  - Software to the rescue – TCP/IP
- Unpredictable packet delivery

IP Flow Detection

Flow detection in routers:

- Flow: set of packets from one *address:port* to another *address:port* with same protocol
- Network controls flow rate by dropping or delaying packets
- With flow detection:
  - drop TCP packets over UDP
  - Discard UDP flow to ensure QoS for other flows

With flow detection:

- Traffic Shaping
  - Identify traffic flows
  - Queue packets during surges and release later
  - High-bandwidth link to low-bandwidth link
- Traffic Policing
  - Discard traffic that exceeds allotted bandwidth

Dealing with congestion

- FIFO queuing
- Priority queues
- Flow-based weighted fair queuing
  - Group all packets from a flow together
- Class-based weighted fair queuing
  - Based on protocols, access control lists, interfaces, etc.
- Custom queues

Inefficient Packets

- Lots of tiny packets
  - Head-of-line blocking
  - Nagle's algorithm:
    - buffer new data if unacknowledged data outstanding
- Header/packet compression
  - Link-to-link
  - Header compression (RFC 3843)
  - Payload compression (RFC 2393)
  - $ delivery vs. $ compression

Differentiated Services (soft QoS)

Some traffic is treated better than others

- Statistical - no guarantees
- TOS bits & Diff-Serv

- Use on Internet is limited due to peering agreement complexities

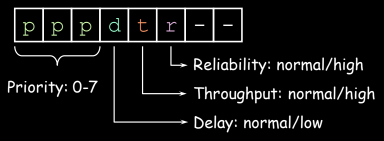
TOS bits

- Advisory tag in IP header for use by routers
- TOS: *Type Of Service*, 4 bits
  - Minimum Delay [0x10]
    - FTP, telnet, ssh
  - Maximum Throughput [0x08]
    - ftp-data, www
  - Maximum reliability [0x04]
    - SNMP, DNS
  - Minimum cost [0x02]
    - NNTP, SMTP

RFC 1349, July, 1992

Differentiated Services (Diff-Serv)

- Revision of interpretation of ToS bits
- ToS field in IP header
  - *Differentiated Sevices Control Point (DSCP)*



RFC 2475, December 1998

Guaranteed QoS (hard QoS)

Guarantee via end-to-end reservation

Reservation & Delivery Protocol

- RSVP: ReSerVation Protocol
  - Hosts request specific quality of service
  - Routers reserve resources
  - RFC 2205
- All routers in the path must support this

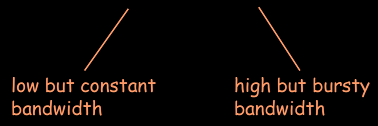
Media Delivery Protocols

- Real-Time Control Protocol (RTCP)
  - Provides feedback on QoS (jitter, loss, delay)
  - RFC 3550
- RTP: Real-Time Transport Protocol
  - *Not* a routing protocol
  - No service guarantees
  - Provides:
    - Payload identification
    - sequence #
    - time stamp
- RTP/RTCP do not provide QoS controls

ATM: Asynchronous Transfer Mode

Late 1980's

Goal: Merge voice & data networking



ATM

Traditional voice networking
- Circuit switching
  - Too costly
  - Poor use of resource
  - Does not lend to multicasting

ATM
- Based on **fixed-size packets** over **virtual circuits**
- Fixed-size cells provide for **predictive scheduling**
- Large cells will not hold up smaller ones
- Rapid switching

ATM

Current standard:
- 53-byte cell: 48-byte data, 5-byte header

Sender specifies traffic type upon connecting:

CBR	Constant bit-rate	*bandwidth*	Uncompressed video, voice
VBR	Variable bit-rate	*Avg, peak bandwidth*	Compressed video, voice
ABR	Available bit-rate	*-none-*	ftp, web access

ATM

Small cells → lots of interrupts

- >100,000/second

ATM hardware supports an **ATM Adaptation Layer** (AAL)

