CSE 523S: Systems Security

Computer & Network Systems Security

Spring 2018
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Plan for Today

- Announcements
  - You should have completed the Python tutorial
  - Get started on HW2… There is an account creation step that requires operator approval. **Don’t wait until the last minute**, the operator may not be available...

- Security News? Questions?
- Assignment
- System Design & Security
  - [x] Why are our computer systems vulnerable?
  - Why are our networks vulnerable?

Assignment

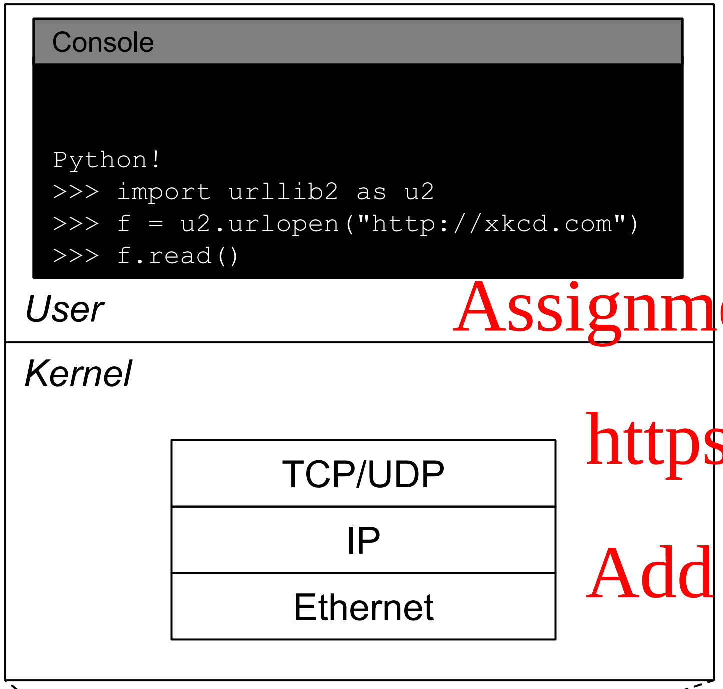
- Wednesday
  - HTAOE: Ch. 2 81-114
- Monday
  - HW2 due
  - HTAOE: Ch. 4 195-223

WHY ARE OUR NETWORKS VULNERABLE?

Networks are Vulnerable

- IP has an any-to-any communications model
  - Within IP you cannot control who sends you a packet
- Networks have weak authentication
  - When a packet arrives, you trust the source address
- Binding between layers and between names & addresses are based on trust
  - Insecure services map between network layers (eg, IP to Ethernet), and names to addresses
- Secure the “channel” only
  - You really want to secure the data and its source, not an address

Understanding Networks



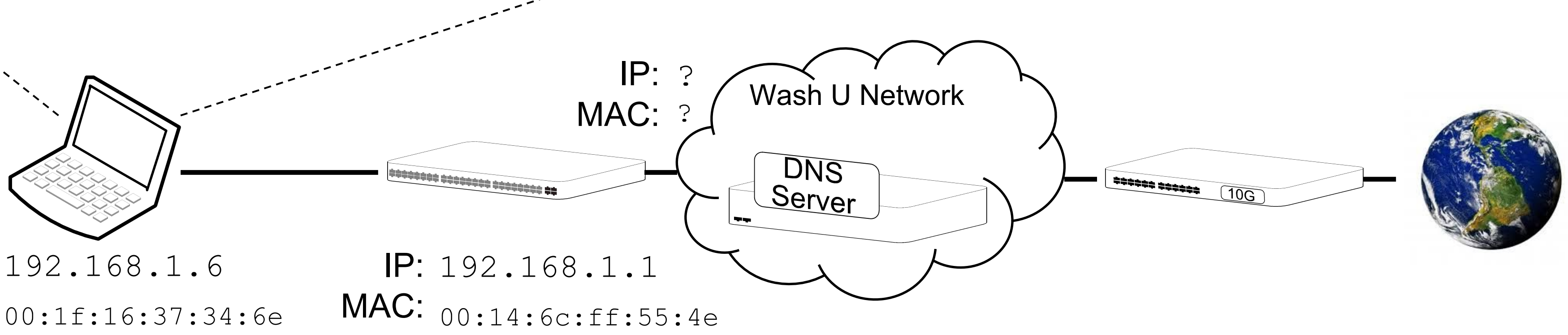
```
Python!
>>> import urllib2 as u2
>>> f = u2.urlopen("http://xkcd.com")
>>> f.read()
```

What do we need to know to answer these questions:

How does the request find its way to the server?

How does the reply find its way back to the client?

Once at the client, how does the reply find its way back to the app?



