CS631 - Advanced Programming in the UNIX Environment
Interprocess Communication

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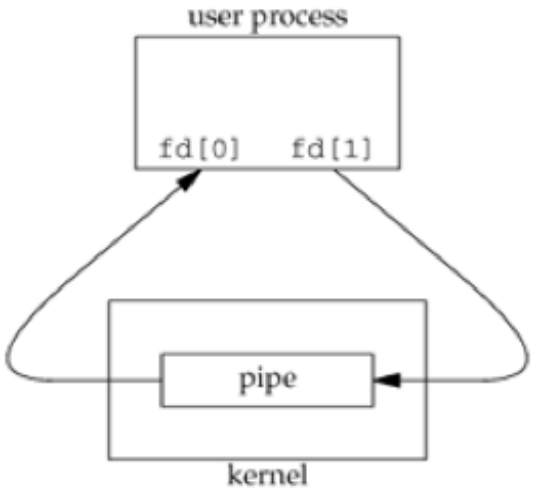
Pipes: `pipe(2)`

```
#include <unistd.h>

int pipe(int filedes[2]);
```

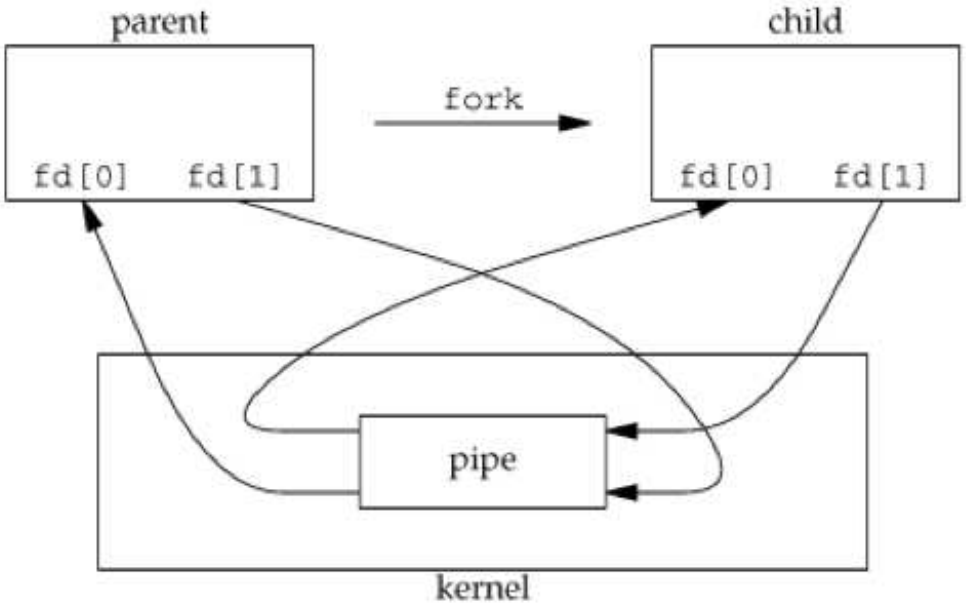
Returns: 0 if OK, -1 otherwise

- oldest and most common form of UNIX IPC
- half-duplex (on some versions full-duplex)

