# Project 1

15-441/641: Computer Networks

Many Thanks to past
TA's

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# What do you have to build?

| Checkpoint 1 (Echo Server) | Checkpoint 2 (HTTP 1.1) | Final Submission |
| --- | --- | --- |
| • I/O Multiplexing using select | • Request Parser<br>• GET, HEAD, POST | • HTTPS<br>• CGI |

# IP Addresses

- 32 bit—4,294,967,296 possible addresses

# Port Numbers

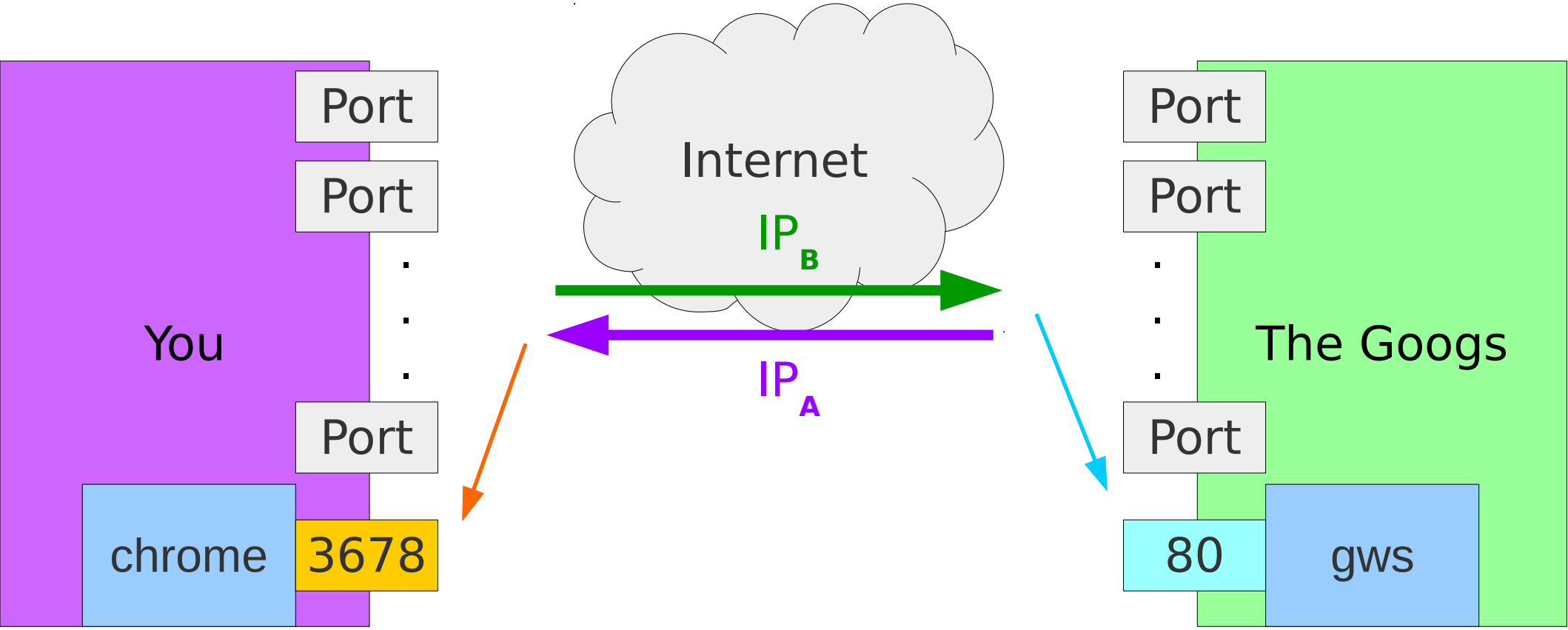
- 16 bit—65,536 possible ports [0,65535]
- [0,1023] are well-known ports (reserved)
  - 80 — Hypertext Transport Protocol (HTTP)
  - 22 — Secure Shell (SSH)
  - 25 — Simple Mail Transfer Protocol (SMTP)
- [1024,49151] are registered ports (IANA)
  - 2967 — Symantec AntiVirus
  - 3074 — XBOX Live
- [49152,65535] are ephemeral ports (temp)

# What's “in” a socket?

I want a program on computer A to talk to a program on computer B

Source <ip,port> + Destination <ip,port>

# IP? Port!?




Source <ip,port> + Destination <ip,port>

Identifies the Machine

Identifies a Socket
(multiple apps want to network!)