Packets are bit strings

```
ffffffffffff001f
1637346e08060001
080006040001001f
1637346ec0a80106
000000000000c0a8
0101000000000000
0000000000000000
00000000
```

```
char pkt[] =
"\xff\xff\xff\xff\xff\x
ff\x00\x1f\x16\x37\x34\
x6e\x08\x06\x00\x01\x08
\x00\x06\x04\x00\x01\x0
0\x1f\x16\x37\x34\x6e\x
c0\xa8\x01\x06\x00\x00\
x00\x00\x00\x00\xc0\xa8
\x01\x01\x00\x00\x00\x0
0\x00\x00\x00\x00\x00\x
00\x00\x00\x00\x00\x00\
x00\x00\x00";
```

If we knew the format rules we understand this packet to be… we’ll decode it in a later slide

Network Layering

- Network protocols are layered; they have well-defined interfaces and separation of concerns

- Typical Internet layering
  - Application
  - TCP
  - IP
  - Ethernet
  - Physical link: wired or wifi

- Network packets encapsulate one protocol inside another
  - (Ethernet (IP (TCP (Application))))

- Applications typically use the “sockets” interface, and specify TCP or UDP
  - All lower-level details are the concern of the OS and underlying infrastructure

- **Our concern is with TCP/IP and Ethernet**

Ethernet

- Is the dominant wired-LAN technology

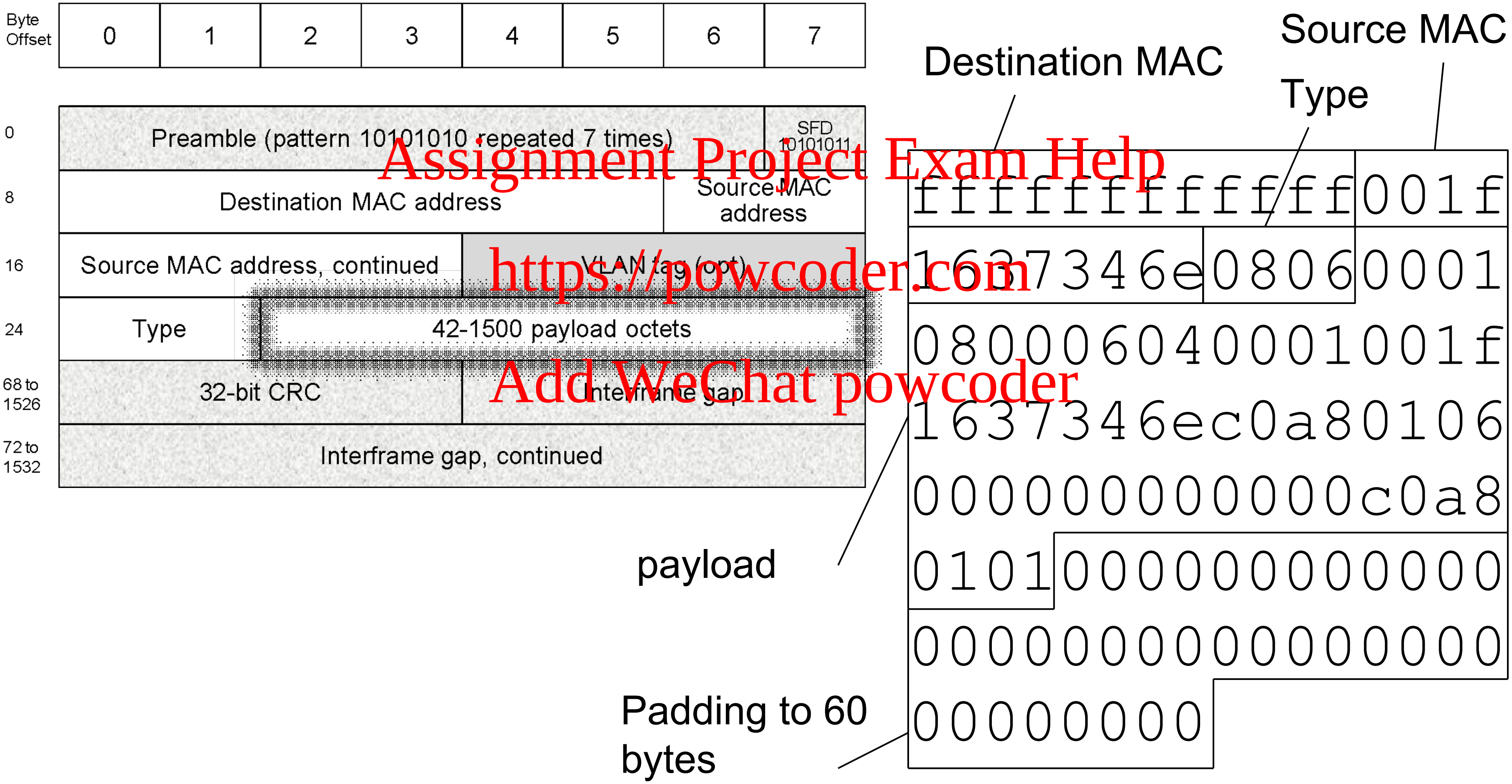
- Much to learn about its history, in your spare time
  - Used to be proprietary, now an IEEE standard
  - Used to be shared medium, now is switched
  - Always gets faster: 1M, 10M, 100M, 1G, 10G, …
  - Is rapidly becoming the only wired protocol that matters (LAN, campus, metro, …)

- Ethernet features
  - Variable length packets
  - Point-to-point communication between machines with MAC addresses
  - Broadcast: send packet to all nodes on local network
  - Virtual LANs (VLANs): limit broadcast domains to a VLAN
  - Uses "**type**" field to help receiver know what to do next

