Outline

• Networking Overview
  – IP Addressing
  – DNS
  – Ports
  – NAT
  – Subnets
  – DHCP

• Test Yourself
Networking Overview

- A server is a computer that has at least one program running on it that can service requests from another program.
- Server hardware is typically more robust than other hardware, but a server can physically be any computer.
- A client is a computer that requests a service to be performed by another computer.
- Consider browsing the web. What is the service provided by a web server?
Servers

- Server hardware is typically more robust and expensive than other hardware, but a server can physically be any computer.
IP Addresses

- An IP address is a unique address that is required of all computers that communicate on a network.
- IPv4 addresses consist of 32 bits separated as 4 numbers of 8 bits each:
  - 128.125.253.146
- IPv6 addresses consist of 128 bits separated as 8 sets of 4 hexadecimal values:
  - NOTE that if all four hexadecimal values are 0, the term will be omitted:
    - fe29:392A:3396::5591:40d3 (4th, 7th, and 8th terms are 0000)

My IP Address
192.168.1.1
IPv6 Address Space

- How many IPv4 addresses are there?
  - 32 bits = $2^{32}$ addresses
    = $2^2 \times 2^{30}$ addresses
    = ~4 billion addresses

- How many IPv6 addresses are there?
  - 128 bits = $2^{128}$ addresses
    = $2^8 \times 2^{120}$ addresses
    = 256 * $2^{120}$ addresses

$2^{10} = 1024 = \sim 10^3 = \text{thousand}$
$2^{20} = 1,048,576 = \sim 10^6 = \text{million}$
$2^{30} = \sim 10^9 = \text{billion}$
$2^{40} = \sim 10^{12} = \text{trillion}$
$2^{50} = \sim 10^{15} = \text{quadrillion}$
$2^{60} = \sim 10^{18} = \text{quintillion}$

$2^{70} = \sim 10^{21} = \text{sextillion}$
$2^{80} = \sim 10^{24} = \text{septillion}$
$2^{90} = \sim 10^{27} = \text{octillion}$
$2^{100} = \sim 10^{30} = \text{nonillion}$
$2^{110} = \sim 10^{33} = \text{decillion}$
$2^{120} = \sim 10^{36} = \text{undecillion}$
IPv4 Classes

- Network numbers are managed by ICANN
- The Internet Assigned Numbers Authority (IANA) was founded by USC/ISI and transferred to ICANN in 1998
  - ICANN was founded primarily to take over control of IANA

<table>
<thead>
<tr>
<th>Class</th>
<th>Network</th>
<th>Host</th>
<th>Range of host addresses</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td></td>
<td>1.0.0.0 to 127.255.255.255</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td></td>
<td>128.0.0.0 to 191.255.255.255</td>
</tr>
<tr>
<td>C</td>
<td>110</td>
<td></td>
<td>192.0.0.0 to 223.255.255.255</td>
</tr>
<tr>
<td>D</td>
<td>1110</td>
<td>Multicast address</td>
<td>224.0.0.0 to 239.255.255.255</td>
</tr>
<tr>
<td>E</td>
<td>1111</td>
<td>Reserved for future use</td>
<td>240.0.0.0 to 255.255.255.255</td>
</tr>
</tbody>
</table>
# IPv4 Special Addresses

<table>
<thead>
<tr>
<th>Address</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>[\text{\texttt{000000000000000000000000000000000000000000000000000000000000000}}]</td>
<td>This host</td>
</tr>
<tr>
<td>[\text{\texttt{00...00}}]</td>
<td>A host on this network</td>
</tr>
<tr>
<td>[\text{\texttt{111111111111111111111111111111111111111111111111111111111111111}}]</td>
<td>Broadcast on the local network</td>
</tr>
<tr>
<td>[\text{\texttt{Network: 1111...1111}}]</td>
<td>Broadcast on a distant network</td>
</tr>
<tr>
<td>[\text{\texttt{127}}]</td>
<td>Loopback</td>
</tr>
</tbody>
</table>

There’s no place like 127.0.0.1.
Finding Your IP Address

- Open a command line and type `ipconfig` in Windows
- `ifconfig` in Mac or Linux
Routing

- Routing is the process of sending data from one computer to another
- Routers use two algorithms – Distance Vector and Link State
  - The specifics of those algorithms are outside the scope of this lecture
Finding a Route