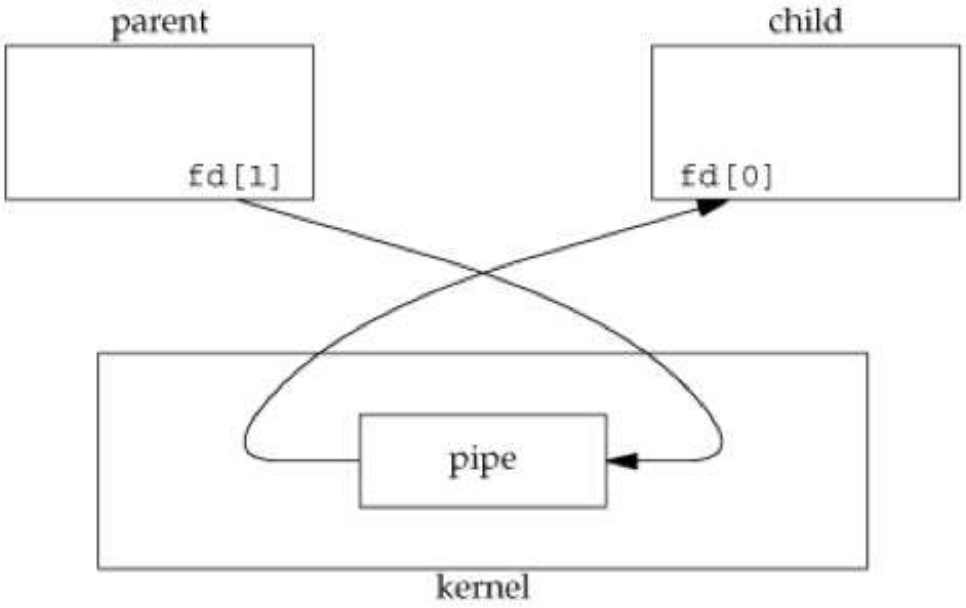
Pipes: `pipe(2)`



Pipes: `pipe(2)`



Pipes: `pipe(2)`



Pipes: `pipe(2)`

```
$ cc -Wall pipe1.c
$ ./a.out
P=> Parent process with pid 23988 (and its ppid 7474).
P=> Sending a message to the child process (pid 23989):
C=> Child process with pid 23989 (and its ppid 23988).
C=> Reading a message from the parent (pid 23988):
Hello child!  I'm your parent pid 23988!
$
```

Pipes: `pipe(2)`

```
$ cc -Wall pipe1.c
$ ./a.out
P=> Parent process with pid 23984 (and its ppid 7474).
P=> Sending a message to the child process (pid 23985):
C=> Child process with pid 23985 (and its ppid 1).
C=> Reading a message from the parent (pid 1):
Hello child!  I'm your parent pid 23984!
$
```

Pipes: `pipe(2)`

```
$ cc -Wall pipe1.c
$ ./a.out
P=> Parent process with pid 23986 (and its ppid 7474).
P=> Sending a message to the child process (pid 23987):
C=> Child process with pid 23987 (and its ppid 23986).
C=> Reading a message from the parent (pid 1):
Hello child!  I'm your parent pid 23986!
$
```

Pipes: `pipe(2)`

A more useful example: displaying some content using the user's preferred pager. (Look, Ma, no temporary files!)

```
$ cat pipe2.c | ${PAGER:-/usr/bin/more}
$ cc -Wall pipe2.c
$ echo $PAGER

$ ./a.out pipe2.c
[...]
^Z
$ ps -o pid,ppid,command
  PID  PPID COMMAND
22306 26650 ./a.out pipe2.c
22307 22306 more
23198 26650 ps -o pid,ppid,command
26650 26641 -ksh
$ fg
$ env PAGER=/bin/cat ./a.out pipe2.c
```

Pipes: `pipe(2)`

```
#include <unistd.h>

int pipe(int filedes[2]);
```

Returns: 0 if OK, -1 otherwise

- oldest and most common form of UNIX IPC
- half-duplex (on some versions full-duplex)
- can only be used between processes that have a common ancestor
- can have multiple readers/writers (`PIPE_BUF` bytes are guaranteed to not be interleaved)

Behavior after closing one end:

- `read(2)` from a pipe whose write end has been closed returns 0 after all data has been read
- `write(2)` to a pipe whose read end has been closed generates `SIGPIPE` signal. If caught or ignored, `write(2)` returns an error and sets `errno` to `EPIPE`.

Pipes: `popen(3)` and `pclose(3)`

```
#include <stdio.h>

FILE *popen(const char *cmd, const char *type);
```

Returns: file pointer if OK, `NULL` otherwise

```
int pclose(FILE *fp);
```

Returns: termination status *cmd* or -1 on error

- historically implemented using unidirectional pipe (nowadays frequently implemented using sockets or full-duplex pipes)
- *type* one of “r” or “w” (or “r+” for bi-directional communication, if available)
- *cmd* passed to `/bin/sh -c`

Pipes: `popen(3)` and `pclose(3)`

```
$ cc -Wall popen.c
$ echo $PAGER

$ ./a.out popen.c
[...]
$ env PAGER=/bin/cat ./a.out popen.c
[...]
$
```

Pipes: `popen(3)` and `pclose(3)`

```
$ cc -Wall popen.c
$ echo $PAGER

$ ./a.out popen.c
[...]
$ env PAGER=/bin/cat ./a.out popen.c
[...]
$ env PAGER=/bin/cat/foo ./a.out popen.c
sh: /bin/cat/foo: Not a directory
$ env PAGER="more; touch /tmp/boo" ./a.out popen.c
$ env PAGER="more; rm /etc/passwd 2>/dev/null" ./a.out popen.c
```

