Introduction to Network Programming

Assignment 1: uft

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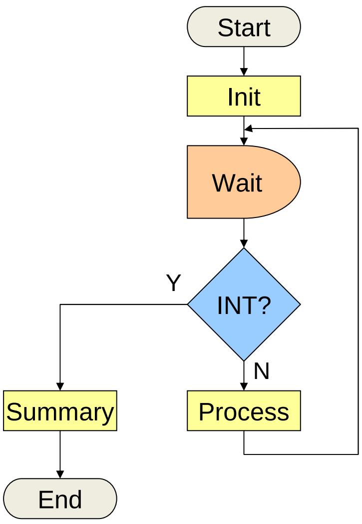
Starting Point

- IDE
  - Unix/Linux available in the department
  - Alternative: cygwin (winsock vs. BSD)
  - Also: MacOS (which is Unix), MS Windows
  - (the three items above: GNU gcc, make, gdb, ...)
  - Programming language: your choice
    - Examples and hints will be given in C/C++
- Information sources
  - Today's slides and exercise
  - Details on the web page
  - man, info, Google
  - Newsgroup
  - Send mail (if everything else has failed)

The Goals

- Workable software
  - Remember that you will need to build upon this later
  - Compiled and tested on the department workstations (Unix/Linux), on your laptop, or some other system accessible from the department via ssh
  - Learning: how to get there
  - Functionality: to actually arrive at a working solution
- Documentation
  - Motivation + protocol documentation: explicitly as text or PDF
  - Code: Inline
  - Shows that you understood the problem and the solutions
  - Helps you to remember what you were thinking today in two months from now
  - Helps us to understand what you meant to do
  - → There should be no “wrong” solutions (only malfunctioning ones)
- Working with development tools
  - make, gcc, gdb, cvs/svn, (autoconf) ...

Program Structure



Initialization
- Parse the command line & arguments
- Resolve hostname
- Bind sockets, join multicast groups (if any)
- Manage signal handling

Main loop
- Manage socket descriptors (there will be many)
- Read data
- Create output
- Signal and failure handling

Cleanup
- Close all descriptors
- Leave multicast groups (if any)
- Free memory

Parse Command Line

`int getopt(cnt,argv,optstring)`

```
int oc;
while( (oc=getopt(argc,argv,"a:hi:sl:D:t:")) != EOF)
{
  switch(oc) {
    case 'a' : addAddress(optarg); break;
    case 'h' : usage(); exit(0);
    case 'i' : addInterface(optarg); break;
    case 's' : summary = true; break;
    case 'l' : dumplen = strtol(optarg,NULL,10); break;
    case 't' : controlAddress(optarg); break;
    case 'D' : duration = strtol(optarg,NULL,10); break;
    default :
      opterr(oc);
  }
}
```


Resolve hostname

- Transform a symbolic name into a protocol-specific address
  ⇨ Attention: different address formats and lengths
- APIs
  - **`gethost*(), inet_aton(), inet_ntoa()`**
  - **`getaddrinfo(), inet_pton(), inet_ntop()`**

⇨ old

The Old Stuff

```
gethostname (char *name_buffer, int buffer_length)
struct hostent *gethostbyname (char *namestr)
struct hostent *gethostbyaddr (struct sockaddr *, size_t, int);

struct hostent {
   char       *h_name;
   char       **h_aliases;
   int        h_addrtype;
   int        h_length;
   char       **h_addr_list;
#define h_addr      h_addrlist [0]
};

struct hostent *gethostent ();
endhostent ();
```


getaddrinfo

```
int getaddrinfo(host,server,hints,result)
```

```
struct addrinfo {
     int              ai_flags;      /* AI_PASSIVE, AI_CANONNAME,
                                        AI_NUMERICHOST */
     int              ai_family;     /* PF_UNSPEC */
     int              ai_socktype;   /* SOCK_xxx */
     int              ai_protocol;   /* 0 or IPPROTO_xxx for IPv4 and IPv6 */
     size_t           ai_addrlen;    /* length of ai_addr */
     char             *ai_canonname; /* canonical name for nodename */
     struct sockaddr  *ai_addr;      /* binary address */
     struct addrinfo  *ai_next;      /* next structure in linked list */
};

void freeaddrinfo(struct addrinfo *res);
const char *gai_strerror(int errcode);
```

