Network Programming

Application Programmming Interface: API

Network programming at different levels:

- send Ethernet, ATM, …packets
- exchange UDP/TCP (and raw IP) packets
- RPC, transactions, Xlib, Corba, …

Goals:

- efficient (avoid copies)
- change protocols with minimal program changes – at link time, at run time

Socket API

- introduced in 1981 by BSD 4.1
- originally only Unix ➠ WinSock ("almost" same)
- connects *sockets* on two hosts
- data transfer phase: like Unix file descriptors; but: no open, notion of permissions, seek, …
- implemented as library (SVR4) or system calls (BSD)
- mainly, two services: datagram and stream communications
- also provides buffering
- alternatives: TLI (SVR4)

Review: Unix file I/O

file descriptor: small, positive integer

```
int fd;
char buf[256];

fd = open("a.txt", O_RDWR | O_CREAT, S_IRUSR);
write(fd, buf, sizeof(buf));
close(fd)
```

➠ roughly same for sockets, except for setup

Creating a socket

- like filedescriptor (type `int`)
- domain, type and protocol:

domain: `PF_INET`, `PF_UNIX`, …

	datagram	`SOCK_DGRAM`	UDP
type:	reliable, sequenced stream	`SOCK_STREAM`	TCP
	raw	`SOCK_RAW`	IP

protocol: usually 0 = default for type

`socket`(*family*, *type*, *protocol*);

```
#include <sys/types.h>
#include <sys/socket.h>
if ((s = socket(PF_INET, SOCK_STREAM, 0)) < 0) {
  perror("socket");
}
```

Endpoint addresses

Each socket association has five components:
(protocol, local address, local port, remote address, remote port)

protocol: `socket`

local address, port: `bind`

remote address, port: `connect`, `sendto`

Address conversion

internally: 32-bit integers

host name to numeric: `gethostbyname()`

dotted quad to numeric: `inet_addr()`

numeric to dotted quad: `inet_ntoa()`

```
struct sin_addr {
  u_long s_addr;              /* 32-bit host address */
}
struct sockaddr_in {
  short sin_family;           /* AF_INET */
  u_short sin_port;           /* network byte order */
  struct sin_addr sin_addr;   /* network address */
}
```

Data representation

- integers:

little endian	least significant byte first	DEC, Intel
big endian	most significant byte first	Sun, SGI, HP, …

- *network byte order* = big endian
- `m = ntohl(m)`: network-to-host byte order, 32 bit
- `m = htonl(m)`: host-to-network byte order
- `ntohs`, `htons`: short (16 bit)
- other problems:
  - characters (ASCII, 8859-x, multi-byte)
  - floating point, structured data, …
  - ➠ XDR, ASN.1 (canonical representation)

Binding the local address

```
int bind(int s, struct sockaddr *addr, int addresslen);
```

- only one socket per port and protocol (almost)
- optional for clients ➠ system chooses random local port

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

int s;
struct sockaddr_in sin;

if ((s = socket(PF_INET, SOCK_DGRAM, 0)) < 0) { /* error */ }
memset((char *)&sin, 0, sizeof(sin));
sin.sin_family      = AF_INET;
sin.sin_port        = htons(6000); /* 0: let the system choose */
sin.sin_addr.s_addr = INADDR_ANY;  /* allow any interface */
if (bind(s, (struct sockaddr *)&sin, sizeof(sin)) < 0) { /* */ }
```

Sending and receiving data

call	device	buffering	opt	peer?
read(), write()	any	single	N	N
readv(), writev()	any	s/g	N	N
recv(), send()	socket	single	Y	N
recvfrom(), sendto()	socket	single	Y	Y
recvmsg(), sendmsg()	socket	s/g	Y	Y

- block size read (may) $\neq$ block size written
- read from stream: may read fewer bytes than requested
- scatter/gather: read/write from/to several buffers at once

Datagram communications: `sendto()`

```
int sendto(int s, char *msg, int len, int flags,
  struct sockaddr *to, int tolen);
```

- sends *len* bytes from buffer *buf*
- to location *to*, with options *flags* (usu. 0)
- successful return $\not\rightarrow$ delivery

Datagram communication: `recvfrom()`

```
int recvfrom(int s, char *buf, int len, int flags,
  struct sockaddr *from, int *fromlen);
```

- receives **up to** *len* bytes into *buf*
- sets *from* to source address of data
- sets *fromlen* to valid length of *from*
- returns number of bytes received, 0 on EOF

Scatter/gather I/O

Allows to write/read to/from several buffers in one call ➠ write header and data, etc.