FIFOs: `mkfifo(2)`

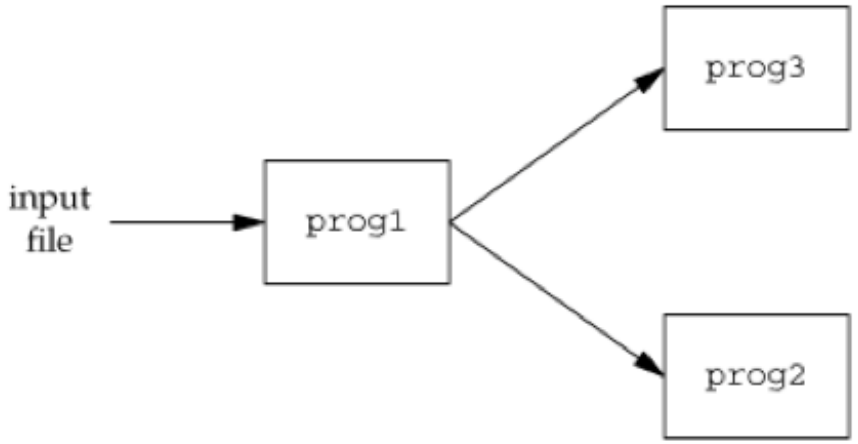
```
#include <sys/stat.h>

int mkfifo(const char *path, mode_t mode);
```

Returns: 0 if OK, -1 otherwise

- aka “named pipes”
- allows unrelated processes to communicate
- just a type of file – test for using `S_ISFIFO(st_mode)`
- *mode* same as for `open(2)`
- use regular I/O operations (ie `open(2)`, `read(2)`, `write(2)`, `unlink(2)` etc.)
- used by shell commands to pass data from one shell pipeline to another without creating intermediate temporary files

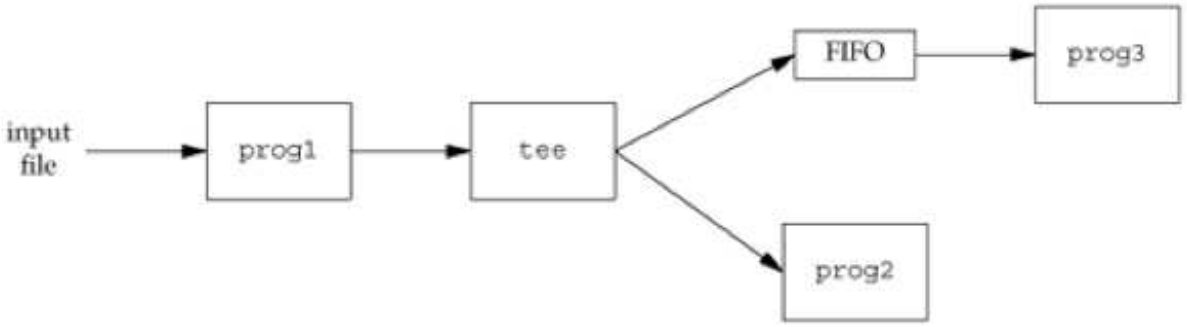
FIFOs: `mkfifo(2)`

Example: split input into sets



FIFOs: `mkfifo(2)`

Example: split input into sets




```
$ mkfifo fifo
$ grep pattern fifo > match &
$ gzcat file.gz | tee fifo | grep -v pattern > nomatch
```

System V IPC

Three types of IPC originating from System V:

- Semaphores
- Shared Memory
- Message Queues

All three use *IPC structures*, referred to by an *identifier* and a *key*; all three are (necessarily) limited to communication between processes on one and the same host.

Since these structures are not known by name, special system calls (`msgget(2)`, `semop(2)`, `shmat(2)`, etc.) and special userland commands (`ipcrm(1)`, `ipcs(1)`, etc.) are necessary.

System V IPC: Semaphores

A semaphore is a counter used to provide access to a shared data object for multiple processes. To obtain a shared resource a process needs to do the following:

1. Test semaphore that controls the resource.
2. If value of semaphore $>$ 0, decrement semaphore and use resource; increment semaphore when done
3. If value == 0 sleep until value $>$ 0

Semaphores are obtained using `semget(2)`, properties controlled using `semctl(2)`, operations on a semaphore performed using `semop(2)`.