# How to: Server

- Create a socket via `socket()`
- Bind to an endpoint via `bind()`
- Listen for connections via `listen()`
- Accept connections via `accept()`
- Read from socket via `recv()`
- Write to socket via `send()`

# socket()

```
#include <sys/socket.h>
int socket(int socket_family, int socket_type, int protocol);
```

Generally set `socket_family` to PF_INET → IPv4

`socket_type` to SOCK_STREAM → TCP

`protocol` to 0 → Yes, TCP

# socket() Code Example

```c
#include <stdio.h>
#include <stdlib.h>
#include <sys/socket.h>

int main(int argc, char* argv[])
{
    int sock = socket(PF_INET, SOCK_STREAM, 0);
    return EXIT_SUCCESS;
}
```

# bind()

```
#include <sys/socket.h>

int bind(int sock, const struct sockaddr* addr, socklen_t addrlen);
```

After creating a socket as described, then create a sockaddr struct.

# bind() Code Example

```
#include <stdio.h>
#include <stdlib.h>
#include <sys/socket.h>
#include <netinet/in.h>

int main(int argc, char* argv[])
{
    int sock = socket(PF_INET, SOCK_STREAM, 0);
    struct sockaddr_in addr;
    addr.sin_family = AF_INET;
    addr.sin_port = htons(1025);
    addr.sin_addr.s_addr = INADDR_ANY;
    int err = bind(sock, (struct sockaddr *)
                   &addr, sizeof(addr));
    return EXIT_SUCCESS;
}
```

# listen()

```
#include <sys/socket.h>

int listen(int sock, int backlog);
```

After `bind()`ing, you can `listen()` for connections.

# listen() Code Example

```
#include <stdio.h>
#include <stdlib.h>
#include <sys/socket.h>
#include <netinet/in.h>

int main(int argc, char* argv[])
{
    int sock = socket(PF_INET, SOCK_STREAM, 0);
    struct sockaddr_in addr;
    addr.sin_family = AF_INET;
    addr.sin_port = htons(1025);
    addr.sin_addr.s_addr = INADDR_ANY;
    int err = bind(sock, (struct sockaddr *)
                  &addr, sizeof(addr));
    int err2 = listen(sock, 5);
    return EXIT_SUCCESS;
}
```

# backlog

- Queue length for incoming sockets
- Fully established already

# accept()

```
#include <sys/socket.h>

int accept(int sockfd, struct sockaddr * addr, struct socklen_t * len);
```

After `listen()`ing, you can `accept()` connections.

Pass in the socket from before, and pointers to data structures defined by you.

These represent connected client state for future use.

# accept() Code Example

```
#include <stdio.h>
#include <stdlib.h>
#include <sys/socket.h>
#include <netinet/in.h>

int main(int argc, char* argv[])
{
    int sock = socket(PF_INET, SOCK_STREAM, 0);
    struct sockaddr_in addr, caddr;
    addr.sin_family = AF_INET;
    addr.sin_port = htons(1025);
    addr.sin_addr.s_addr = INADDR_ANY;
    int err = bind(sock, (struct sockaddr *)
                &addr, sizeof(addr));
    int err2 = listen(sock, 5);
    socklen_t len = sizeof(caddr);
    int client = accept(sock, (struct sockaddr *)
                        &caddr, &len);
    return EXIT_SUCCESS;
}
```

# recv()

```
#include <sys/socket.h>
int recv(int sockfd, void * buf, size_t len, int flags);
```

After `accept()`ing, you can `recv()` data.