- Converts cells to variable-sized (larger) packets:
  AAL 1: for CBR
  AAL 2: for VBR
  AAL 3/4: ABR data
  AAL 5: ABR data, simplified
  AAL 6: MPEG-2 video

Programming Interfaces

Sockets

- IP lets us send data between machines
- TCP & UDP are *transport layer* protocols
  - Contain **port number** to identify transport endpoint (application)
- One popular abstraction for transport layer connectivity: **sockets**
  - Developed at Berkeley

Sockets

Attempt at generalized IPC model

Goals:

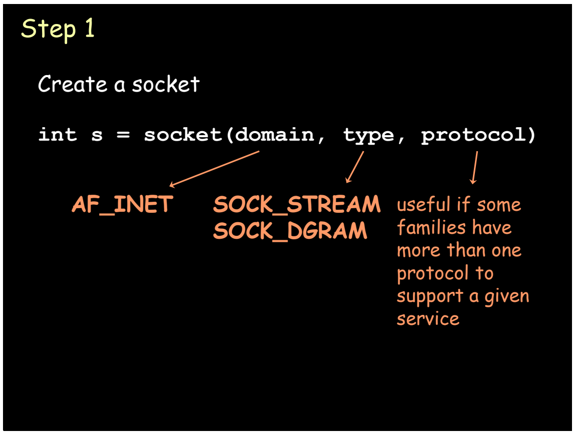
- communication between processes should not depend on whether they are on the same machine
- efficiency
- compatibility
- support different protocols and naming conventions

Socket

Abstract object from which messages are sent and received

- Looks like a file descriptor
- Application can select particular style of communication
  - Virtual circuit, datagram, message-based, in-order delivery
- Unrelated processes should be able to locate communication endpoints
  - Sockets should be named
  - Name meaningful in the communications domain

Programming with sockets



Step 1

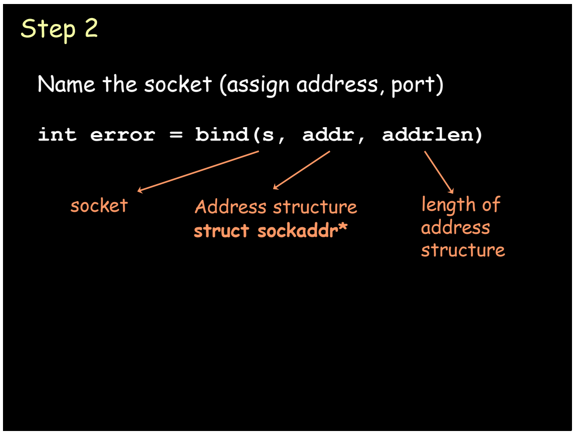
Create a socket

```
int s = socket(domain, type, protocol)
```

AF_INET

SOCK_STREAM
SOCK_DGRAM

useful if some families have more than one protocol to support a given service



Step 2

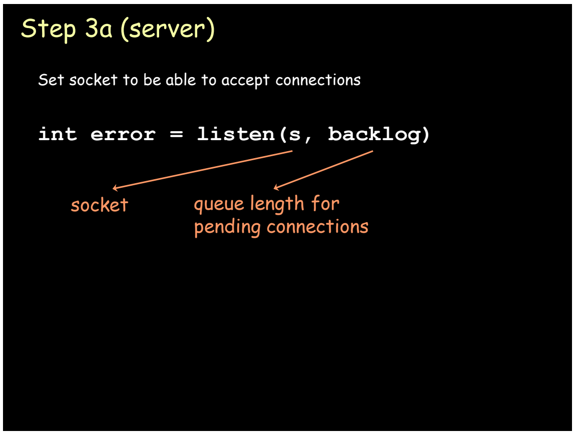
Name the socket (assign address, port)

```
int error = bind(s, addr, addrlen)
```