```
struct iovec {
  caddr_t iov_base; /* base address of buffer */
  int     iov_len;  /* length of buffer */
}
int writev(int s, struct iovec iov[], inv iovcnt);
int readv(int s, struct iovec iov[], int iovcnt);
```

- writes *iovcnt* buffers from array *iov*
- returns total number of bytes read/written
- on reading, may not fill all buffers

Client/server model

- common, but not the only use of sockets …
- server process ("daemon") waits for connection requests
- file server, time server, X server, …
- asymmetric, but data exchange in both directions
- single process can be both client and server
- two modes:
  - sequential: one connection at a time
  - parallel: each connection forks a new server
- location usually through well-known port number ➠ one per host
- somehow need to find host that offers service

Connecting to a server: `connect()`

`int connect(int s, struct sockaddr *name, int namelen);`

- client issues `connect()` to
  - establish remote address, port (stream, datagram sockets)
  - establish connection (stream socket)
- fails: host not listening to port, timeout

Establish connection queue: `listen()`

`int listen(int s, int backlog)`

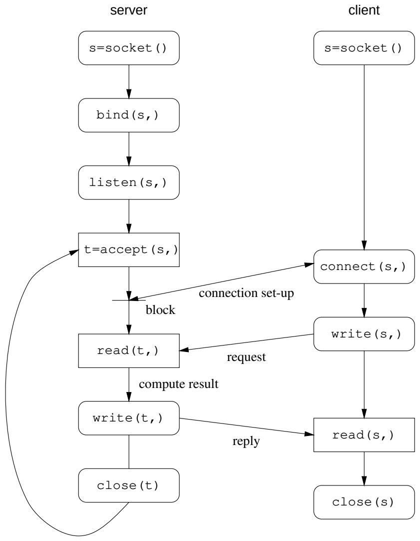
- only used for stream sockets
- socket being listened to can't be used for client
- does **not** wait for connections, but needed
- allows *backlog* pending connection requests while waiting for `accept()`

Accepting connections: `accept()`

`int accept(int s, struct sockaddr *addr, int *addrlen);`

- by connection-oriented server, after `listen()`
- can't "preview" connection ➠ accept and close
- returns a **new** socket for data exchange with client
- optionally, returns address of client

Client/server interaction



Stream client

```
/*
* client host port
*/
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <string.h>
#include <unistd.h>
#include <stdlib.h>
#include <stdio.h>

extern struct in_addr host2ip(char *host);

int main(int argc, char *argv[])
{
  int s;
  struct sockaddr_in sin;
  char msg[80] = "Hello World!";
  int n;

  if (argc < 3) { printf("%s host port\n", argv[0]); return -1; }
```



```
  if ((s = socket(PF_INET, SOCK_STREAM, 0)) < 0) {
    perror("socket"); return -1;
  }
  sin.sin_family = AF_INET;
  sin.sin_port   = htons(atoi(argv[2]));
  sin.sin_addr   = host2ip(argv[1]);
  if (connect(s, (struct sockaddr *)&sin, sizeof(sin)) < 0) {
    perror("connect"); return -1;
  }
  if (write(s, msg, strlen(msg)+1) < 0) {
    perror("write"); return -1;
  }
  if ((n = read(s, msg, sizeof(msg))) < 0) {
    perror("read"); return -1;
  }
  printf("%d bytes: %s\n", n, msg);
  if (close(s) < 0) { perror("close"); return -1; }
  return 0;
}
```

Stream server: echo

```
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <arpa/inet.h>
#include <string.h>
#include <unistd.h>
#include <stdlib.h>
#include <stdio.h>

int main(int argc, char *argv[])
{
  int s, t;
  struct sockaddr_in sin;
  char msg[80];
  int sinlen;

  if (argc < 2) { printf("%s port\n", argv[0]); return -1; }

  if ((s = socket(PF_INET, SOCK_STREAM, 0)) < 0) {
    perror("socket"); return -1;
  }
```