System V IPC: Semaphores

```
$ cc -Wall semdemo.c
1$ ./a.out

2$ ./a.out

$ ipcs -s
```

System V IPC: Shared Memory

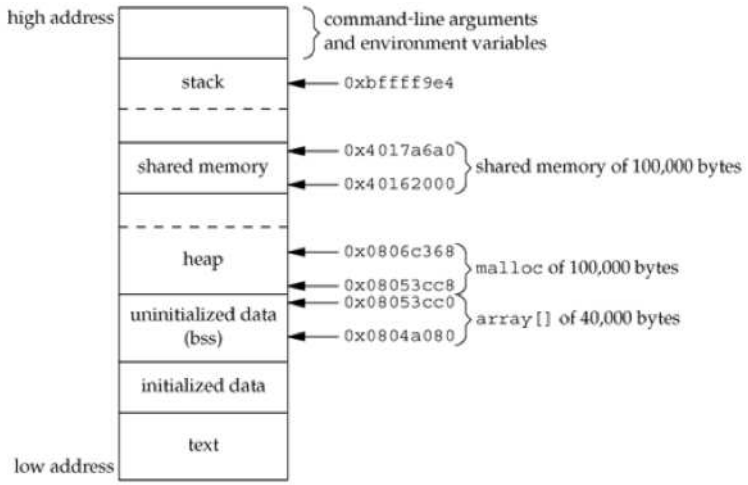
- fastest form of IPC
- access to shared region of memory often controlled using semaphores
- obtain a shared memory identifier using `shmget(2)`
- catchall for shared memory operations: `shmctl(2)`
- attach shared memory segment to a processes address space by calling `shmat(2)`
- detach it using `shmdt(2)`

System V IPC: Shared Memory

```
$ cc -Wall shmdemo.c
$ ./a.out "Cow says: 'Moo!'"
$ ./a.out
$ ipcs -m
```

System V IPC: Shared Memory

```
$ cc -Wall memory-layout.c
$ ./a.out
array[] from 804a080 to 8053cc0
stack around bffff9e4
malloced from 8053cc8 to 806c368
shared memory attached from 40162000 to 4017a6a0
```



System V IPC: Message Queues

- linked list of messages stored in the kernel
- create or open existing queue using `msgget(2)`
- add message at end of queue using `msgsnd(2)`
- control queue properties using `msgctl(2)`
- receive messages from queue using `msgrcv(2)`

The message itself is contained in a user-defined structure such as

```
struct mymsg {
    long mtype;      /* message type */
    char mtext[512]; /* body of message */
};
```

System V IPC: Message Queues

```
$ cc -Wall msgsend.c -o msgsend
$ cc -Wall msgrecv.c -o msgrecv
$ ipcs -q
$ ./msgsend 1
$ ipcs -q
$ ./msgsend 1
$ ipcs -q
$ ./msgrecv 1
$ ipcs -q
$ ./msgrecv 1
$ ipcs -q
$ ./msgrecv 1
^C
$ ipcs -q
$ ./msgsend 2
$ ipcrm -q <msqid>
```

Sockets: `socketpair(2)`

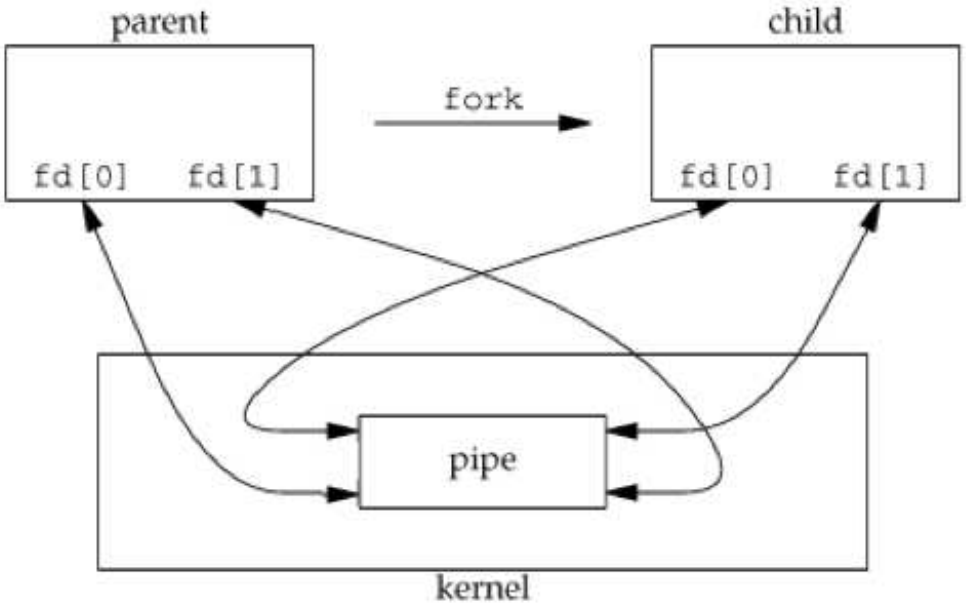
```
#include <sys/socket.h>

int socketpair(int d, int type, int protocol, int *sv);
```