socket

Address structure
struct sockaddr*

length of address structure



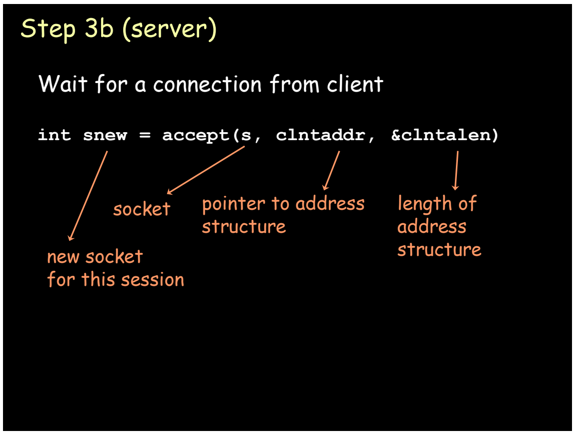
Step 3a (server)

Set socket to be able to accept connections

```
int error = listen(s, backlog)
```

socket

queue length for pending connections



Step 3b (server)

Wait for a connection from client

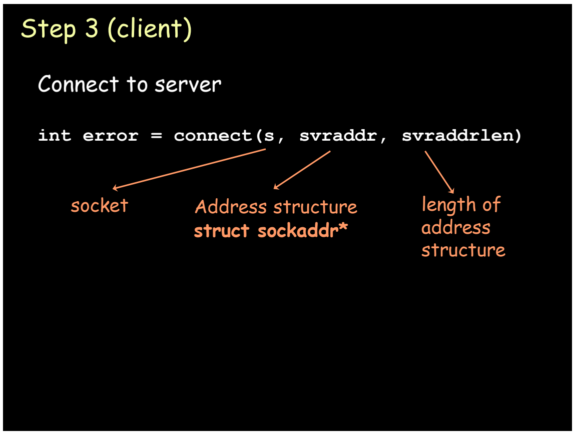
```
int snew = accept(s, clntaddr, &clntalen)
```

new socket for this session

socket

pointer to address structure

length of address structure



Step 3 (client)

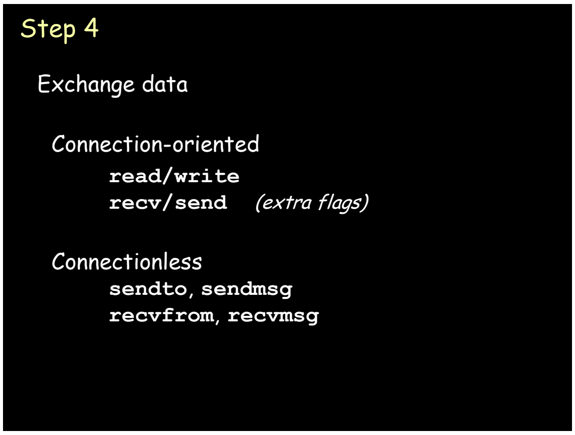
Connect to server

```
int error = connect(s, svraddr, svraddrlen)
```

