CSE 461: Transport Layer Connections

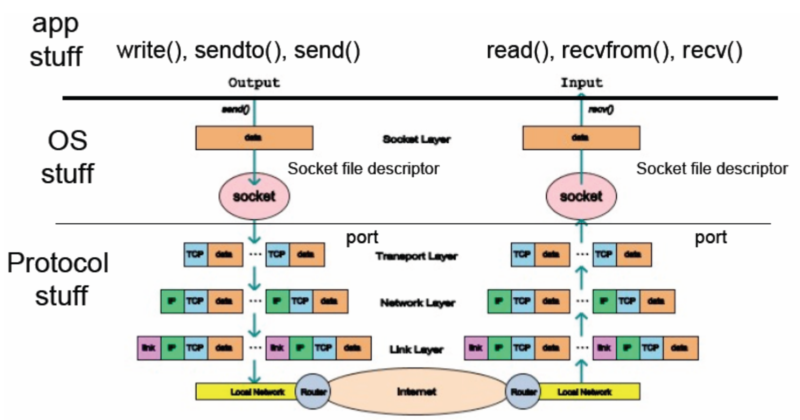
Naming Processes/Services

- Process here is an abstract term for your Web browser (HTTP), Email servers (SMTP), hostname translation (DNS), RealAudio player (RTSP), etc.

- How do we identify for remote communication?
  - Process id or memory address are OS-specific and transient

- So TCP and UDP use Ports
  - 16-bit integers representing mailboxes that processes "rent"
    - typically from OS
  - Identify endpoint uniquely as (IP address, protocol, port)
    - OS converts into process-specific channel, like "socket"

Processes as Endpoints

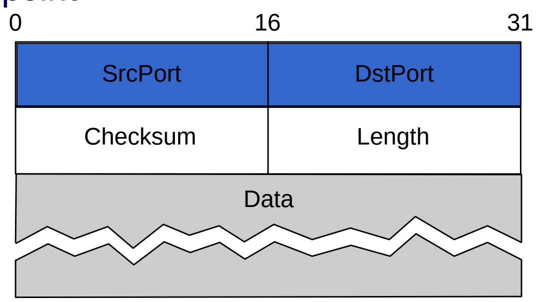


Picking Port Numbers

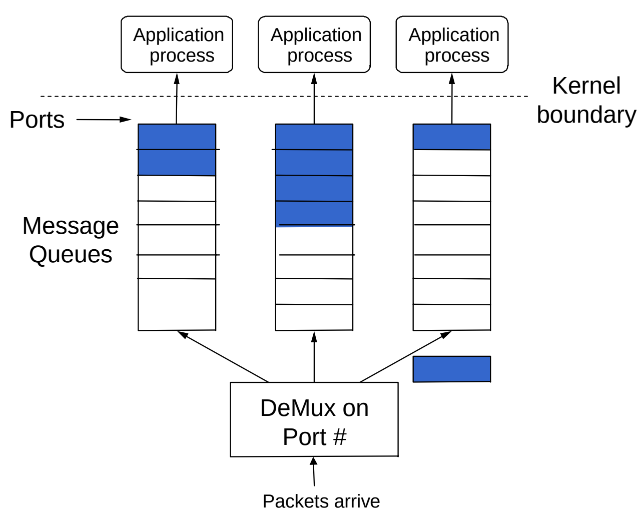
- We still have the problem of allocating port numbers
  - What port should a Web server use on host X?
  - To what port should you send to contact that Web server?
- Servers typically bind to “well-known” port numbers
  - e.g., HTTP 80, SMTP 25, DNS 53, … look in /etc/services
  - Ports below 1024 reserved for “well-known” services
- Clients use OS-assigned temporary (ephemeral) ports
  - Above 1024, recycled by OS when client finished

User Datagram Protocol (UDP)

- Provides message delivery between processes
  - Source port filled in by OS as message is sent
  - Destination port identifies UDP delivery queue at endpoint