Conversion functions (1)

Dotted decimal notation: aaa.bbb.ccc.ddd (IPv4 only)

```
in_addr_t inet_addr (char *buffer)
in_addr_t inet_aton (char *buffer)
char *inet_ntoa (in_addr_t ipaddr)
```

aaa.bbb.ccc.ddd (IPv4), aaaa:bbbb:cccc:dddd:eeee:ffff:gggg:hhhh (IPv6)

```
int inet_pton(int af, const char *src, void *dst)
```

dst: in_addr or in6_addr

```
const char *inet_ntop(int af, const void *src, char *dst, size_t)
```

src: in_addr bzw. in6_addr
char dst[INET_ADDRSTRLEN] bzw. char dst[INET6_ADDRSTRLEN]

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Conversion Functions (2)

Network vs. Host Byte Order

All data in the network is sent as “Big Endian”
Conversion into local representation may be required

- needed on “Little-Endian” (LSB-first) architectures such as Intel
- is a no-op on MSB-first, but should **always** be done for portability

```
netshort  = htons (hostshort)      16-bit value
netlong   = htonl (hostlong)       32-bit value
hostshort = ntohs (netshort)       16-bit value
hostlong  = ntohl (netlong)        32-bit value
```

BSD Socket Interface

- The BSD mechanism for Inter-Process Communication (IPC)
- Transparency between local and remote communications
- Socket Descriptor: feels like file i/o or stdin/stdout

- Support for different address families (some 30 in socket.h)
  - (Named) Pipes (e.g., AF_UNIX), ...
  - Internet Protocols (AF_INET, AF_INET6)
  - Other
- Crucial for the spreading of IP in the 1980s!
- Supports different types of communications, u.a.
  - SOCK_STREAM: TCP   SOCK_DGRAM: UDP
  - SOCK_RAW: Raw IP   SOCK_PACKET: Link-Layer-Frames

Socket Creation

```
int socket(domain,type,proto)
int bind(sd,addr,addrlen)
```

```
int createSocket(const sockaddr_in &addr)
{
    int sd=socket(PF_INET,SOCK_DGRAM,0);
    if (sd<0) return -1;

    int yes = 1;
    setsockopt(sd, SOL_SOCKET, SO_REUSEADDR, (char*)&yes, sizeof yes);
    fcntl(sd,F_SETFL,O_NONBLOCK);
    if (bind(sd,reinterpret_cast<const sockaddr *>(&addr),sizeof addr)<0) {
        std::cerr << strerror(errno) << std::endl;
        return -1;
    }
    return sd;
}
```

Socket domain
PF_INET, PF_INET6
Socket type
SOCK_STREAM, SOCK_DGRAM, ...
Protocol
0 (any), 6 (tcp), 17 (udp)

Address Structures

- Identification of a peer by means of IP address, port number, and protocol

```
struct sockaddr_in {
        sa_family_t    sin_family;
        in_port_t      sin_port;
        struct in_addr sin_addr;
    };
```

```
struct sockaddr_in6 {
        sa_family_t     sin6_family;
        in_port_t       sin6_port;
        uint32_t        sin6_flowinfo;
        struct in6_addr sin6_addr;
    };
```

IPv4 address (historically motivated, cumbersome)

```
struct in_addr {
    in_addr_t    s_addr;
};
```

IPv6 address (abbreviated)

```
struct in6_addr {
        uint8_t     u6_addr8[16];
#define s6_addr in6_u.u6_addr8
};
```


Passive Waiting

- Data reception (UDP), accepting incoming connections (TCP)
- **`bind (int sd, struct sockaddr *, socklen_t len);`**
- UDP: done
- TCP: enable connection setup from others
  - **`listen (int sd, in backlog);`**
  - Permits <backlog> pending connection setup requests in the kernel
- `setsockopt ()` and `ioctl ()` to set further parameters
  - Buffer size, Type-of-Service, TTL, multicast addresses, ...