socket

Address structure
struct sockaddr*

length of address structure



Step 4

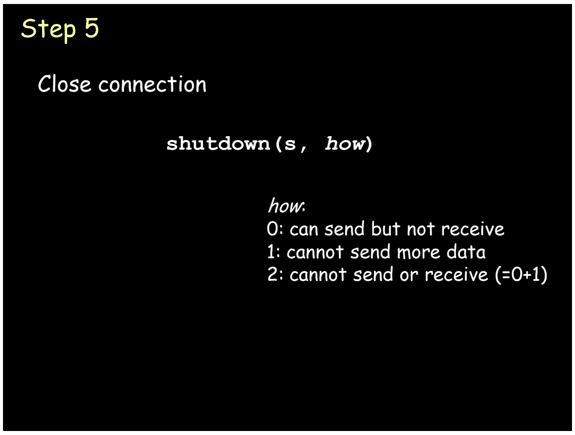
Exchange data

Connection-oriented

read/write
recv/send *(extra flags)*

Connectionless

sendto, sendmsg
recvfrom, recvmsg

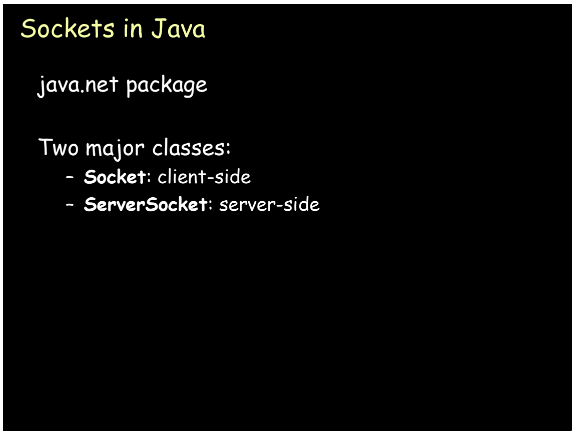


Step 5

Close connection

```
shutdown(s, how)
```

how:
0: can send but not receive
1: cannot send more data
2: cannot send or receive (=0+1)

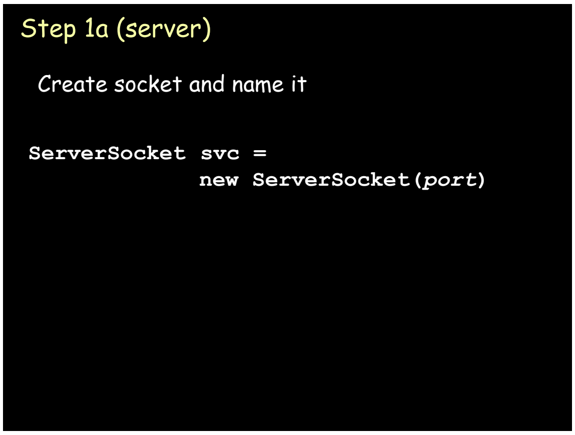


Sockets in Java

java.net package

Two major classes:

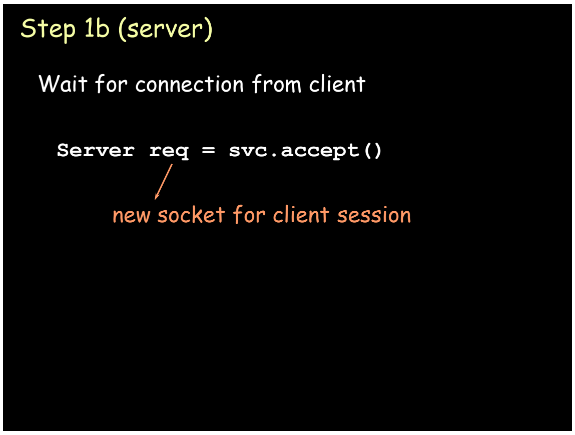
- **Socket**: client-side
- **ServerSocket**: server-side



Step 1a (server)

Create socket and name it

```
ServerSocket svc =
            new ServerSocket(port)
```

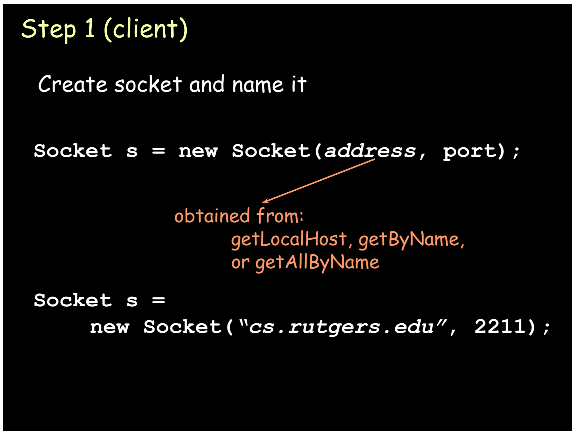


Step 1b (server)