Ethernet II Frame Format

<table>
<tr><th>Byte Offset</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></tr>
<tr><td>0</td><td colspan="7">Preamble (pattern 10101010 repeated 7 times)</td><td>SFD 10101011</td></tr>
<tr><td>8</td><td colspan="6">Destination MAC address</td><td colspan="2">Source MAC address</td></tr>
<tr><td>16</td><td colspan="4">Source MAC address, continued</td><td colspan="4">VLAN tag (opt)</td></tr>
<tr><td>24</td><td colspan="2">Type</td><td colspan="6">42-1500 payload octets</td></tr>
<tr><td>68 to 1526</td><td colspan="4">32-bit CRC</td><td colspan="4">Interframe gap</td></tr>
<tr><td>72 to 1532</td><td colspan="8">Interframe gap, continued</td></tr>
</table>

Ethernet II Illustrated Frame



Byte Offset	0	1	2	3	4	5	6	7
0	Preamble (pattern 10101010 repeated 7 times)							SFD 10101011
8	Destination MAC address						Source MAC address	
16	Source MAC address, continued				VLAN tag (opt)			
24	Type		42-1500 payload octets					
68 to 1526	32-bit CRC				Interframe gap			
72 to 1532	Interframe gap, continued							

```
ffffffffffff001f
1637346e08060001
080006040001001f
1637346ec0a80106
000000000000c0a8
0101000000000000
0000000000000000
00000000
```

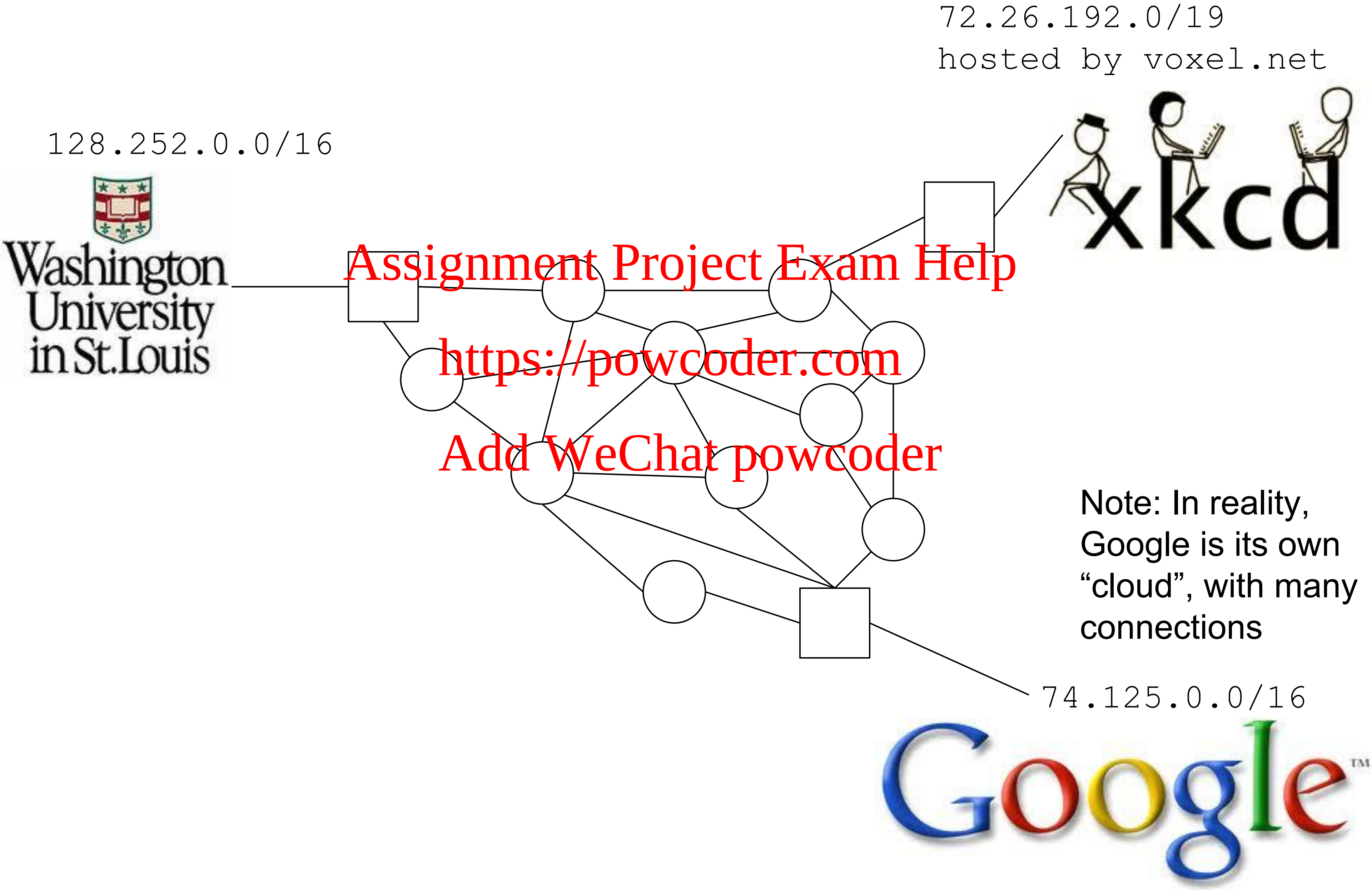
Internet Protocol, IP

- IP allows distinct networks to be connected

- From 30,000 feet
  - Each network is assigned an **IP address range**
    - WU: 128.252.0.0 - 128.252.255.255 (128.252.0.0/16)
  - A dynamic, globally distributed protocol is used to create **routes** between address ranges
  - A dynamic, globally distributed service is used to map **domain names** to IP addresses
  - IP supports multiple protocols for communications: UDP, TCP, ICMP, …