```
  sin.sin_family      = AF_INET;
  sin.sin_port        = htons(atoi(argv[1]));
  sin.sin_addr.s_addr = INADDR_ANY;
  if (bind(s, (struct sockaddr *)&sin, sizeof(sin)) < 0) {
    perror("bind"); return -1;
  }
  if (listen(s, 5) < 0) { perror("listen"); return -1; }
  sinlen = sizeof(sin);
  if ((t = accept(s, (struct sockaddr *)&sin, &sinlen)) < 0) {
    perror("accept"); return -1;
  }
  printf("From %s:%d.\n",
    inet_ntoa(sin.sin_addr), ntohs(sin.sin_port));
  if (read(t, msg, sizeof(msg)) < 0) {perror("read"); return -1;}
  if (write(t, msg, strlen(msg)) < 0) {perror("write"); return -1;}
  if (close(t) < 0) { perror("close"); return -1; }
  if (close(s) < 0) { perror("close"); return -1; }
  return 0;
}
```

Event-based programs

- `read()` is blocking ➠ server only works with single socket
- need I/O multiplexing ➠ event-based programming
- also need to handle time-outs, connection requests
- all events (mouse clicks, windows, etc.) handled by event loop
- **do**
  wait for event(s)
  handle event (hopefully short)
  forever
- harder to maintain state, recursion
- alternative 1: "interrupts" (signals) ➠ called at any time
- alternaitve 2: threads (separate scheduling, same address space)

Multiplexing with `select()`

```
int select(int nfds, fd_set *readfds, fd_set *writefds,
  fd_set *exceptfds, struct timeval *timeout)
```

- block until >= 1 file descriptors have something to be read, written, or an exception, or timeout
- set bit mask for descriptors to watch using `FD_SET`
- returns with bits for ready descriptors set ➠ check with `FD_ISSET`
- cannot specify amount of data ready

GMD fokus

`select()` server example

```
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <arpa/inet.h>
#include <sys/time.h>
#include <string.h>
#include <unistd.h>
#include <stdlib.h>
#include <stdio.h>

int main(int argc, char *argv[])
{
  int s = -1, t = -1;
  int n;
  struct sockaddr_in sin;
  char msg[80];
  fd_set rfds;
  int sinlen;
  struct timeval tv;

  if (argc < 2) { printf("%s port\n", argv[0]); return -1; }
```

```
  if ((s = socket(PF_INET, SOCK_STREAM, 0)) < 0) {
    perror("socket"); return -1;
  }
  sin.sin_family      = AF_INET;
  sin.sin_port        = htons(atoi(argv[1]));
  sin.sin_addr.s_addr = INADDR_ANY;
  if (bind(s, (struct sockaddr *)&sin, sizeof(sin)) < 0) {
    perror("bind"); return -1;
  }
  if (listen(s, 5) < 0) { perror("listen"); return -1; }
  tv.tv_sec = 10;
  tv.tv_usec = 0;
  while (1) {
    FD_ZERO(&rfds);
    if (s > 0) FD_SET(s, &rfds);
    if (t > 0) FD_SET(t, &rfds);
    n = select(64, &rfds, NULL, NULL, &tv);
    if (n == 0) { printf("Timeout!\n"); }
    else if (n > 0) {
      if (s > 0 && FD_ISSET(s, &rfds)) {
        sinlen = sizeof(sin);
        if ((t = accept(s, (struct sockaddr *)&sin, &sinlen)) < 0) {
          perror("accept"); return -1;
```

```
        }
        printf("From %s:%d.\n",
          inet_ntoa(sin.sin_addr), ntohs(sin.sin_port));
      }
      if (t > 0 && FD_ISSET(t, &rfds)) {
        if ((n=read(t,msg,sizeof(msg))) < 0) {perror("read"); return -1;}
        if (n == 0) { close(t); t = -1; }
        else {
          if (write(t,msg,n)<0) {perror("write");return -1;}
        }
      }
    }
  }
  if (close(t) < 0) { perror("close"); return -1; }
  if (close(s) < 0) { perror("close"); return -1; }
  return 0;
}
```


inetd

- server processes (“daemons”): routed, snmpd, in.rlogind, ftpd, mountd, telnetd, …
- each service, one process ➠ lots of idle processes, listening sockets
- `inetd`: Internet services daemon
- opens sockets, forks processes when request arrives
- stdin/stdout connected to network
- but: process creation overhead

Evaluation

- not *quite* the same as files ➠ open("foo.com:3456",...)?
- fixed-length address structure for IPv6?
- asymmetric ➠ client, server
- cannot easily pass QOS parameters (use `ioctl`)
- only single address, no point-to-multipoint
- different IPC (Unix sockets, pipes, ...) for local communication ➠ no distribution transparency