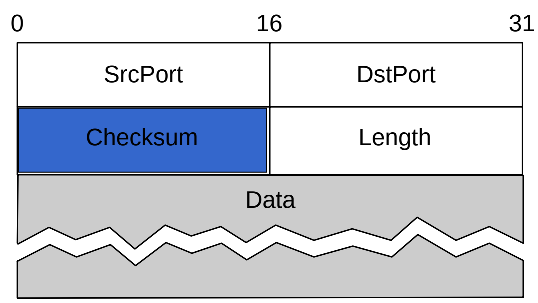


UDP Delivery



UDP Checksum

- UDP includes optional protection against errors
  - Checksum intended as an end-to-end check on delivery
  - So it covers data, UDP header

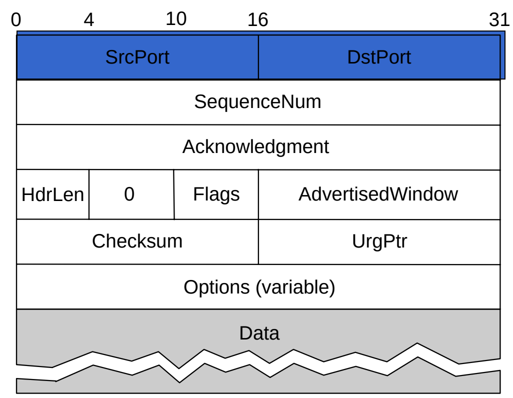


Transmission Control Protocol (TCP)

- Reliable bi-directional bytestream between processes
  - Message boundaries are not preserved
- Connections
  - Conversation between endpoints with beginning and end
- Flow control
  - Prevents sender from over-running receiver buffers
- Congestion control
  - Prevents sender from over-running network buffers