- This is a very complicated process, but running `tracert` (Windows) or `traceroute` (Mac, Linux) from a command line or terminal will show you all the routers visited from your computer to a destination.
Trans-Oceanic Pipelines
Satellite Communication
Domain Name System (DNS)

- Some servers can be identified by a hostname and domain name
  - An example would be www.usc.edu
  - www is the hostname (or an alias for a hostname)
  - usc.edu is the domain name
- To find the IP address of a hostname/domain name combination from a command line, run `ping` or `nslookup` from a command line or terminal
DNS Namespace

- The hostname/domain name combination will be mapped to an IP address through DNS servers
  - DNS is a hierarchical domain-based naming scheme implemented through a distributed database system for implementing
  - DNS was conceived at USC’s ISI and managed there until 1998
  - DNS is now managed by ICANN
DNS Resource Records

- Every domain has a set of resource records associated with it, which is what DNS will return based on a certain name
- A resource record consists of five items
  - Domain Name – the domain of the record
  - Time To Live – the higher the value, the more stable the record
  - Class – always IN for Internet resources (rarely used outside of that)
  - Type – what kind of record it is (see table below)
  - Value – the value associated with the record

<table>
<thead>
<tr>
<th>Type</th>
<th>Meaning</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOA</td>
<td>Start of Authority</td>
<td>Parameters for this zone</td>
</tr>
<tr>
<td>A</td>
<td>IP address of a host</td>
<td>32-Bit integer</td>
</tr>
<tr>
<td>MX</td>
<td>Mail exchange</td>
<td>Priority, domain willing to accept e-mail</td>
</tr>
<tr>
<td>NS</td>
<td>Name Server</td>
<td>Name of a server for this domain</td>
</tr>
<tr>
<td>CNAME</td>
<td>Canonical name</td>
<td>Domain name</td>
</tr>
<tr>
<td>PTR</td>
<td>Pointer</td>
<td>Alias for an IP address</td>
</tr>
<tr>
<td>HINFO</td>
<td>Host description</td>
<td>CPU and OS in ASCII</td>
</tr>
<tr>
<td>TXT</td>
<td>Text</td>
<td>Uninterpreted ASCII text</td>
</tr>
</tbody>
</table>
Sample DNS Database

; Authoritative data for cs.vu.nl

<table>
<thead>
<tr>
<th>Name</th>
<th>TTL</th>
<th>Type</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>cs.vu.nl</td>
<td>86400</td>
<td>SOA</td>
<td>star boss (952771,7200,7200,2419200,86400)</td>
</tr>
<tr>
<td>cs.vu.nl</td>
<td>86400</td>
<td>TXT</td>
<td>&quot;Divisie Wiskunde en Informatica.&quot;</td>
</tr>
<tr>
<td>cs.vu.nl</td>
<td>86400</td>
<td>TXT</td>
<td>&quot;Vrije Universiteit Amsterdam.&quot;</td>
</tr>
<tr>
<td>cs.vu.nl</td>
<td>86400</td>
<td>MX</td>
<td>1 zephyr.cs.vu.nl</td>
</tr>
<tr>
<td>cs.vu.nl</td>
<td>86400</td>
<td>MX</td>
<td>2 top.cs.vu.nl</td>
</tr>
<tr>
<td>flits.cs.vu.nl</td>
<td>86400</td>
<td>HINFO</td>
<td>Sun Unix</td>
</tr>
<tr>
<td>flits.cs.vu.nl</td>
<td>86400</td>
<td>A</td>
<td>130.37.16.112</td>
</tr>
<tr>
<td>flits.cs.vu.nl</td>
<td>86400</td>
<td>A</td>
<td>192.31.231.165</td>
</tr>
<tr>
<td>flits.cs.vu.nl</td>
<td>86400</td>
<td>MX</td>
<td>1 flits.cs.vu.nl</td>
</tr>
<tr>
<td>flits.cs.vu.nl</td>
<td>86400</td>
<td>MX</td>
<td>2 zephyr.cs.vu.nl</td>
</tr>
<tr>
<td>flits.cs.vu.nl</td>
<td>86400</td>
<td>MX</td>
<td>3 top.cs.vu.nl</td>
</tr>
<tr>
<td><a href="http://www.cs.vu.nl">www.cs.vu.nl</a></td>
<td>86400</td>
<td>CNAME</td>
<td>star.cs.vu.nl</td>
</tr>
<tr>
<td>ftp.cs.vu.nl</td>
<td>86400</td>
<td>CNAME</td>
<td>zephyr.cs.vu.nl</td>
</tr>
<tr>
<td>rowboat</td>
<td></td>
<td>A</td>
<td>130.37.56.201</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MX</td>
<td>1 rowboat</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MX</td>
<td>2 zephyr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HINFO</td>
<td>Sun Unix</td>
</tr>
<tr>
<td>little-sister</td>
<td></td>
<td>A</td>
<td>130.37.62.23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HINFO</td>
<td>Mac MacOS</td>
</tr>
<tr>
<td>laserjet</td>
<td></td>
<td>A</td>
<td>192.31.231.216</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HINFO</td>
<td>&quot;HP Laserjet IIISi&quot; Proprietary</td>
</tr>
</tbody>
</table>
Actual DNS Records