The `socketpair(2)` call creates an unnamed pair of connected sockets in the specified domain `d`, of the specified *type*, and using the optionally specified *protocol*.

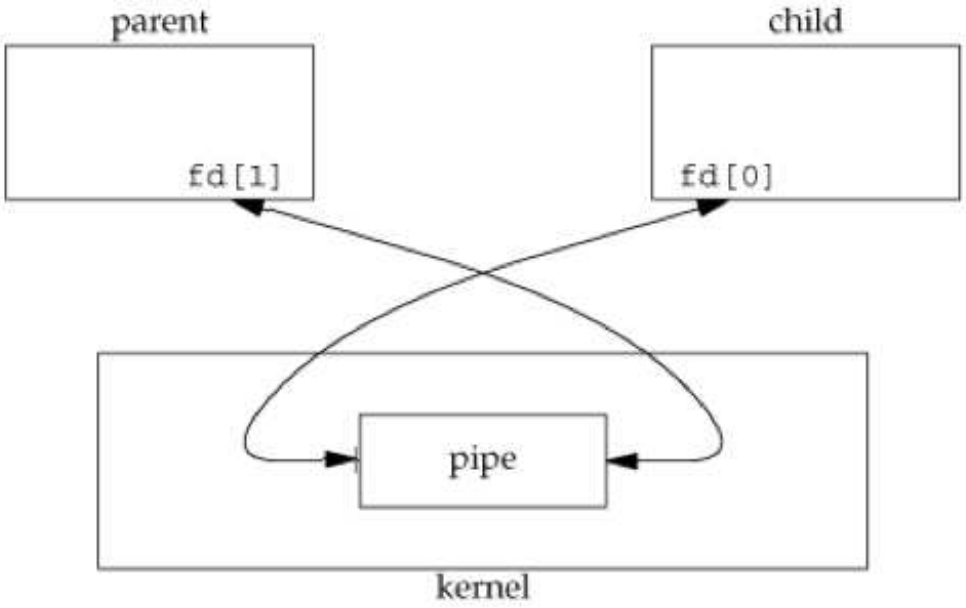
The descriptors used in referencing the new sockets are returned in *sv[0]* and *sv[1]*. The two sockets are indistinguishable.

`This call is currently implemented only for the UNIX domain.`

Sockets: `socketpair(2)`



Sockets: `socketpair(2)`



Sockets: `socketpair(2)`

```
$ cc -Wall socketpair.c
$ ./a.out
78482 --> sending: In Xanadu, did Kublai Khan . . .
78483 --> sending: A stately pleasure dome decree . . .
78483 --> reading: In Xanadu, did Kublai Khan . . .
78482 --> reading: A stately pleasure dome decree . . .
$
```

Sockets: `socket(2)`

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

int socket(int domain, int type, int protocol);
```

Some of the currently supported domains are:

Domain	Description
PF_LOCAL	local (previously UNIX) domain protocols
PF_INET	ARPA Internet protocols
PF_INET6	ARPA IPv6 (Internet Protocol version 6) protocols
PF_ARP	RFC 826 Ethernet Address Resolution Protocol
...	...

Some of the currently defined types are:

Type	Description
SOCK_STREAM	sequenced, reliable, two-way connection based byte streams
SOCK_DGRAM	connectionless, unreliable messages of a fixed (typically small) maximum length
SOCK_RAW	access to internal network protocols and interfaces
...	...

Sockets: Datagrams in the UNIX/LOCAL domain