Wait for connection from client

```
Server req = svc.accept()
```

new socket for client session



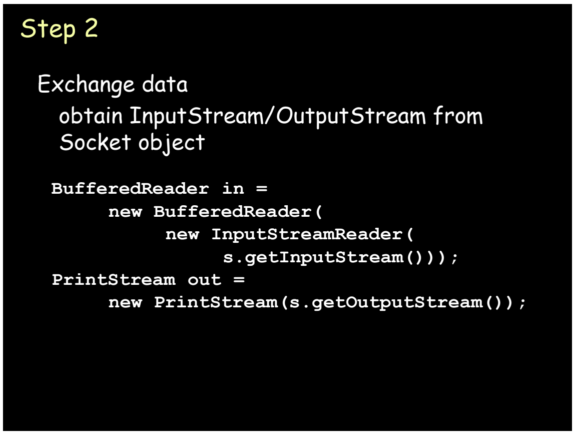
Step 1 (client)

Create socket and name it

```
Socket s = new Socket(address, port);
```

obtained from:
getLocalHost, getByName,
or getAllByName

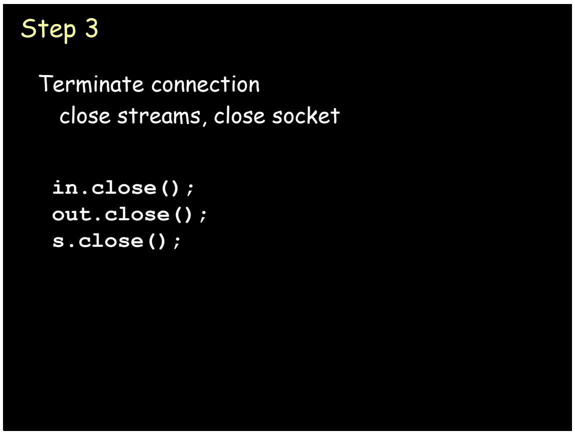
```
Socket s =
     new Socket("cs.rutgers.edu", 2211);
```



Step 2

Exchange data
obtain InputStream/OutputStream from
Socket object

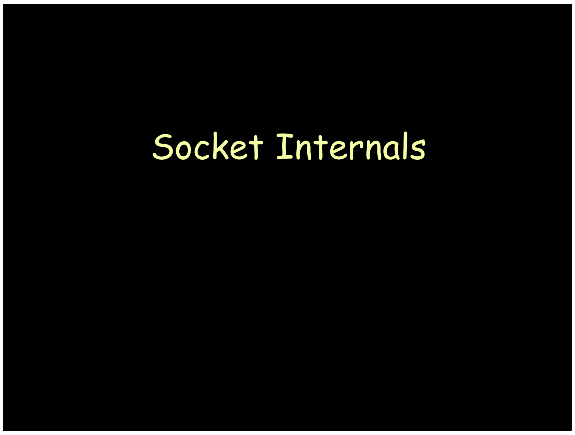
```
BufferedReader in =
     new BufferedReader(
          new InputStreamReader(
               s.getInputStream()));
PrintStream out =
     new PrintStream(s.getOutputStream());
```



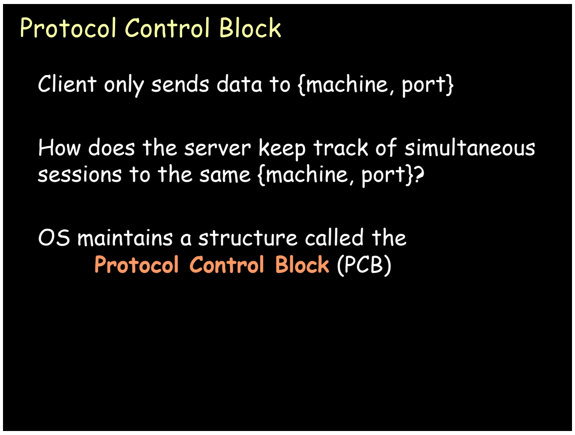
Step 3

Terminate connection
close streams, close socket

```
in.close();
out.close();
s.close();
```