- Two aspects of IP to understand
  - Node model
  - Packet format

IP Nodes and Routes



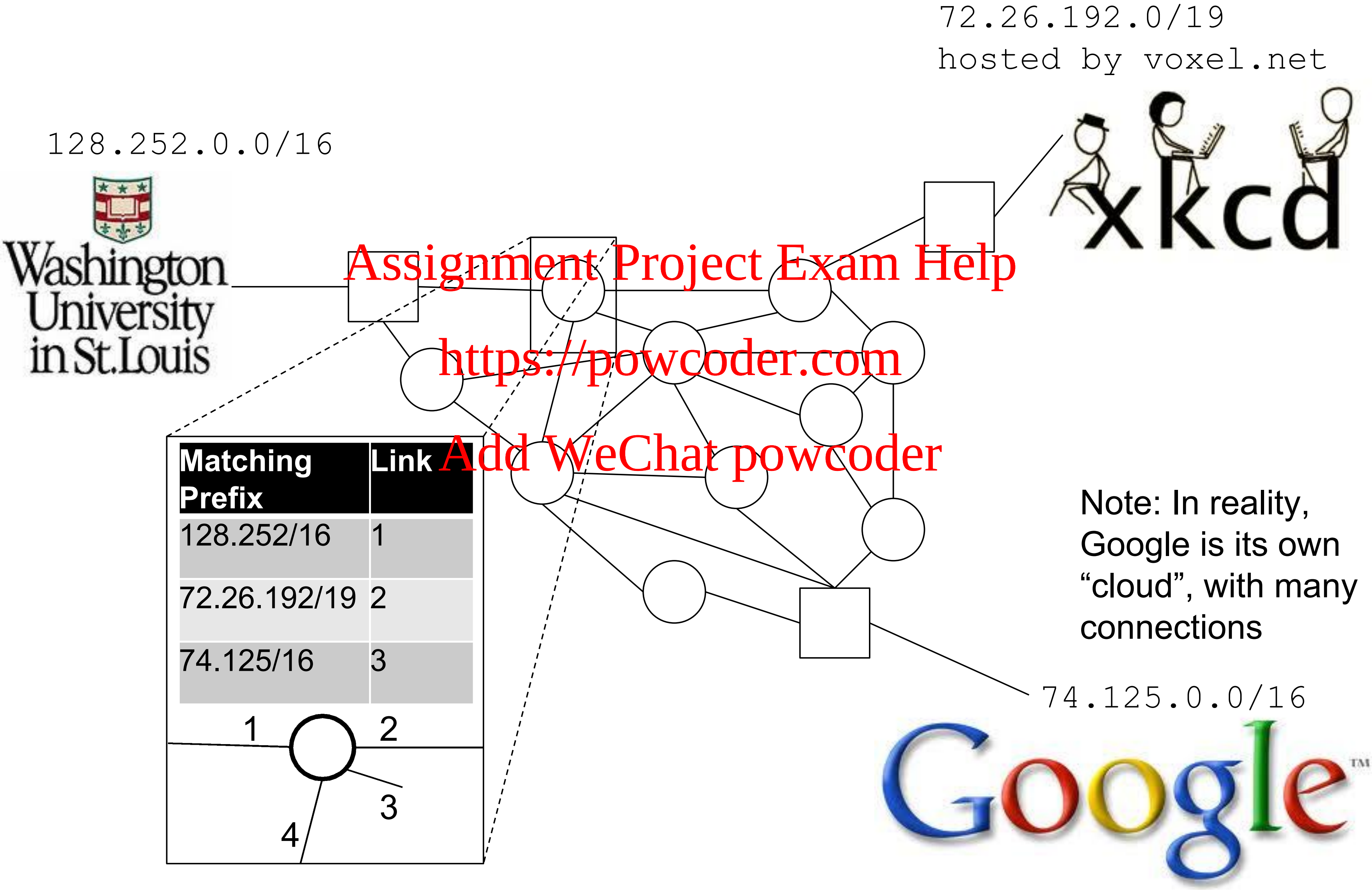
72.26.192.0/19
hosted by voxel.net

128.252.0.0/16

74.125.0.0/16

Note: In reality, Google is its own “cloud”, with many connections

IP Nodes and Routes



Matching Prefix	Link
128.252/16	1
72.26.192/19	2
74.125/16	3

Note: In reality, Google is its own “cloud”, with many connections

IP Packet Format

Bit Offset	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31

<table>
<tr><td>0</td><td>Version</td><td>Header Length</td><td>DiffServ</td><td>ECN</td><td colspan="2">Total Datagram Length (bytes)</td></tr>
<tr><td>32</td><td colspan="4">Identification</td><td>Flags</td><td>Fragment Offset</td></tr>
<tr><td>64</td><td colspan="2">Time to live</td><td colspan="2">Protocol</td><td colspan="2">Header checksum</td></tr>
<tr><td>96</td><td colspan="6">Source IP address</td></tr>
<tr><td>128</td><td colspan="6">Destination IP address</td></tr>
<tr><td>160</td><td colspan="6">0 to 10 IP option words</td></tr>
<tr><td>160 to 480</td><td colspan="6">0 to 16384 data words</td></tr>
</table>