Connections (TCP)

- `connect (int sd, struct sockaddr *target, socklen_t len);`
  - Creates (synchronously) a connection
  - Function call returns only when the connection is established, if a timeout occurs without response (may be several minutes), or *possibly* when ICMP error messages indicate failure (e.g., destination unreachable)
  - Option: TCP_NODELAY for asynchronous connection setup
- Accepting an incoming connection (cannot reject anyway ☺)
  - `new_sd = accept (int sd, struct sockaddr *peer, socklen_t *peerlen);`
  - Creates a new socket descriptor for the new connection
  - The original one (sd) continues to be used for accepting further connections
- Closing a connection
  - `shutdown (int sd, int mode)`
  - 0: no further sending, 1: no further reception, 2: neither sending nor receiving
  - `close(sd)` to clean up – beware of data loss!

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Sending Data

- Connection-oriented (TCP)
  - `write (int sd, char *buffer, size_t length);`
  - `writev (int sd, struct iovec *vector, int count);`
    - List of buffers, each with pointer to memory and length
  - `send (int sd, char *buffer, size_t length, int flags)`
    - May be used for out-of-band data
- Connectionless (UDP)
  - `sendto (int sd, char *buffer, size_t length, int flags, struct sockaddr *target, socklen_t addrlen)`
  - `sendmsg (int sd, struct msghdr *msg, int flags)`
    - Target address
    - Pointer to the memory containing the data
    - Control information

Receiving Data

- Connection-oriented (TCP)
  - **`read (int sd, char *buffer, size_t length);`**
  - **`readv (int sd, struct iovec *vector, int count);`**
    - List of buffers, each with pointer to memory and length
  - **`recv (int sd, char *buffer, size_t length, int flags)`**
    - May be used for out-of-band data

- Connectionless (UDP)
  - `recvfrom (int sd, char *buffer, size_t length, int flags, struct sockaddr *target, socklen_t addrlen)`
  - `recvmsg (int sd, struct msghdr *msg, int flags)`
    - Sender address
    - Pointer to the data
    - Control information

Further Functions

- **`getpeername (int sd, struct sockaddr *peer, size_t *len)`**
  - Obtain the address of the communicating peer
- **`getsockname (int sd, struct sockaddr *local, size_t *len)`**
  - Obtain the address of the local socket (useful if dynamically assigned)

- Modify socket parameters
  - `getsockopt (int sd, int level, int option_id, char *value, size_t length)`
  - `setsockopt (int sd, int level, int option_id, char *value, size_t length)`
  - Examples:
    - Buffer size, TTL, Type-of-Service, TCP-Keepalive, SO_LINGER, ...
  - **`ioctl (int sd, int request, ...);`**
  - **`fcntl (int sd, int cmd [, long arg] [, ...]);`**
    - E.g., to control whether I/O is non-blocking

Multicast reception

- Multicast JOIN

```
setsockopt (sd, IPPROTO_IP, IP_ADD_MEMBERSHIP,
  struct ip_mreq *mreq, sizeof (ip_mreq));
struct ip_mreq {
  struct in_addr imr_multiaddr;     /* IP multicast address of
  group */
  struct in_addr imr_interface;     /* local IP address of
  interface */
};
```

- Multicast-LEAVE
  - `setsockopt (sd, IPPROTO_IP, IP_DROP_MEMBERSHIP, struct ip_mreq *mreq, sizeof (ip_mreq));`
- Optional: Allow repeated use of an address (needed for multicasting)
  - `char one = 1;`
  - `setsockopt (sd, SOL_SOCKET, SO_REUSEADDR, &one, sizeof (char))`