Socket Internals

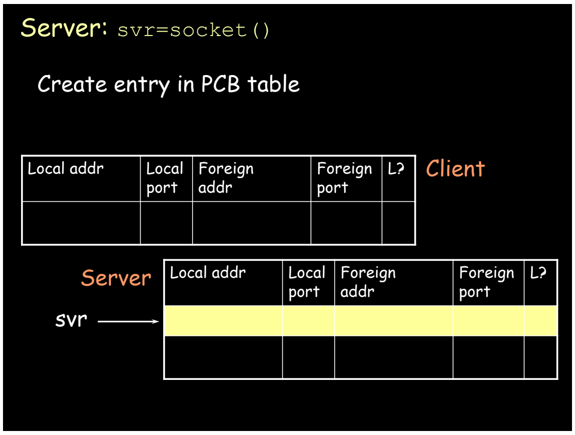


Protocol Control Block

Client only sends data to {machine, port}

How does the server keep track of simultaneous sessions to the same {machine, port}?

OS maintains a structure called the
Protocol Control Block (PCB)



Server: `svr=socket()`

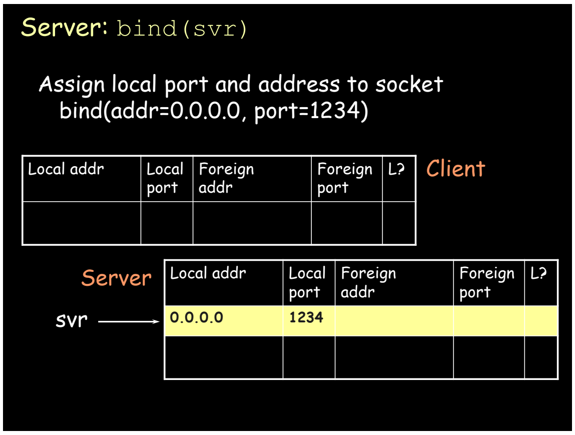
Create entry in PCB table

Client

Local addr	Local port	Foreign addr	Foreign port	L?

Server

	Local addr	Local port	Foreign addr	Foreign port	L?
svr →					



Server: `bind(svr)`

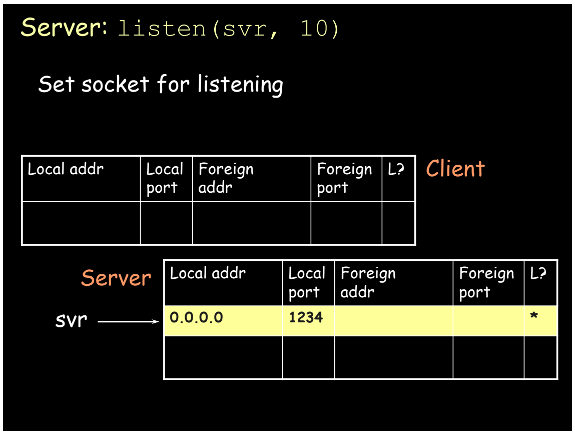
Assign local port and address to socket
bind(addr=0.0.0.0, port=1234)

Client

Local addr	Local port	Foreign addr	Foreign port	L?

