Overview

- Virtual functions summary and worksheet
- Domain Name Service (DNS)
- Client side network programming steps and calls
- dig and ncat tools
C++ virtual functions

• Dynamic dispatch – decide at runtime what code to invoke
• “Most derived” function gets called
• The virtual keyword is sticky
• vtable
  • Function pointers to each virtual function of the class
  • Pointers to “most derived” function for that class
• vptr – virtual table pointer for each object instance
Section Exercise 1 (5 min)

Virtual functions worksheet
Network Programming

OSI model
Berkeley/POSIX Sockets API

- What is a socket?
  - Endpoint or an interface for sending and receiving data at a node
- You can use read() and write() to send and receive data
- The socket() system call creates a socket and returns a file descriptor
Pictorially

Web server

128.95.4.33

file descriptor
fd 5  fd 8  fd 9  fd 3

index.html
pic.png

Internet

client  client

OS’s descriptor table

<table>
<thead>
<tr>
<th>file descriptor</th>
<th>type</th>
<th>connected to?</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>pipe</td>
<td>stdin (console)</td>
</tr>
<tr>
<td>1</td>
<td>pipe</td>
<td>stdout (console)</td>
</tr>
<tr>
<td>2</td>
<td>pipe</td>
<td>stderr (console)</td>
</tr>
<tr>
<td>3</td>
<td>TCP</td>
<td>local: 128.95.4.33:80, remote: 44.1.19.32:7113</td>
</tr>
<tr>
<td>5</td>
<td>file</td>
<td>index.html</td>
</tr>
<tr>
<td>8</td>
<td>file</td>
<td>pic.png</td>
</tr>
<tr>
<td>9</td>
<td>TCP</td>
<td>local: 128.95.4.33:80, remote: 10.12.3.4:5544</td>
</tr>
</tbody>
</table>
Network programming for the client side

The five steps to communicate with a server:

1. Domain name lookup to figure out IP address and port to talk to
2. Create a socket
3. Connect to the server
4. Read and Write to transfer data through the socket
5. Close the socket
Network Addresses

• For IPv4, an IP address is a 4-byte tuple
  - e.g., 128.95.4.1 (80:5f:04:01 in hex)
• For IPv6, an IP address is a 16-byte tuple
  - e.g., 2d01:0db8:f188:0000:0000:0000:0000:1f33
    ‣ 2d01:0db8:f188::1f33 in shorthand
DNS – Domain Name System/Service

- A hierarchical distributed naming system any resource connected to the Internet or a private network.
- Resolves queries for names into IP addresses.
- The sockets API lets you convert between the two.
  - Aside: getnameinfo() is the inverse of getaddrinfo()
- Is on the application layer on the Internet protocol suite.
Dig demo

dig +trace attu.cs.washington.edu
Resolving DNS names

• The POSIX way is to use `getaddrinfo()`.
• Set up a “hints” structure with constraints, e.g. IPv6, IPv4, or either.
• Tell `getaddrinfo()` which host and port you want resolved.
• Host - a string representation: DNS name or IP address
• `getaddrinfo()` gives you a list of results in an “addrinfo” struct.
IPv4 address structures

// Port numbers and addresses are in *network order*.

// A mostly-protocol-independent address structure.
struct sockaddr {
    short int   sa_family;  // Address family; AF_INET, AF_INET6
    char        sa_data[14]; // 14 bytes of protocol address
};

// An IPv4 specific address structure.
struct sockaddr_in {
    short int   sin_family;  // Address family, AF_INET == IPv4
    unsigned short int sin_port; // Port number
    struct in_addr  sin_addr;   // Internet address
    unsigned char   sin_zero[8]; // Same size as struct sockaddr
};

struct in_addr {
    uint32_t   s_addr;  // IPv4 address
};
IPv6 address structures

// A structure big enough to hold either IPv4 or IPv6 structures.
struct sockaddr_storage {
    sa_family_t ss_family; // address family
    // a bunch of padding; safe to ignore it.
    char      __ss_pad1[_SS_PAD1SIZE];
    int64_t   __ss_align;
    char      __ss_pad2[_SS_PAD2SIZE];
};

