HW3 is due in just over a week!
- OK to work with a partner - get settled down and get started now

Midterm
- handed back today
  - please check our arithmetic
  - stats: mean 73.7, median 80, std dev 16.9
  - Overall no major problems - lots of people missed one of the two bugs in the “buggy code” question
- sample solution is up on the Web - please check before asking questions about grading (simple arithmetic questions ok anytime)
End Game

Quarter ends with an exam on Friday, Aug. 17

When should the last project be due?

- Thur. Aug. 16, 11 pm?
- Wed. Aug. 15, 11 pm, no late days?
- Wed. Aug. 15, 11 pm, late days ok (conflicts with studying for exam)
- Something else?
Networking — a (very brief) overview
Networks from 10,000 ft

clients

Internet

servers

Google

hulu

facebook
The “physical” layer

Individual bits are modulated onto a wire or transmitted over radio
- physical layer specifies how bits are encoded at a signal level
- e.g., a simple spec would encode “1” as +1V, “0” as -1V

1 0 1 0 1 →

1 0 1 0 1

computer

NIC

copper wire

optical cable

radio frequency band

computer

NIC

physical

physical
The “data link” layer

Multiple computers on a LAN contend for the network medium

- media access control (MAC) specifies how computers cooperate
- link layer also specifies how bits are packetized and NICs are addressed
The “network” layer (IP)

The Internet Protocol (IP) routes packets across multiple networks

- every computer has a unique Internet address (IP address)
- individual networks are connected by routers that span networks

```
128.95.4.3  128.95.4.10  128.95.4.12
128.95.4.1   128.95.10.95
128.95.10.55  128.95.10.72
128.95.10.1
```
The “network” layer (IP)

Protocols to:

- let a host find the MAC address of an IP address on the same network
- let a router learn about other routers and figure out how to get IP packets one step closer to their destination
The “network” layer (IP)

Packet encapsulation

- an IP packet is encapsulated as the payload of an Ethernet frame
- as IP packets traverse networks, routers pull out the IP packet from an ethernet frame and plunk it into a new one on the next network
**The “transport” layer (TCP, UDP)**

**TCP**
- the “transmission control protocol”
- provides apps with reliable, ordered, congestion-controlled byte streams
- fabricates them by sending multiple IP packets, using sequence numbers to detect missing packets, and retransmitting them
- a single host (IP address) can have up to 65,535 “ports”
  - kind of like an apartment number at a postal address
The “transport” layer (TCP, UDP)

TCP

› useful analogy: how would you send a book by mail via postcards?
› split the book into multiple postcards, send each one by one, including sequence numbers that indicate the assembly order
› receiver sends back postcards to acknowledge receipt and indicate which got lost in the mail
The “transport” layer (TCP)

Packet encapsulation -- same as before!
The “transport” layer (TCP)

Applications use OS services to establish TCP streams
- the “Berkeley sockets” API -- a set of OS system calls
- clients `connect()` to a server IP address + application port number
- servers `listen()` for and `accept()` client connections
- clients, servers `read()` and `write()` data to each other
The “transport” layer (UDP)

UDP

- the “user datagram protocol”
- provides apps with unreliable packet delivery
- UDP datagrams are fragmented into multiple IP packets
  - UDP is a really thin, simple layer on top of IP
Layer 5: session layer
- supposedly handles establishing, terminating application sessions
- RPC kind of fits in here

Layer 6: presentation layer
- supposedly maps application-specific data units into a more network-neutral representation
- encryption (SSL) kind of fits in here
The “application” layer

Application protocols

- the format and meaning of messages between application entities
- e.g., HTTP is an application level protocol that dictates how web browsers and web servers communicate
  - HTTP is implemented on top of TCP streams
The “application” layer

Packet encapsulation -- same as before!
The “application” layer

Packet encapsulation -- same as before!

| ethernet header | IP header | TCP header | HTTP header | HTTP payload (e.g., HTML page) |
The “application” layer

Popular application-level protocols:

- **DNS**: translates a DNS name ([www.google.com](http://www.google.com)) into one or more IP addresses (74.125.155.105, 74.125.155.106, ...)
  - a hierarchy of DNS servers cooperate to do this
- **HTTP**: web protocols
- **SMTP, IMAP, POP**: mail delivery and access protocols
- **ssh**: remote login protocol
- **bittorrent**: peer-to-peer, swarming file sharing protocol
See you next time!