Server

	Local addr	Local port	Foreign addr	Foreign port	L?
svr →	0.0.0.0	1234			



Server: `listen(svr, 10)`

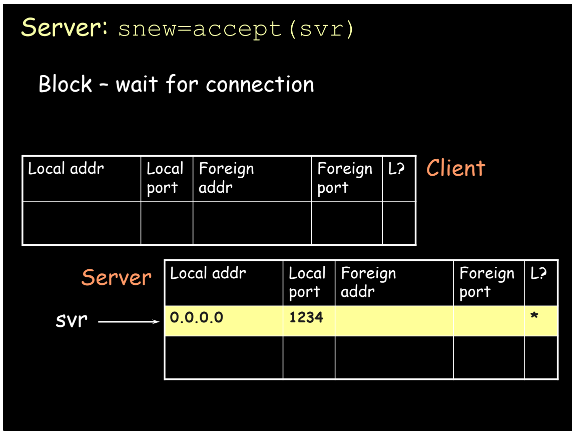
Set socket for listening

Client

Local addr	Local port	Foreign addr	Foreign port	L?

Server

	Local addr	Local port	Foreign addr	Foreign port	L?
svr →	0.0.0.0	1234			*



Server: `snew=accept(svr)`

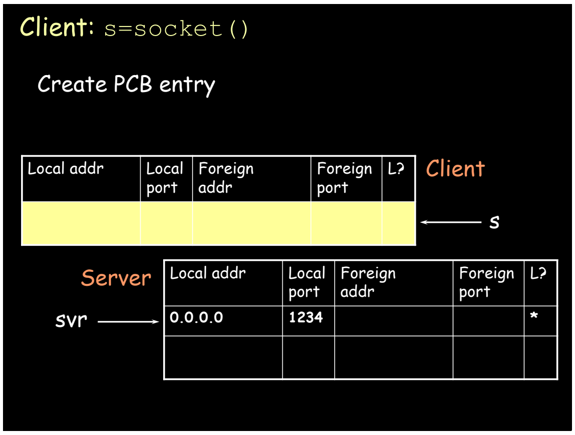
Block - wait for connection

Client

Local addr	Local port	Foreign addr	Foreign port	L?

Server

	Local addr	Local port	Foreign addr	Foreign port	L?
svr	0.0.0.0	1234			*



Client: `s=socket()`

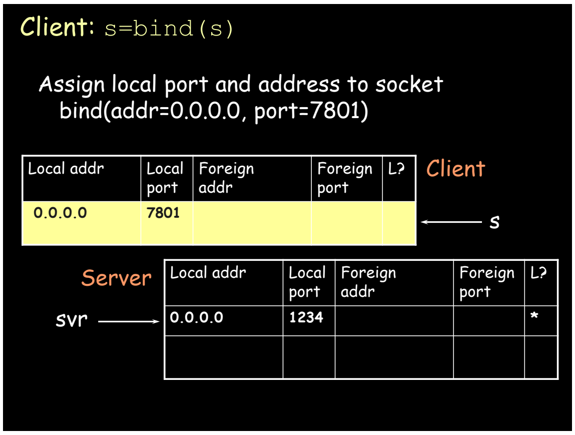
Create PCB entry

Client

Local addr	Local port	Foreign addr	Foreign port	L?	
					s

Server

	Local addr	Local port	Foreign addr	Foreign port	L?
svr	0.0.0.0	1234			*



Client: `s=bind(s)`

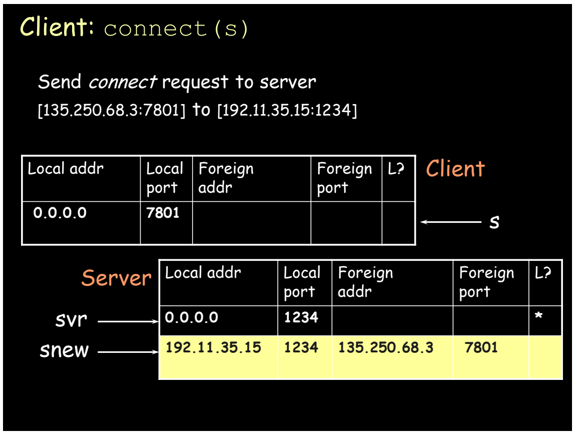
Assign local port and address to socket
bind(addr=0.0.0.0, port=7801)