// An IPv6 specific address structure.
struct sockaddr_in6 {
    u_int16_t sin6_family; // address family, AF_INET6
    u_int16_t sin6_port;   // Port number
    u_int32_t sin6_flowinfo; // IPv6 flow information
    struct in6_addr sin6_addr; // IPv6 address
    u_int32_t sin6_scope_id; // Scope ID
};

struct in6_addr {
    unsigned char s6_addr[16]; // IPv6 address
};
getaddrinfo() and structures

```c
int getaddrinfo(const char *hostname, // hostname to look up
    const char *servname, // service name
    const struct addrinfo *hints, // desired output type
    struct addrinfo **res); // result structure

// Hints and results take the same form. Hints are optional.
struct addrinfo {
    int ai_flags; // Indicate options to the function
    int ai_family; // AF_INET, AF_INET6, or AF_UNSPEC
    int ai_socktype; // Socket type, (use SOCK_STREAM)
    int ai_protocol; // Protocol type
    size_t ai_addrlen; // INET_ADDRSTRLEN, INET6_ADDRSTRLEN
    struct sockaddr *ai_addr; // Address (input to inet_ntop)
    char *ai_canonname; // canonical name for the host
    struct addrinfo *ai_next; // Next element (It's a linked list)
};

// Converts an address from network format to presentation format
const char *inet_ntop(int af, // family (see above)
    const void * restrict src, // in_addr or in6_addr
    char * restrict dest, // return buffer
    socklen_t size); // length of buffer
```
Generating these structures

```c
#include <stdlib.h>
#include <arpa/inet.h>

int main(int argc, char **argv) {
    struct sockaddr_in sa;  // IPv4
    struct sockaddr_in6 sa6; // IPv6

    // IPv4 string to sockaddr_in.
    inet_pton(AF_INET, "192.0.2.1", &(sa.sin_addr));

    // IPv6 string to sockaddr_in6.
    inet_pton(AF_INET6, "2001:db8:63b3:1::3490", &(sa6.sin6_addr));
    return EXIT_SUCCESS;
}
```
Generating these structures

#include <stdlib.h>
#include <arpa/inet.h>

int main(int argc, char **argv) {
    struct sockaddr_in6 sa6; // IPv6
    char astring[INET6_ADDRSTRLEN]; // IPv6

    // IPv6 string to sockaddr_in6.
    inet_pton(AF_INET6, "2001:db8:63b3:1::3490", &(sa6.sin6_addr));

    // sockaddr_in6 to IPv6 string.
    inet_ntop(AF_INET6, &(sa6.sin6_addr), astring, INET6_ADDRSTRLEN);
    printf("%s\n", astring);
    return EXIT_SUCCESS;
}
DNS Resolution Demo

dnsresolve.cc
Network programming for the client side

- Recall the five steps, here are the corresponding calls:
  1. `getaddrinfo()` to figure out IP address and port to talk to
  2. `socket()` for creating a socket
  3. `connect()` to connect to the server
  4. `read()` and `write()` to transfer data through the socket
  5. `close()` to close the socket
Network programming for the client side

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socket() — Create the socket

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

int socket(int domain,  // e.g. AF_NET, AF_NET6
            int type,    // e.g. SOCK_STREAM, SOCK_DGRAM
            int protocol); // Usually 0
```

Note that socket() just creates a socket, it isn’t bound yet to a local address.
Demo

socket.cc
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connect() – Establish the connection

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

int connect(int sockfd, // socket fd from step 2
             struct sockaddr *serv_addr, // server info
             int addrrlen); // size of serv_addr struct
```
Demo (Along with ncat demo)

connect.cc
(nc –lv 5454 to create listener)
Network programming for the client side

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  4. `read()` and `write()` to transfer data through the socket
  5. `close()` to close the socket
read() and write()

- By default, both are blocking calls
- `read()` will wait for some data to arrive, then immediately read whatever data has been received by the network stack
  - Might return less data read than asked for
  - Blocks while data isn’t received
- Conversely, `write()` queues your data to OS’s send buffer, then returns while OS does the rest in the background
  - When `write()` returns the receiver probably hasn’t received the data yet
  - When the send buffer fills up, `write()` will also block
Demo (Along with more ncat)

sendreceive.cc
(nc -l 5454 to create listener)
Network programming for the client side

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  3. `connect()` to connect to the server
  4. `read()` and `write()` to transfer data through the socket
  5. `close()` to close the socket
close() – Close the connection

```c
#include <unistd.h>

int close(int sockfd);
```

Remember to close the socket when you’re done!
Network programming for the client side

• Recall the five steps, here’s the corresponding calls:
  1. getaddrinfo() to figure out IP address and port to talk to
  2. socket() for creating a socket
  3. connect() to connect to the server
  4. read() and write() to transfer data through the socket
  5. close() to close the socket
Section Exercise

• The TA has set up a game server for you to communicate with (gameserver.py)
• Using the sample client code from section/lecture and what you know about I/O calls in C++, your job is to implement a C++ client called gameclient.cc such that you can communicate with the game server much like you can with the netcat tool