UDP & TCP

- Two primary protocols for applications
  - UDP: unreliable datagrams
  - TCP: reliable, in-order byte streams
- “Ports” are used to demultiplex to apps on hosts
  - Example in a few slides

User Datagram Protocol, UDP

- Connection-less communications
  - Messages are sent, no in-protocol means for reliability

- Not reliable
  - May not arrive
  - May arrive out of order
  - May be duplicated

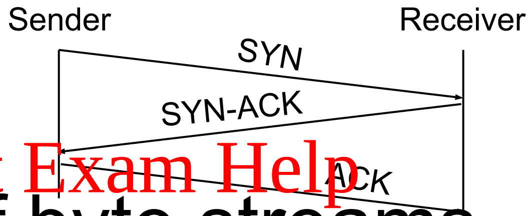
- No support for managing congestion

UDP Packet Format

<table>
<tr><td>Bit Offset</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>30</td><td>31</td></tr>
<tr><td>0</td><td colspan="16">Source port number (opt)</td><td colspan="16">Destination port number</td></tr>
<tr><td>32</td><td colspan="16">Length</td><td colspan="16">Datagram checksum (opt)</td></tr>
<tr><td>64</td><td colspan="32">0 to 16376 data words</td></tr>
</table>

Transport Control Protocol, TCP

- Connection-oriented
  - 3-way handshake used between communicating end hosts
    - SYN, SYN-ACK, ACK



- Reliable, ordered delivery of byte streams
  - All will arrive
  - Will arrive in order
  - Will not be duplicated

- Includes provision for “congestion control” so that sender-receiver pairs scale up/down their data rates in response to (un)dropped packets.

TCP Packet Format

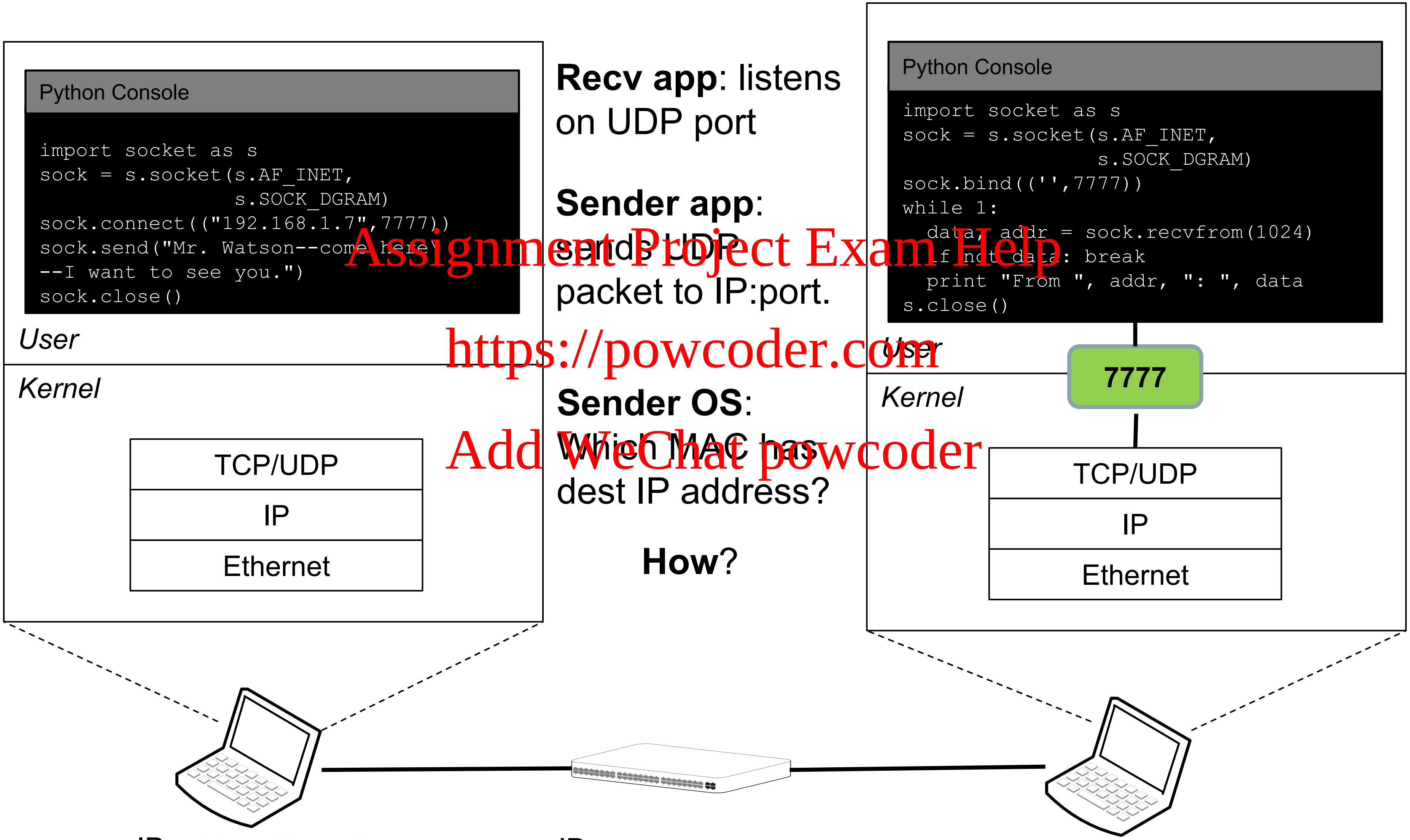
<table>
<tr><td>Bit Offset</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>30</td><td>31</td></tr>
<tr><td>0</td><td colspan="16">Source port number</td><td colspan="16">Destination port number</td></tr>
<tr><td>32</td><td colspan="32">Sequence number</td></tr>
<tr><td>64</td><td colspan="32">Acknowledgement number</td></tr>
<tr><td>96</td><td colspan="4">Data offset</td><td colspan="3">Res</td><td>NS</td><td>CWR</td><td>ECE</td><td>URG</td><td><b>ACK</b></td><td>PSH</td><td>RST</td><td><b>SYN</b></td><td>FIN</td><td colspan="16">Window size (bytes)</td></tr>
<tr><td>128</td><td colspan="16">Checksum</td><td colspan="16">Urgent pointer</td></tr>
<tr><td>160</td><td colspan="32">Options and data</td></tr>
</table>

