# CS631 - Advanced Programming in the UNIX Environment
# –
# Advanced I/O / HTTP

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# Nonblocking I/O

Recall from our lecture on signals that certain system calls can block forever:

- `read(2)` from a particular file, if data isn't present (pipes, terminals, network devices)
- `write(2)` to the same kind of file
- `open(2)` of a particular file until a specific condition occurs
- `read(2)` and `write(2)` of files that have mandatory locking enabled
- certain `ioctls(2)`
- some IPC functions (such as `sendto(2)` or `recv(2)`)

See `eintr.c` from that lecture.

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Nonblocking I/O lets us issue an I/O operation and not have it block forever. If the operation cannot be completed, return is made immediately with an error noting that the operating would have blocked (`EWOULDBLOCK` or `EAGAIN`).

# Nonblocking I/O

Ways to specify nonblocking mode:

- pass `O_NONBLOCK` to `open(2)`:

```
open(path, O_RDRW|O_NONBLOCK);
```

- set `O_NONBLOCK` via `fcntl(2)`:

```
flags = fcntl(fd, F_GETFL, 0);
fcntl(fd, F_SETFL, flags|O_NONBLOCK);
```

# Nonblocking I/O

```
$ cc -Wall nonblock.c
$ ./a.out >/dev/null
wrote 100000 bytes
[...]
$ ./a.out | ( sleep 3; cat >/dev/null ) 2>&1 | more
[...]
$ ( ./a.out | cat >/dev/null ) 2>&1 | more
[...]
write error: Resource temporarily unavailable
wrote 3392 bytes
wrote 65536 bytes
write error: Resource temporarily unavailable
[...]
$ nc -l 8080

$ ./a.out | nc hostname 8080
[...]
```

# Resource Locking

Ways we have learned so far to ensure only one process has exclusive access to a resource:

- open file using `O_CREAT|O_EXCL`, then immediately `unlink(2)` it
- create a “lockfile” – if file exists, somebody else is using the resource
- use of a semaphore

What are some problems with each of these?

# Advisory Locking

```
#include <fcntl.h>

int flock(int fd,int operation);
```

Returns: 0 if OK, -1 otherwise

- applies or removes an advisory lock on the file associated with the file descriptor fd
- *operation* can be `LOCK_NB` and any one of:
  - `LOCK_SH`
  - `LOCK_EX`
  - `LOCK_UN`
- locks entire file

# Advisory Locking

```
$ cc -Wall flock.c
1$ ./a.out
Shared lock established - sleeping for 10 seconds.
[...]
Giving up all locks.

2$ ./a.out
Shared lock established - sleeping for 10 seconds.
Now trying to get an exclusive lock.
Unable to get an exclusive lock.
[...]
Exclusive lock established.

1$ ./a.out
[blocks until the other process terminates]
```

# Advisory “Record” Locking

Record locking is done using `fcntl(2)`, using one of `F_GETLK`, `F_SETLK` or `F_SETLKW` and passing a

```
struct flock {
    short l_type;   /* F_RDLCK, F_WRLCK, or F_UNLCK */
    off_t l_start;  /* offset in bytes from l_whence */
    short l_whence; /* SEEK_SET, SEEK_CUR, or SEEK_END */
    off_t l_len;    /* length, in bytes; 0 means "lock to EOF" */
    pid_t l_pid;    /* returned by F_GETLK */
}
```

Lock types are:

- `F_RDLCK` – Non-exclusive (read) lock; fails if write lock exists.
- `F_WRLCK` – Exclusive (write) lock; fails if any lock exists.
- `F_UNLCK` – Releases our lock on specified range.

# Advisory "Record" locking

```
#include <unistd.h>

int lockf(int fd, int value, off_t size);
```

Returns: 0 on success, -1 on error

*value* can be:

- `F_ULOCK` – unlock locked sections
- `F_LOCK` – lock a section for exclusive use
- `F_TLOCK` – test and lock a section for exclusive use
- `F_TEST` – test a section for locks by other processes

| | | Request for | |
|---|---|---|---|
| | | read lock | write lock |
| Region currently has | no locks | OK | OK |
| | one or more read locks | OK | denied |
| | one write lock | denied | denied |

# Advisory “Record” locking

Locks are:

- released if a process terminates
- released if a filedescriptor is closed (!)
- not inherited across `fork(2)`
- inherited across `exec(2)`
- released upon `exec(2)` if close-on-exec is set