Zone File Editor

sigmacoding.com (Last saved 8/28/2014 5:55:36 PM MST)

A (Host) □
- Host
- Points to
- TTL

CNAME (Alias) □
- Host
- Points to
- TTL

MX (Mail Exchanger) □
- Priority
- Host
- Points to
- TTL

Filter
- Select: A, None, With Records
- A Record (Host)
- CNAME (Alias)
- MX (Mail Exchanger)
- TXT (Text)
- SRV (Service)
- AAAA (IPv6 Host)
- NS (Nameserver)

Answer Center
- Why should I upgrade to Premium DNS?
- Upgrading to Premium DNS
- What are zone files and zone records?
- Checking Your Domain Name's Zone File Records
Ports

- Since more than one networked program can run on a computer at the same time, we need a way to uniquely identify them
  - Ports allow us to do just that
- A client application will specify the port on the server with which to communicate, and that uniquely identifies the server application
- A port is in the range from 0 to 65535 (16 bits)
  - Ports from 0-1023 (inclusively) are reserved for well-known applications, so root or administrator access is required to run a program on a port in that range
  - Ports from 1024-49151 (inclusively) are registered ports and can be used by any application
  - Ports from 49152-65535 are dynamic or private ports and are typically used by the operating system when an application needs to pass an application off to a non-registered port
Well-Known Ports

<table>
<thead>
<tr>
<th>Port</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>FTP data</td>
</tr>
<tr>
<td>21</td>
<td>FTP control</td>
</tr>
<tr>
<td>22</td>
<td>SSH</td>
</tr>
<tr>
<td>23</td>
<td>Telnet</td>
</tr>
<tr>
<td>25</td>
<td>SMTP</td>
</tr>
<tr>
<td>53</td>
<td>DNS</td>
</tr>
<tr>
<td>80</td>
<td>HTTP</td>
</tr>
<tr>
<td>143</td>
<td>IMAP</td>
</tr>
<tr>
<td>443</td>
<td>HTTPS</td>
</tr>
</tbody>
</table>

- There are many others, but these are some of the more popular ones
Public and Private IP Addresses

- Public IP addresses are able to be seen by any computer in the world and are required for communicating on the Internet.
- Private IP addresses are typically secured behind a firewall, so explicit access has to be allowed to them.
  - Private IPv4 addresses are in the following ranges:
    - Class A Private: 10.0.0.0 – 10.255.255.255
      - $2^9=1$ network with $2^{24}$ addresses
    - Class B Private: 172.16.0.0 – 172.31.255.255
      - $2^4=16$ networks with $2^{16}$ addresses
    - Class C Private: 192.168.0.0 – 192.168.255.255
      - $2^8=256$ networks with $2^8$ hosts on each network
  - Private IP addresses must use NAT (see future slide) if accessing the Internet because private IP addresses cannot communicate outside local networks.
  - If a computer is unable to obtain an IP address, an address in the range 169.254.0.0 – 169.254.255.255 may be assigned.
    - This IP address is NOT available to the Internet.
Network Address Translation (or IP Masquerading) allows a computer to have a private IP address

- Private IP addresses are not able to be accessed by hosts outside of the local network
- A NAT server (usually implemented in a router) substitutes its own public IP address in place of the computer’s private IP address
- The NAT server must maintain a NAT table that links the private IP address and TCP/UDP source port combination to the destination IP address
  - Since the NAT server’s public IP address has been substituted for the computer’s private IP address in the packet, the response from the destination computer will come back to the NAT server
  - The port will let the NAT server know to which computer to forward the response
NAT Example