Sockets

- Apps primarily use sockets API to connect
  - Create a socket by specifying address family (AF_INET), and type (SOCK_DGRAM or SOCK_STREAM)
  - Connect it to an address and port
  - Send and receive
  - Library also includes helper functions

- Network byte ordering is distinct from host byte ordering
  - Little-endian: least significant byte at lower address
  - Big-endian: most significant byte at lower address
  - X86: little-endian; network: big-endian
  - Apps must convert to and from network byte order: `ntohl()`, `htonl()`

Two Machines on an Ethernet LAN



```
import socket as s
sock = s.socket(s.AF_INET,
                s.SOCK_DGRAM)
sock.connect(("192.168.1.7",7777))
sock.send("Mr. Watson--come here
--I want to see you.")
sock.close()
```

Recv app: listens on UDP port

Sender app: sends UDP packet to IP:port.

Sender OS: Which MAC has dest IP address?

How?

```
import socket as s
sock = s.socket(s.AF_INET,
                s.SOCK_DGRAM)
sock.bind(('',7777))
while 1:
  data, addr = sock.recvfrom(1024)
  if not data: break
  print "From ", addr, ": ", data
s.close()
```

IP: `192.168.1.6`
MAC: `00:1f:16:37:34:6e`

IP: `192.168.1.1`
MAC: `00:14:6c:ff:55:4e`

IP: `192.168.1.7`
MAC: `00:1f:42:81:e4:a1`

Address Resolution, ARP

- General protocol for mapping between protocol layers

- In practice, a protocol for mapping IP addresses to Ethernet MAC addresses
  - Not part of TCP/IP per-se, but you won’t find a network without it

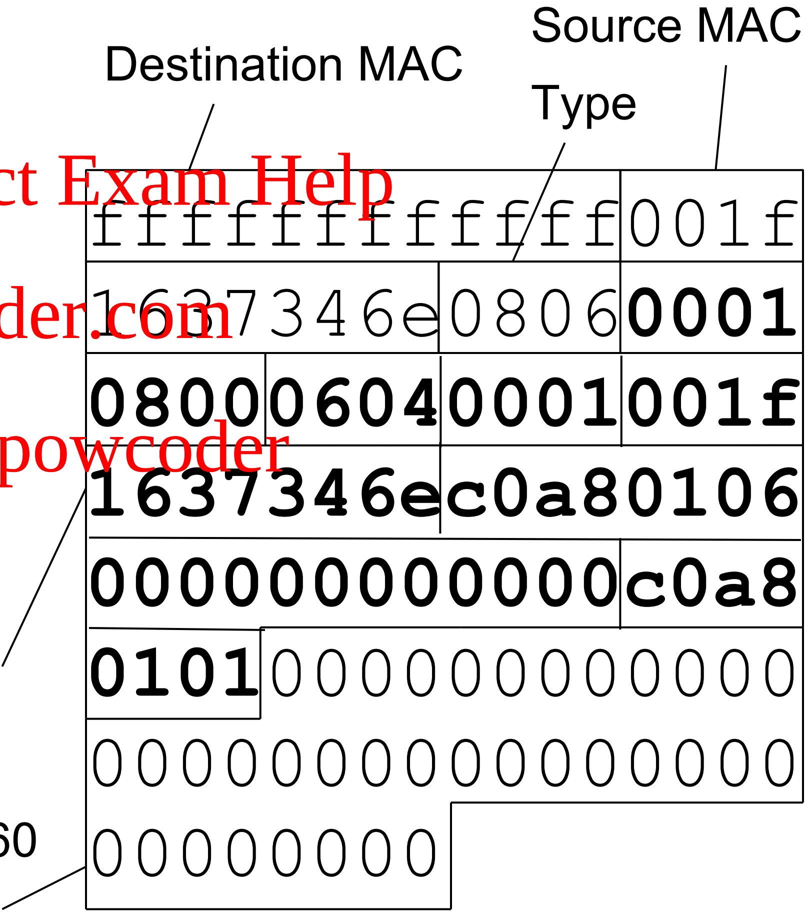
- Two operations
  - Request: Who has <TGT-IP>? Tell <MY-MAC>
  - Reply: <TGT-IP> is at <TGT-MAC>