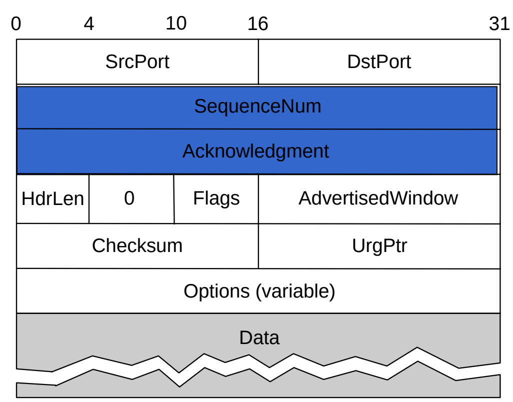
TCP Header Format

- Ports plus IP addresses identify a connection



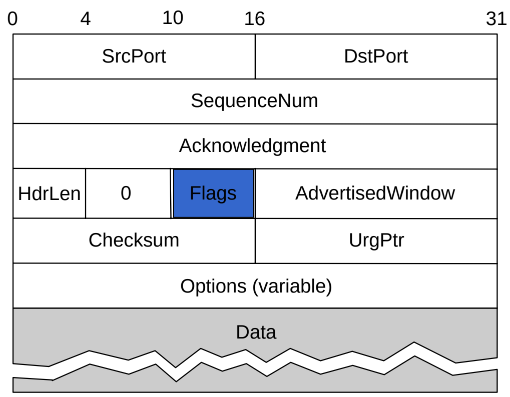
TCP Header Format

- Sequence, Ack numbers used for the sliding window



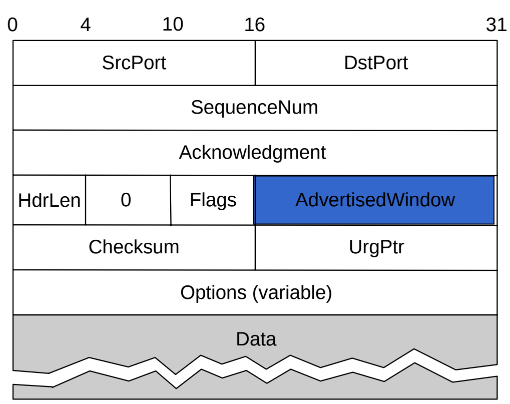
TCP Header Format

- Flags may be URG, ACK, PUSH, RST, SYN, FIN



TCP Header Format

- Advertised window is used for flow control



TCP Connection Establishment

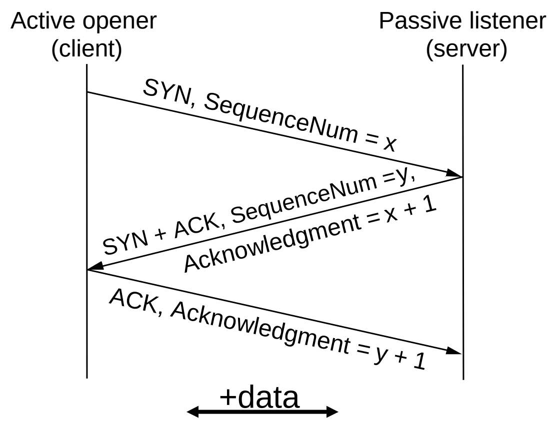
- Both connecting and closing are (slightly) more complicated than you might expect
- That they *can* work is reasonably straightforward
- Harder is what to do when things go wrong
  - TCP SYN+ACK attack
- Close looks a bit compicated because both sides have to close to be done
  - Conceptually, there are two one-way connections
  - Don't want to hang around forever if other end crashes

TCP Connection Establishment

- Both sender and receiver must be ready before we start to transfer the data
  - Sender and receiver need to agree on a set of parameters
  - e.g., the Maximum Segment Size (MSS)
- This is "signaling"
  - It sets up state at the endpoints
  - Compare to "dialing" in the telephone network
- In TCP a Three-Way Handshake is used