**LAN**
- Packet
  - Source IP Addr = 192.168.1.101
  - Source Port = 54847

**Internet**
- Packet
  - Source IP Addr = 65.96.14.76
  - Source Port = 1

**NAT Translation Table**

<table>
<thead>
<tr>
<th>Local IP Address</th>
<th>Source Port #</th>
<th>Internet IP Address</th>
<th>Source Port #</th>
</tr>
</thead>
<tbody>
<tr>
<td>process X, Host A</td>
<td>192.168.1.101</td>
<td>54,847 = 65.96.14.76</td>
<td>1</td>
</tr>
<tr>
<td>Host B</td>
<td>192.168.1.103</td>
<td>24,123 = 65.96.14.76</td>
<td>2</td>
</tr>
<tr>
<td>process Y, Host A</td>
<td>192.168.1.101</td>
<td>42,156 = 65.96.14.76</td>
<td>3</td>
</tr>
<tr>
<td>Host C</td>
<td>192.168.1.102</td>
<td>33,543 = 65.96.14.76</td>
<td>4</td>
</tr>
</tbody>
</table>
Subnets

- Since network addresses are so scarce, we can take a few bits away from the host address to make a subnet within a network.

- To implement subnetting, the router needs a subnet mask that indicates the split between the network and the subnet/host combination.

- The subnet mask will consist of all 1’s followed by all 0’s.
  - 255.255.255.0 = 11111111 11111111 11111111 00000000 \text{ VALID}
  - 255.255.255.2 = 11111111 11111111 11111111 00000010 \text{ NOT VALID}

- The subnet mask can also be written using slash notation.
  - The number after the slash will represent the number of bits to be used in the subnet address.
  - This would correspond to the number of 1’s in the subnet mask.
  - 255.255.255.0 could be written as /24
Subnet Example #1

- Assume a host has an IP address of 74.125.127.104 with a subnet mask of 255.255.255.192 (also written as 74.125.127.104/26)
  - What is the network address? (i.e. what class IP address is this?)
  - What is the subnet mask in binary?
  - How many hosts can be in the subnet?

- 74.125.127.104  =  01001010  01111101  01111111  01101000
- 255.255.255.192  =  11111111  11111111  11111111  11000000

- Network Address – this is a Class A address, so the first 8 bits are allocated for the network: 74.0.0.0
- Subnet Mask in binary will have the first 26 bits as 1’s with the last 6 bits as 0’s
- # Hosts – the last 6 bits are reserved for hosts, giving $2^6-2=62$ host addresses for this subnet
  - Remember that the address with all 0s and all 1s are reserved
Subnet Example #2

- To get the network/subnet address from an IP address and subnet mask, perform a logical AND operation between them.

137.229.154.221 = 1000 1001  1110 0101  1001 1010  1101 1101
255.255.224.0 = 1111 1111  1111 1111  1110 0000 0000 0000
137.229.128.0 = 1000 1001  1110 0101  1000 0000  0000 0000

- The network/subnet address is 137.229.128.0
- This subnet mask provides 19 bits for the network address and 13 bits for the host address.
- Another way we could have written the IP address with the subnet mask is 137.229.154.221/19
- *Note that the subnet mask can never contain fewer bits than the number of bits in the network address.*

› Why does that make sense?
Dynamic Host Control Protocol (DHCP) is used for a computer or router to automatically assign IP addresses and other network configuration (such as the gateway and subnet mask) to computers on the network.

- These addresses can be private or public IP addresses.
- Most routers assign private IP addresses, such as 192.168.1.101.
- Routers often have DHCP servers built into them.
Outline

• Networking Overview
  – IP Addressing
  – DNS
  – Ports
  – NAT
  – Subnets
  – DHCP

• Test Yourself
Test Yourself

- For each of the following IP addresses and subnets, write out the IP address in binary, subnet mask in decimal and binary, subnet address in decimal and binary, and the range of IP addresses that can be assigned to hosts.
  - 65.145.211.3/15
  - 145.21.48.129/26
  - 211.14.68.244/29

- Explain why the following IP address/subnet combination does not make sense.
  - 225.14.25.124/22

- Why are ports needed for NAT?