ARP Ethernet:IP Packet Format

<table>
<tr><th>Byte Offset</th><th>0</th><th>1</th><th>2</th><th>3</th></tr>
<tr><td>0</td><td colspan="2">Hardware type (Eth is 1)</td><td colspan="2">Protocol type (IP is 0x0800)</td></tr>
<tr><td>4</td><td>HW Addr Len
(Eth is 6)</td><td>Proto Addr Len
(IP is 4)</td><td colspan="2">Operation (1 request, 2 reply)</td></tr>
<tr><td>8</td><td colspan="4">Sender HW Address (SHA)</td></tr>
<tr><td>12</td><td colspan="2">SHA, continued</td><td colspan="2">Sender Protocol Address (SPA)</td></tr>
<tr><td>16</td><td colspan="2">SPA, continued</td><td colspan="2">Target HW Address (THA)</td></tr>
<tr><td>20</td><td colspan="4">THA, continued</td></tr>
<tr><td>24</td><td colspan="4">Target Protocol Address (TPA)</td></tr>
</table>

ARP Illustrated Packet

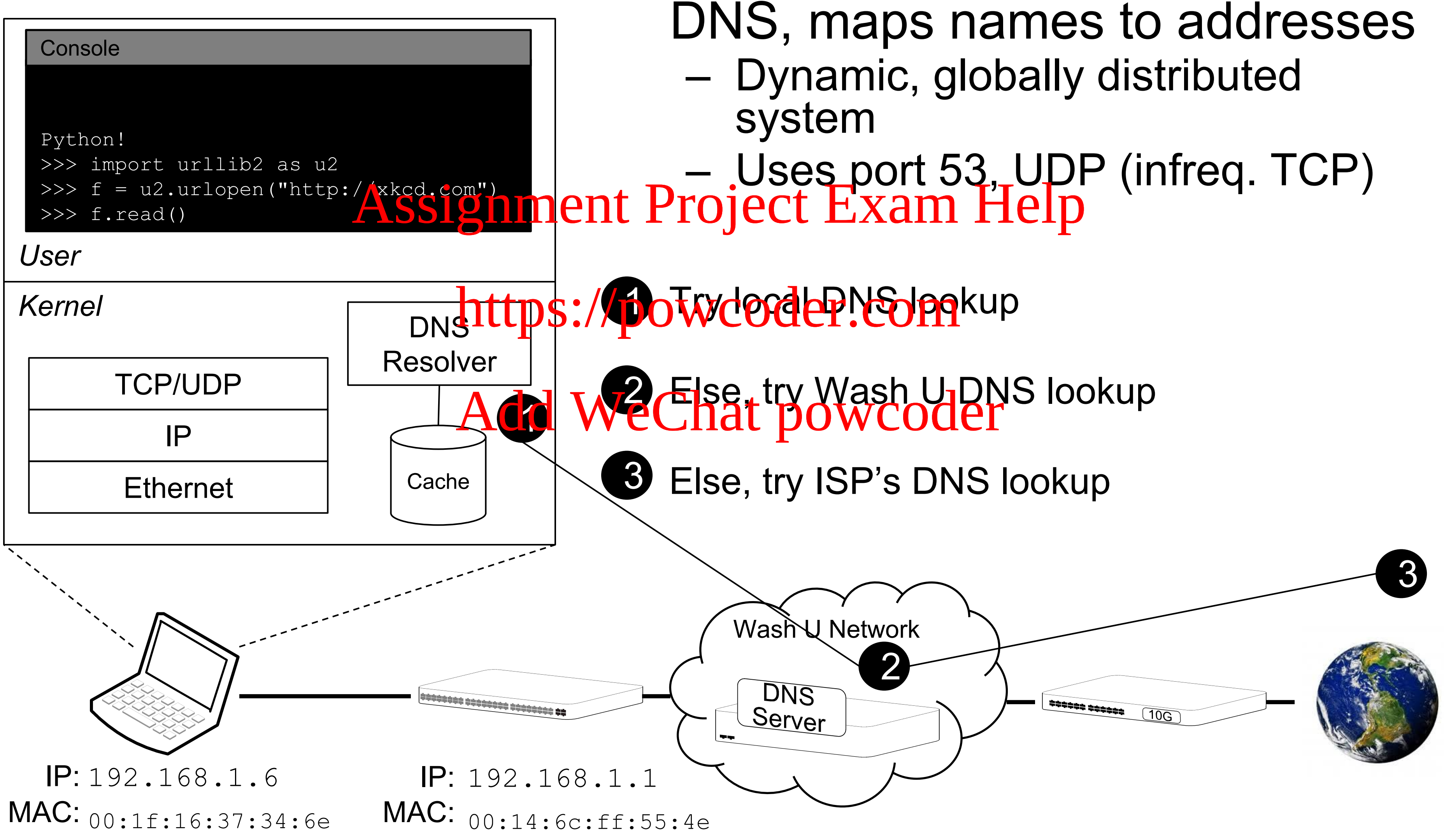
Byte Offset	0	1	2	3
0	Hardware type (Eth is 1)		Protocol type (IP is 0x0800)	
4	HWAddr Len (Eth is 6)	Proto Addr Len (IP is 4)	Operation (1 request, 2 reply)	
8	Sender HW Address (SHA)			
12	SHA, continued		Sender Protocol Address (SPA)	
16	SPA, continued		Target HW Address (THA)	
20	THA, continued			
24	Target Protocol Address (TPA)			



```
ffffffffffff001f
1637346e08060001
0800060400010001f
1637346ec0a80106
000000000000c0a8
0101000000000000
0000000000000000
00000000
```