Client

Local addr	Local port	Foreign addr	Foreign port	L?	
0.0.0.0	7801				s

Server

	Local addr	Local port	Foreign addr	Foreign port	L?
svr	0.0.0.0	1234			*



Client: `connect(s)`

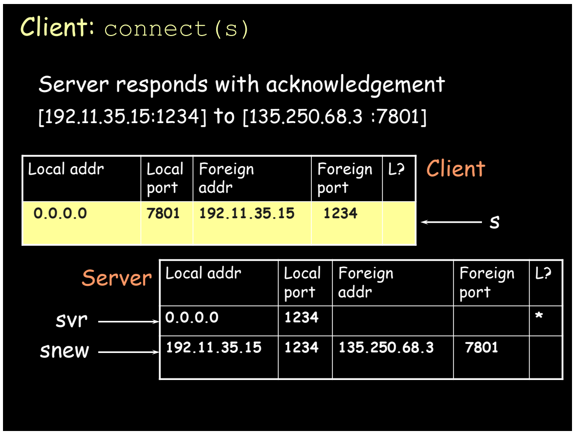
Send *connect* request to server
[135.250.68.3:7801] to [192.11.35.15:1234]

Client

Local addr	Local port	Foreign addr	Foreign port	L?	
0.0.0.0	7801				s

Server

	Local addr	Local port	Foreign addr	Foreign port	L?
svr	0.0.0.0	1234			*
snew	192.11.35.15	1234	135.250.68.3	7801	



Client: `connect(s)`

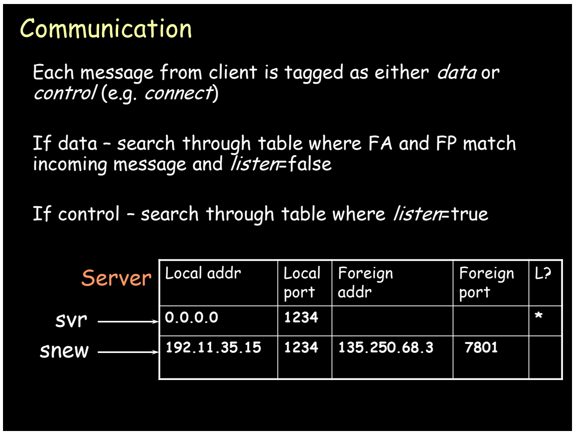
Server responds with acknowledgement
[192.11.35.15:1234] to [135.250.68.3 :7801]

Client

Local addr	Local port	Foreign addr	Foreign port	L?	
0.0.0.0	7801	192.11.35.15	1234		s

Server

	Local addr	Local port	Foreign addr	Foreign port	L?
svr	0.0.0.0	1234			*
snew	192.11.35.15	1234	135.250.68.3	7801	



Communication

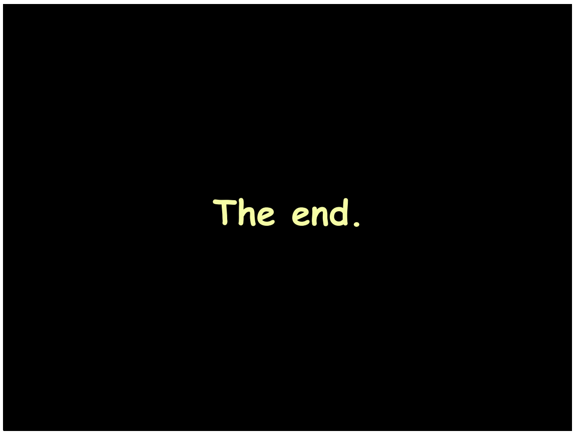
Each message from client is tagged as either *data* or *control* (e.g. *connect*)

If data - search through table where FA and FP match incoming message and *listen*=false

If control - search through table where *listen*=true

Server

	Local addr	Local port	Foreign addr	Foreign port	L?
svr	0.0.0.0	1234			*
snew	192.11.35.15	1234	135.250.68.3	7801	



The end.