For now set `flags` to 0

# recv() Code Example

```c
#include <stdio.h>
#include <stdlib.h>
#include <sys/socket.h>
#include <netinet/in.h>

int main(int argc, char* argv[])
{
    char buf[256];
    int sock = socket(PF_INET, SOCK_STREAM, 0);
    struct sockaddr_in addr, caddr;
    addr.sin_family = AF_INET;
    addr.sin_port = htons(1025);
    addr.sin_addr.s_addr = INADDR_ANY;
    int err = bind(sock, (struct sockaddr *)
             &addr, sizeof(addr));
    int err2 = listen(sock, 5);
    socklen_t len = sizeof(caddr);
    int client = accept(sock, (struct sockaddr *)
                        &caddr, &len);
    ssize_t read = recv(client, buf, 256, 0);
    return EXIT_SUCCESS;
}
```

# send()

```
#include <sys/socket.h>
int send(int sockfd, void * buf, size_t len, int flags);
```

After `accept()`ing, you can `send()` data.

For now set `flags` to 0

# send() Code Example

```c
#include <stdio.h>
#include <stdlib.h>
#include <sys/socket.h>
#include <netinet/in.h>

int main(int argc, char* argv[])
{
    char buf[256];
    int sock = socket(PF_INET, SOCK_STREAM, 0);
    struct sockaddr_in addr, caddr;
    addr.sin_family = AF_INET;
    addr.sin_port = htons(1025);
    addr.sin_addr.s_addr = INADDR_ANY;
    int err = bind(sock, (struct sockaddr *)
             &addr, sizeof(addr));
    int err2 = listen(sock, 5);
    socklen_t len = sizeof(caddr);
    int client = accept(sock, (struct sockaddr *)
                        &caddr, &len);
    ssize_t sent = send(client, buf, 256, 0);
    return EXIT_SUCCESS;
}
```

# How to: Server

- Create a socket via `socket()`
- Bind to an endpoint via `bind()`
- Listen for connections via `listen()`
- Accept connections via `accept()`
- Read from socket via `recv()`
- Write to socket via `send()`

Source <ip,port> + Destination <ip,port>

# How to: Client

- Create a socket via `socket()`
- Connect to an endpoint via `connect()`
- Read from socket via `recv()`
- Write to socket via `send()`

# connect()

```
#include <sys/socket.h>

int connect(int socket, const struct sockaddr *serv_addr, socklen_t protocol);
```

Use socket as before, get `serv_addr` from `getaddrinfo()`.

Free with `freeaddrinfo()`.

# connect() Code Example

```
#include <netdb.h>
#include <stdlib.h>
#include <string.h>
#include <sys/socket.h>

int main(int argc, char* argv[])
{
   struct addrinfo addr, *caddr;
   memset(&addr, 0, sizeof(addr));
   addr.ai_family = AF_INET;
   addr.ai_socktype = SOCK_STREAM;
   getaddrinfo("www.google.com", "80", &addr, &caddr);
   int sock = socket(caddr->ai_family, caddr->ai_socktype,
                     caddr->ai_protocol);
   connect(sock, caddr->ai_addr, caddr->ai_addrlen);
   return EXIT_SUCCESS;
}
```

# How to: Client

- Create a socket via `socket()`
- Connect to an endpoint via `connect()`
- Read from socket via `recv()`
- Write to socket via `send()`

Source <ip,port> + Destination <ip,port>

# Socket Programming Gotchas

- Endianness Matters: Network Byte Order
  - `htons()` - host to network short
  - `ntohs()` -network to host short
- Cleanup state—avoid memory leaks
  - `freeaddrinfo()`
  - Check correctness with `valgrind`
- Error Handling
  - Tedious, but worth it (and required!)
- Timeouts
  - Implement for robust networking behavior

# Socket Programming Gotchas

- Never expect to `recv()` what you `send()`
  - Assume partial receipt of data possible
  - Use buffers intelligently to mitigate this
  - Send byte counts first, read until finished
- Prepare your code for random failures
  - We introduce random faults when grading
  - Test too—`ctrl+c` server and client randomly
- Cleanup Allocated Memory
  - `close()` sockets, etc.