Internet Names and Addresses

- The Domain Name System, DNS, maps names to addresses
  - Dynamic, globally distributed system
  - Uses port 53, UDP (infreq. TCP)



```
Python!
>>> import urllib2 as u2
>>> f = u2.urlopen("http://xkcd.com")
>>> f.read()
```

1 Try local DNS lookup

2 Else, try Wash U DNS lookup

3 Else, try ISP's DNS lookup

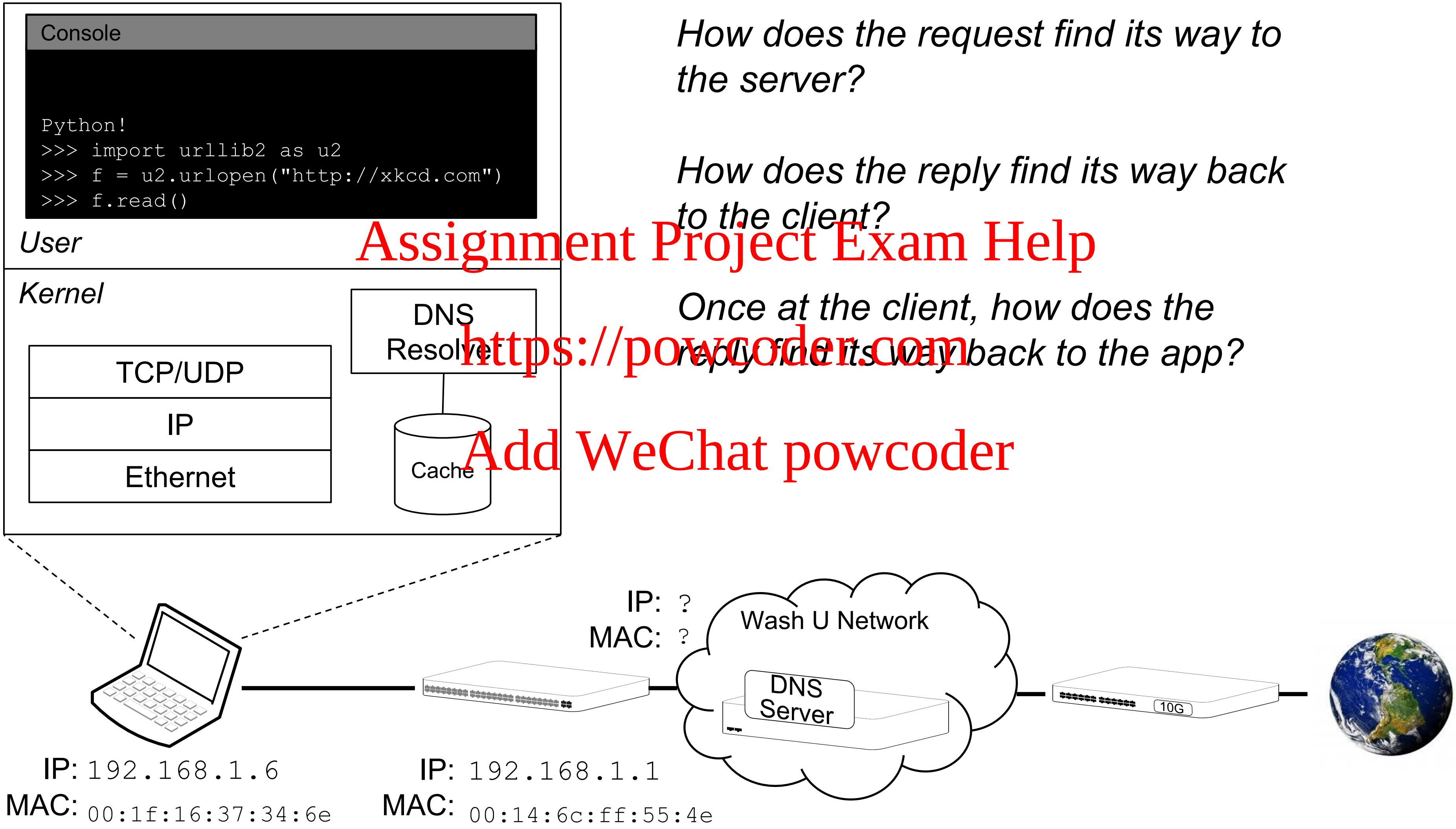
Other questions to answer

- How do we get a MAC address?
  - Pre-configured or set it yourself

- How do we get an IP address?
  - Static allocation or via DHCP

- How do we get to the Internet from within LAN?
  - Default gateway. How do we find it?

Understanding Networks



```
Python!
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>>> f = u2.urlopen("http://xkcd.com")
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```

How does the request find its way to the server?

How does the reply find its way back to the client?

Once at the client, how does the reply find its way back to the app?

Issues we will revisit

- Where do protocols assume trust?
  - Are addresses valid?
  - Are gateways valid?
  - Are name:address bindings valid?
- What can someone else observe?

Helpful Tools

- On your machine
  - wireshark to log and inspect packets
  - host, dig and nslookup to map names to addresses
- On the Internet
  - ARIN’s service to name:address mappings and prefix owners
    - https://www.arin.net/

Assignment

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