I/O Multiplexing (select)

```
int select(maxfdset,read,write,ext,timer)
```

- Calculate file descriptor sets (FDSET)
- Determine earliest timeout
- Call select()
- Error?
  - Fatal → Terminate
  - Repairable (e.g. interrupted system call) → repeat
- Timeout?
  - Timer handling; use struct timeval { … } to specify (sec, usec) pair
  - NULL pointer == blocking (no timeout), (0, 0) == polling
- Success
  - Determine active file descriptors and handle events

fd_set Makros

```
fd_set wfdset;
FD_ZERO (&wfdset);
FD_SET (fd, &wfdset);
  .
  .
  .
if (FD_ISSET(fd, &wfdset))
   . . .
```


I/O Multiplexing (poll)

`int poll(pollfd,n_fd,timeout)`

-
```
struct pollfd {
        int     fd;      // file descriptor
        int     events;  // events to watch for
        int     revents; // occurred events
};
```
- Poll events:
  - POLLIN input pending
  - POLLOUT socket writable (only needed with non-blocking i/o)
  - POLLHUP, POLLERR
- Timeout is specified in milliseconds
  - -1 == no timeout, 0 == return immediately (perform real polling)
- Handling otherwise identical to select()

Timeouts (1)

- Protocols use many timeouts
  - Will be set, reset, and canceled frequently
  - Must be implemented efficiently
- select () and poll () allow you to specify one timeout
  - poll () in milliseconds
  - select () microseconds via struct timeval
- Keep an ordered list of all your timeouts
  - Store absolute time for the timeout
  - Pointer to the context (e.g., local protocol state of the "connection")
  - Event this timeout is about
- Before calling select/poll
  - Determine current time (gettimeofday ())
  - Determine first timeout in list and calculate delta
    (if timeout has already passed initiate handling right away)
  - Parameterize poll/select() with the delta

Timeouts (2)

Example:
Timeout 200ms

```
struct timeval    tv, delta, now;

/* some event occurs -> calculate absolute time in tv */
gettimeofday (&tv, NULL);
tv.tv_usec += 200*1000;
if (tv.tv_usec >= 1000000) {
        tv.tv_usec -= 1000000;
        tv.tv_sec++;
}

/* ... many other activities -> back in mainloop */
gettimeofday (&now, NULL);
delta.tv_usec = tv.tv_usec – now.tv_usec;
delta.tv_sec  = tv.tv_sec  - now.tv_sec;
if (delta.tv_usec < 0) {
    delta.tv_usec += 1000000;
    delta.tv_sec--;
}
if (delta.tv_sec < 0) {
    /* timeout has also passed -> handle now */
}
switch (n = select (..., ..., ..., ..., &delta) {
    ...
}
```

Packet pacing

- To achieve a target bit rate, need to send packets in regular intervals
- Calculate your target packet interval from the packet size…
  - Your own header + 8 bytes UDP + 20 bytes IPv4 + 1024 bytes payload
- …and the target bit rate on the command line

- Use a recurring timer for transmission
  - Important: calculate your transmission interval based upon a single initial absolute time value
    - E.g. calculate your initial transmission time based upon getttimeofday ()
    - Always add your constant interval to the previous timeout value without calling gettimeofday () again for this purpose
  - Do not do regular calculations
    - This will lead to underutilization as it does not account for local processing time

Beware of threads

- If your coding language allows you to avoid them
  - Will save you hassle (and overhead) in synchronizing access to internal data structures

- Instead
  - Maintain your own state explicitly in some data structure
  - Remember what to do next
    - E.g., send data at a certain time, wait for a response, etc.
  - “Register” all socket descriptors for your mainloop
  - “Register” all your timeouts
  - Process incoming events for all contexts one by one

UDP file transfer: uft

- "Reliable" transfer of a file from one endpoint to another
- Two client modes of operation
  - Initiate a transfer from a server: send a request and then wait for data
  - Initiate a transfer to a server: send data
- Two server modes of operation
  - Wait for incoming requests for files from a client
  - Wait for incoming files from a client
- Distinguished by means of command line options