```
1$ cc -Wall udgramsend.c -o send
1$ cc -Wall udgramread.c -o read
1$ ./read
socket --> socket

2$ ls -l socket
srwxr-xr-x  1 jans  users   0 Oct 31 19:17 socket
2$ ./send socket
2$

--> The sea is calm tonight, the tide is full . . .
1$
```

Sockets: Datagrams in the UNIX/LOCAL domain

- create socket using `socket(2)`
- attach to a socket using `bind(2)`
- binding a name in the UNIX domain creates a socket in the file system
- both processes need to agree on the name to use
- these files are only used for rendezvous, not for message delivery once a connection has been established
- sockets must be removed using `unlink(2)`

Sockets: Datagrams in the Internet Domain

```
1$ cc -Wall dgramsend.c -o send
1$ cc -Wall dgramread.c -o read
1$ ./read
Socket has port #64293

2$ netstat -na | grep 64293
udp4       0      0  *.64293                *.*
2$ ./send localhost 64293
2$

--> The sea is calm tonight, the tide is full . . .
1$
```

Sockets: Datagrams in the Internet Domain

- Unlike UNIX domain names, Internet socket names are not entered into the file system and, therefore, they do not have to be unlinked after the socket has been closed.
- The local machine address for a socket can be any valid network address of the machine, if it has more than one, or it can be the wildcard value `INADDR_ANY`.
- “well-known” ports (range 1 - 1023) only available to super-user
- request any port by calling `bind(2)` with a port number of 0
- determine used port number (or other information) using `getsockname(2)`
- convert between network byteorder and host byteorder using `htons(3)` and `ntohs(3)` (which may be noops)

Sockets: Connections using stream sockets

```
1$ cc -Wall streamread.c -o read
1$ cc -Wall streamwrite.c -o write
1$ ./read
Socket has port #65398

2$ ./write localhost 65398
2$ ./write localhost 65398
--> Half a league, half a league . . .
Ending connection
--> Half a league, half a league . . .
Ending connection

2$ nc localhost 65398
moo
2$
```

Sockets: Connections using stream sockets

- connections are asymmetrical: one process requests a connection, the other process accepts the request
- one socket is created for each accepted request
- mark socket as willing to accept connections using `listen(2)`
- pending connections are then `accept(2)`ed
- `accept(2)` will block if no connections are available
- `select(2)` to check if connection requests are pending

Sockets: Connections using stream sockets

```
1$ cc -Wall strchkread.c -o read
1$ ./read
Socket has port #65398
Do something else
Do something else
2$ ./write localhost 65398
2$ ./write localhost 65398
-> Half a league, half a league . . .
Ending connection
Do something else
--> Half a league, half a league . . .
Ending connection
^C
1$
```

Sockets: Other Useful Functions

I/O on sockets is done on descriptors, just like regular I/O, ie the typical `read(2)` and `write(2)` calls will work. In order to specify certain flags, some other functions can be used:

- `send(2)`, `sendto(2)` and `sendmsg(2)`
- `recv(2)`, `recvfrom(2)` and `recvmsg(2)`

To manipulate the options associated with a socket, use `setsockopt(2)`:

Option	Description
SO_DEBUG	enables recording of debugging information
SO_REUSEADDR	enables local address reuse
SO_REUSEPORT	enables duplicate address and port bindings
SO_KEEPALIVE	enables keep connections alive
SO_DONTROUTE	enables routing bypass for outgoing messages
SO_LINGER	linger on close if data present
SO_BROADCAST	enables permission to transmit broadcast messages
SO_OOBINLINE	enables reception of out-of-band data in band
SO_SNDBUF	set buffer size for output
SO_RCVBUF	set buffer size for input
SO_SNDLOWAT	set minimum count for output
SO_RCVLOWAT	set minimum count for input
SO_SNDTIMEO	set timeout value for output
SO_RCVTIMEO	set timeout value for input
SO_TIMESTAMP	enables reception of a timestamp with datagrams
SO_TYPE	get the type of the socket (get only)
SO_ERROR	get and clear error on the socket (get only)

More Information

- http://www.cs.stevens.edu/~jschauma/631/ipctut.pdf
- http://www.cs.stevens.edu/~jschauma/631/ipc.pdf
- http://www.cs.cf.ac.uk/Dave/C/node25.html
- http://beej.us/guide/bgipc/output/html/singlepage/bgipc.html