Three-Way Handshake

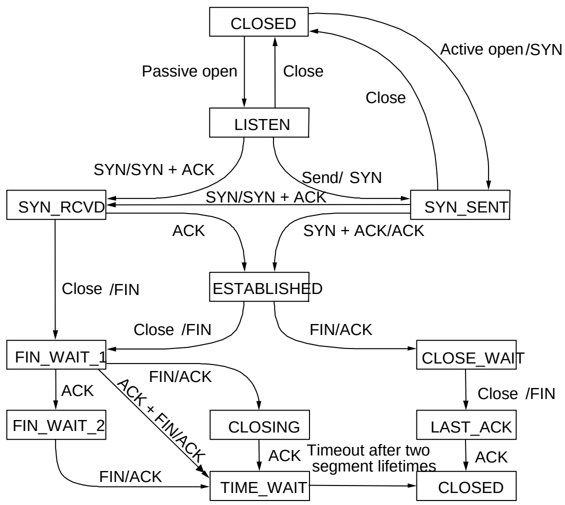
- Opens both directions for transfer



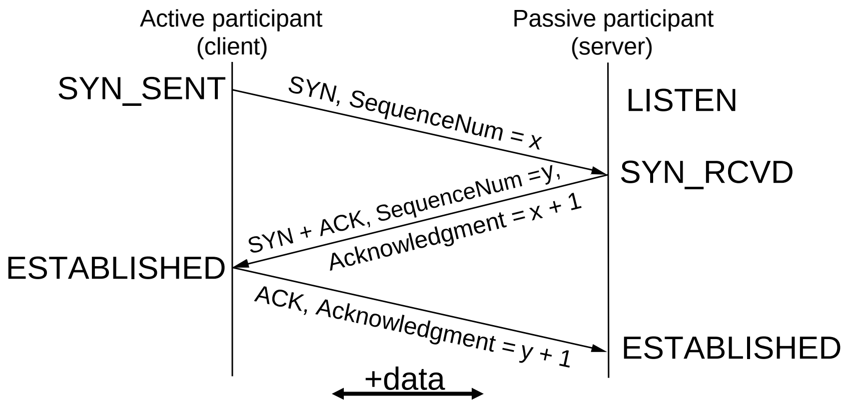
Some Comments

- We could abbreviate this setup, but it was chosen to be robust, especially against delayed duplicates
  - Three-way handshake from Tomlinson 1975
- Choice of changing initial sequence numbers (ISNs) minimizes the chance of hosts that crash getting confused by a previous incarnation of a connection
- But with random ISN it actually proves that two hosts can communicate
  - Weak form of authentication

TCP State Transitions



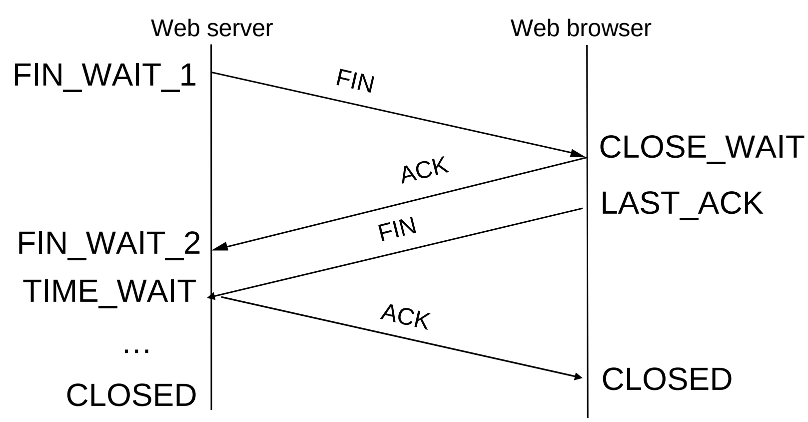
Again, with States



Connection Teardown

- Orderly release by sender and receiver when done
  - Delivers all pending data and “hangs up”
- Cleans up state in sender and receiver
- TCP provides a “symmetric” close
  - both sides shutdown independently

TCP Connection Teardown



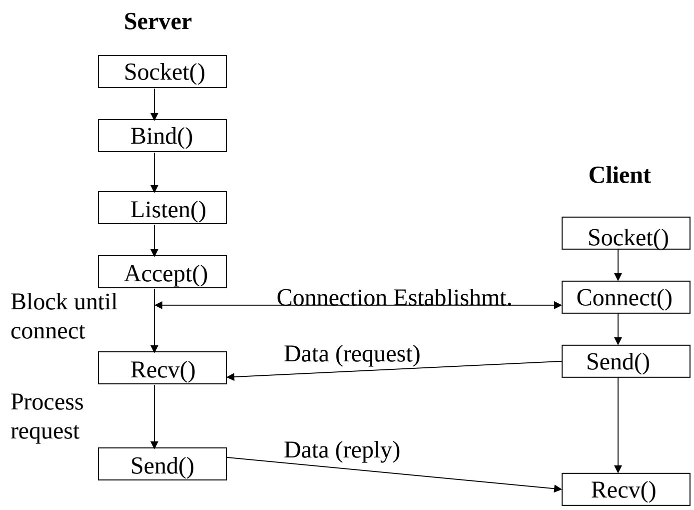
The TIME_WAIT State

- We wait 2MSL (two times the maximum segment lifetime of 60 seconds) before completing the close
- Why?
- ACK might have been lost and so FIN will be resent
- Could interfere with a subsequent connection