- File transmission shall take place in chunks of 1024 bytes
- File identification to be conveyed (i.e., the file name)
- File size to be included
- File checking information (e.g., a checksum)
- Other information conceivable

- Support "simulated" packet loss


```
uft [-a|-s] [-p <port>] [-l <lossrate>]
uft <host> [-p <port>] [-l <lossrate>] –b <bitrate> [-t|-r] <file>
```

-a:	server mode: accept incoming files from any host
-s:	server mode: accept requests for files to send from any host
-t:	client mode: send a file to the target host
-r:	client mode: request transmission of a file from a host
<host>	the host to send to or request from (hostname or IPv4 address)
-p:	specify the port number to use (use a default if not given)
-b:	transmission bitrate for the file (gross transmission rate)
<file>	the name of the file to send or request

Further options may be useful; up to you.
Remember to do report errors (locally and across the network) as needed.
You may want to do something useful if the user aborts either process (Ctrl-C).

Hints (1)

- Transport address(es) to receive data on
  - socket (SOCK_DGRAM, AF_INET, …)
  - Create and bind an individual UDP socket for every address
  - Remember host vs. network byte order
- Generation of artificial packet loss
  - Write your own small lossy_sendto (...)

```
double p_loss = ...;

lossy_sendto (int sd, void *msg, size_t len, ...) {
    if ((double) rand () / (double) MAXRANDNUMBER > p_loss)
        return sendto (sd, msg, len, ...);
    return len;
}
```


Hints (2)

- Timer handling
  - gettimeofday(2) yield detailed system clock reading as (sec, usec) pair
  - If you work with timeout, calculate its absolute time
  - In the mainloop, determine the time to wait based upon the current time
    - This result is what you feed into poll() or select()
    - Note that both use completely different time formats
  - If poll()/select() returns 0, a timeout has occurred
- DO NOT USE SIGNALS FOR TIMING
  - Such as done by alarm()
  - This may just cause system call interruptions that you do not want or need
  - Better to stay in control all the time

Hints (3)

- Signals
  - You may need to catch at least SIGINT: signal (SIGINT, signalhandler);
    - This may occur at any point in time, so you may want to postpone processing to the main loop (probably not needed in our simple example)
    - In this case, you would just set a global variable and return (terminate = 1;)
    - Need to check the variable regularly even if no packets arrive
  - Will cause interrupted system calls (errno == EINTR)
    - Need to check for this also in your main loop and behave accordingly
- File access
  - Regular i/o operation (open/close/read/write, fopen/fclose/fread/fwrite)
  - MS Windows: you may need O_BINARY to avoid eol conversion
  - Use fstat () to obtain file attributes (including file size)

Hints (4)

```
/* command line processing goes here */

if ((s = socket (AF_INET, SOCK_DGRAM, 0)) == -1) {
   perror ("cannot create socket");
   exit (-1);
}

listen_addr.sin_family      = AF_INET;
listen_addr.sin_addr.s_addr = INADDR_ANY;
listen_addr.sin_port        = htons (listen_port);
if (bind (s, (struct sockaddr *) &listen_addr,
    sizeof (listen_addr)) == -1) {
    perror ("cannot bind to address");
    exit (-1);
}

... recvfrom (s, ...); ...
... sendto (s, ...); ...
```

Hints (5)

```
n_fd           = 1;
fds [0].fd     = s;
fds [0].events = POLLIN;
fds [0].revents= 0;

for (;;) {

for (i = 0; i < n_fd; i++)
    fds [i].events = POLLIN;

switch (poll (fds, n_fd, 600000)) {
    case -1:
        perror ("poll failed");
        sleep (1);
        break;
    case 0:
        fprintf (stderr, "Timeout...\n");
        break;

    default:
        for (i = 0; i < n_fd; i++) {
          if (fds [i].revents & POLLIN) {
              if (i == 0) {
                  /* process events on socket fds [i].fd */
              }
}}}
```