# Concurrency

- Threads
  - Server gives each client its own thread
  - Not in this class!
- `select()`
  - Watch a set of sockets (in main thread)
  - Use `select()` to find sockets ready for I/O
  - Server-side only—clients are agnostic

# select()

```
#include <sys/select.h>
int select(int nfds, fd_set *readfds, fd_set *writefds,
           fd_set *exceptfds, struct timeval *timeout);
void FD_CLR(int fd, fd_set *set); - removes fd from set
int FD_ISSET(int fd, fd_set *set); - is fd in set?
void FD_SET(int fd, fd_set *set); - adds fd to set
void FD_ZERO(fd_set *set); - clears set
```

Manipulate set of descriptors with `FD_*`, then `select()`.

# Select() Usage - Example

```
//Other inits
fd_set readfds;
// pretend we've connected both to a server at this point
//s1 = socket(...);
//s2 = socket(...);
//connect(s1, ...)...
//connect(s2, ...)...
// clear the set ahead of time FD_ZERO(&readfds);
// add our descriptors to the set
FD_SET(s1, &readfds);
FD_SET(s2, &readfds);
// since we got s2 second, it's the "greater", so we use that for
// the n param in select() n = s2 + 1;
// wait until either socket has data ready to be recv()d
rv = select(n, &readfds, NULL, NULL, &tv);
if (rv == -1) {
    perror("select"); // error occurred in select()
} else {
// one or both of the descriptors have data
    if (FD_ISSET(s1, &readfds)) {
        recv(s1, buf1, sizeof buf1, 0);
    }
    if (FD_ISSET(s2, &readfds)) {
        recv(s2, buf2, sizeof buf2, 0);
    }
}
```

* Taken from Beej's Guide

# Error Checking

- Read documentation first
- Sometimes you need to:

```
#include <errno.h>

...
switch (errno)
{

...
}
```

# More on Project1

# Reading data

- Check return value of `recv()`
  - Error – handle the error and clear up state
  - If peer shutdown connection, clear up state
- Maintain state
  - Maintain a read buffer
  - Keep track of number of bytes to read
  - May need multiple reads to get all data
  - Only one read per socket when `select()` returns

# Writing date

- Check return value of `send()`
  - Error – handle the error and clear up state
  - If peer shutdown connection, clear up state
- Maintain state
  - Maintain a write buffer
  - Keep track of number of bytes to write
  - May need multiple writes to send all data

# Remember

- Code quality
- Robustness
  - Handle errors
  - Buffer overflows
  - Connection reset by peer

# Common mistakes

- Make sure your executable is named correctly
- tar your complete repo and submit. Autolab expects to find a .git folder with your submission
- Don't forget to update the tag when you make changes to your code. We run a checkout with the tag name and not your last commit

# Checkpoint 1 docs

- **Makefile** – make sure nothing is hard coded specific to your user; should build a file which runs the echo server (must be named lisod)
- **All of your source code** – all .c and .h files
- **readme.txt –** file contatining a brief description of your current implementation of server
- **tests.txt –** file containing a brief description of your testing methods for server
- **vulnerabilities.txt –** identify at least one vulnerability in your current implementation

Questions???

# System Call Documentation:

**POSIX** – Portable Operating System Interface for Unix
IEEE 1003.1-2008, The Open Group

"POSIX.1-2008 defines a standard operating system interface and environment, including a command interpreter (or "shell"), and common utility programs to support applications portability at the source code level."

http://pubs.opengroup.org/onlinepubs/9699919799/

Also, more correct, your system's man pages!

Another excellent resource:

Beej's Guide to Network Programming

http://beej.us/guide/bgnet/