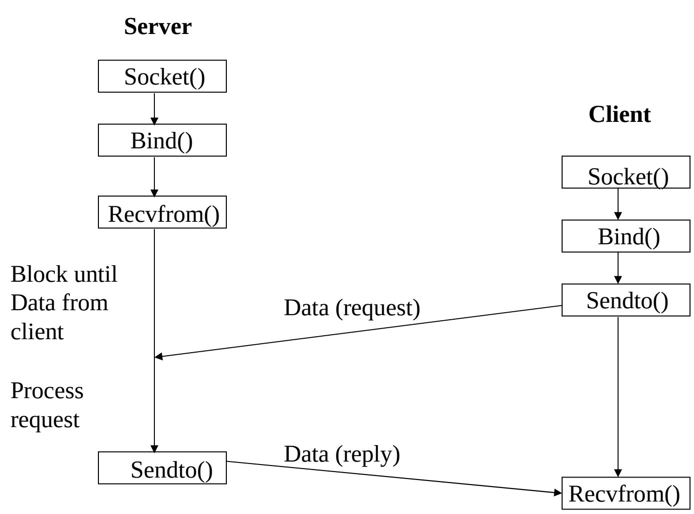
Berkeley Sockets interface

- Networking protocols implemented in OS
  - OS must expose a programming API to applications
  - most OSs use the “socket” interface
  - originally provided by BSD 4.1c in ~1982.
- Principle abstraction is a “socket”
  - a point at which an application attaches to the network
  - defines operations for creating connections, attaching to network, sending and receiving data, closing connections

TCP (connection-oriented)



UDP (connectionless)



Using Sockets: UDP

- import java.net.*;
- UDP sockets:
  - new DatagramSocket(); // binds to ephemeral port number
  - new DatagramSocket(port); // tries to bind to 'port'
- DatagramPacket
  - Unit of transfer between application and networking software
  - new DatagramPacket(byte[] buf, int len);
  - new DatagramPacket(byte[] buf, int len, InetAddress addr, int port);
- Sending data:
  - Construct a DatagramPacket
  - Set its data field, and its address components
  - myDatagramSocket.*send*(myDatagramPacket)

Java / UDP

- Java also has an interface supporting `connect(SocketAddr addr)`, but it's a layer above UDP
  - Filters incoming packets not from *addr*
  - Filters outgoing packets not from *addr*
- Performance / correctness issue:
  - Is a copy of the data portion of a `DatagramPacket` made when `send()` is invoked,
    or is a reference to the `byte[] buf` kept?
- Blocking vs. non-blocking IO
  - Non-blocking options
    1. import java.net.*;
       – DatagramSocket.setSOTimeout(int timeout);
    2. import java.nio.*;
       – More general (complicated) support

Using Sockets: TCP

- The TCP distinction between passive and active open is embedded in the (typical) socket interfaces
  - There are two kinds of sockets:
    - Socket
    - ServerSocket
- Server starts, creates a server socket, binds it to a local port, and listens for a client to connect
- Client starts, creates a socket on an ephemeral port, and connects to the server socket
- As a result of the connection, the server socket creates a *new* socket to return to the application
  - Provides a handy way to identify/name a single flow in the application code

TCP Server-side: Java

- Create:
  - `ServerSocket ss = new ServerSocket();`
  - `ServerSocket ss = new ServerSocket(port);`
- Listen:
  - `Socket s = ss.accept();`

TCP Client side: Java

- Create:
  - `Socket s = new Socket();`
- Connect:
  - `s.connect(serverAddress);`
  - `S.connect(serverAddress, timeout);`
- Use:
  - It's Java, the sockets support streams, the mind boggles
  - `BufferedReader in = new BufferedReader(new InputStreamReader(s.getInputStream()));`
    - `in.readLine();`
  - `PrintWriter out = new PrintWriter(s.getOutputStream(), true);`
    - `Out.print(data);`
  - `OutStream outStream = s.getOutputStream();`
    - `outStream.write( buf, 0, n);  // byte[] buf for n bytes starting at offset 0`

Key Concepts

- We use ports to name processes in TCP/UDP
  - "Well-known" ports are used for popular services
- Connection setup and teardown complicated by the effects of the network on messages
  - TCP uses a three-way handshake to set up a connection
  - TCP uses a symmetric disconnect