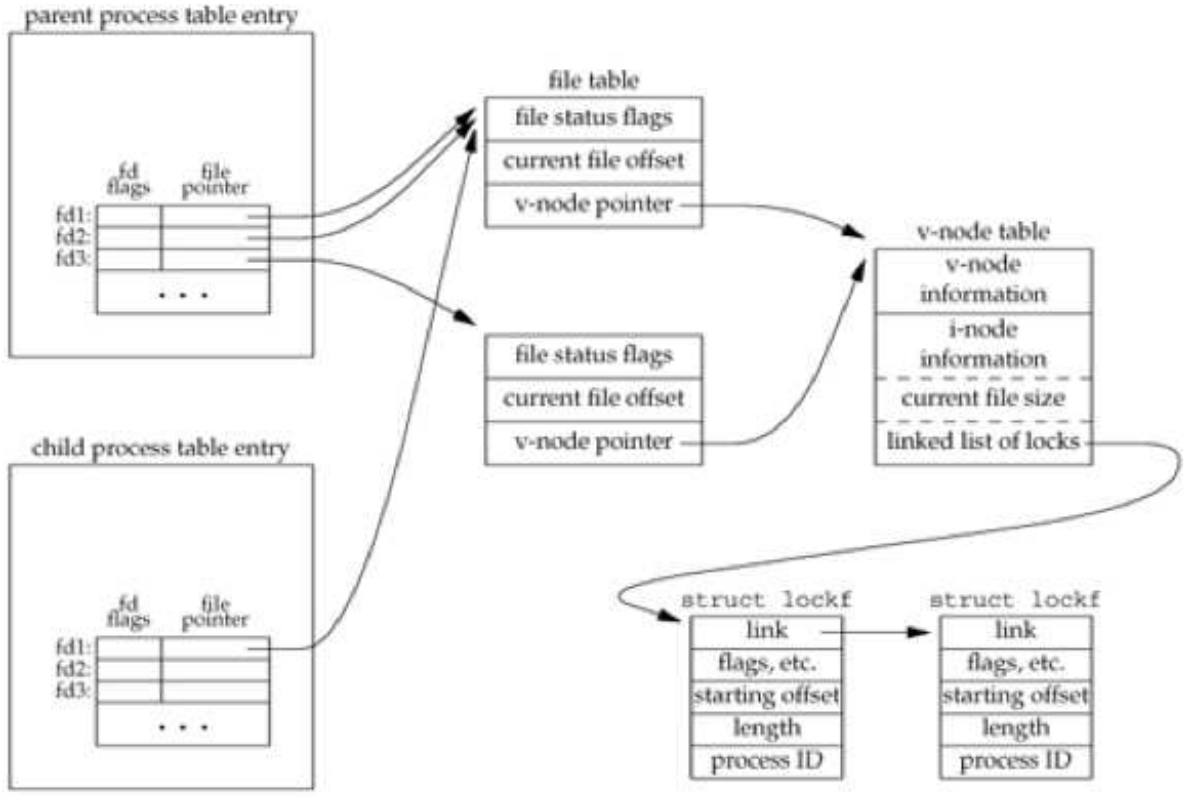
# Advisory “Record” locking

Locks are associated with a *file and process pair*, not with a *filedescriptor*!

```
fd1 = open(pathname, ...);
write_lock(fd1...);          /* lock byte 0 */
if ((pid = fork()) > 0) {
        fd2 = dup(fd1);
        fd3 = open(pathname, ...);
} else if (pid == 0) {
        read_lock(fd1...); /* lock byte 1 */
}
```

# Advisory “Record” locking

Locks are associated with a *file and process pair*, not with a *filedescriptor*!



# Mandatory locking

- not implemented on all UNIX flavors
  - `chmod g+s,g-x file`
- possible to be circumvented:

```
$ mandatory-lock /tmp/file &
$ echo foo > /tmp/file2
$ rm /tmp/file
$ mv /tmp/file2 /tmp/file
```

# I/O Multiplexing

Standard I/O loop:

```
while ((n = read(fd1, buf, BUFFSIZE)) > 0) {
        if (write(fd2, buf, n) != n) {
                fprintf(stderr, "write error\n");
                exit(1);
         }
}
```

Suppose you want to read from multiple file descriptors - now what?

# I/O Multiplexing

When handling I/O on multiple file descriptors, we have the following options:

- blocking mode: open one fd, block, wait (possibly forever), then test the next fd
- fork and use one process for each, communicate using signals or other IPC
- non-blocking mode: open one fd, immediately get results, open next fd, immediately get results, sleep for some time
- asynchronous I/O: get notified by the kernel when either fd is ready for I/O

# I/O Multiplexing

Instead of blocking forever (undesirable), using *non-blocking* mode (busy-polling is inefficient) or using *asynchronous I/O* (somewhat limited), we can:

- build a set of file descriptors we're interested in
- call a function that will return if any of the file descriptors are ready for I/O (or a timeout has elapsed)

# I/O Multiplexing

```
#include <sys/types.h>
#include <sys/time.h>
#include <unistd.h>

int select(int maxfdp1, fd_set *readfds, fd_set *writefds
           fd_set *exceptfds, struct timeval *tvptr);
```

Returns: count of ready descriptors, 0 on timeout, -1 otherwise

Arguments passed:

- which descriptors we're interested in
- what conditions we're interested in
- how long we want to wait
  - `tvptr == NULL` means wait forever
  - `tvptr->tv_sec == tvptr->tv_usec == 0` means don't wait at all
  - wait for specified amount of time

`select(2)` tells us both the total count of descriptors that are ready as well as which ones are ready.

# I/O Multiplexing

- filedescriptor sets are manipulated using the `FD_*` functions/macros
- read/write sets indicate readiness for read/write; *except* indicates an exception condition (for example OOB data, certain terminal events)
- EOF means ready for read - `read(2)` will just return 0 (as usual)
- `pselect(2)` provides finer-grained timeout control; allows you to specify a signal mask (original signal mask is restored upon return)
- `poll(2)` provides a conceptually similar interface

See also:

- last week's `strchkread.c`
- `http://daniel.haxx.se/docs/poll-vs-select.html`

# Asynchronous I/O

- System V derived async I/O
  - limited to STREAMS
  - enabled via `ioctl(2)`
  - uses `SIGPOLL`
- BSD derived async I/O
  - limited to terminals and networks
  - enabled via `fcntl(2)` (`O_ASYNC`, `F_SETOWN`)
  - uses `SIGIO` and `SIGURG`

Mentioned here for completeness's sake only.
See `aio(7)` for an example of POSIX AIO.

# Memory Mapped I/O

```
#include <sys/types.h>
#include <sys/mman.h>

void *mmap(void *addr, size_t len, int prot, int flags, int fd, off_t offset);
```

Returns: pointer to mapped region if OK

Protection specified for a region:

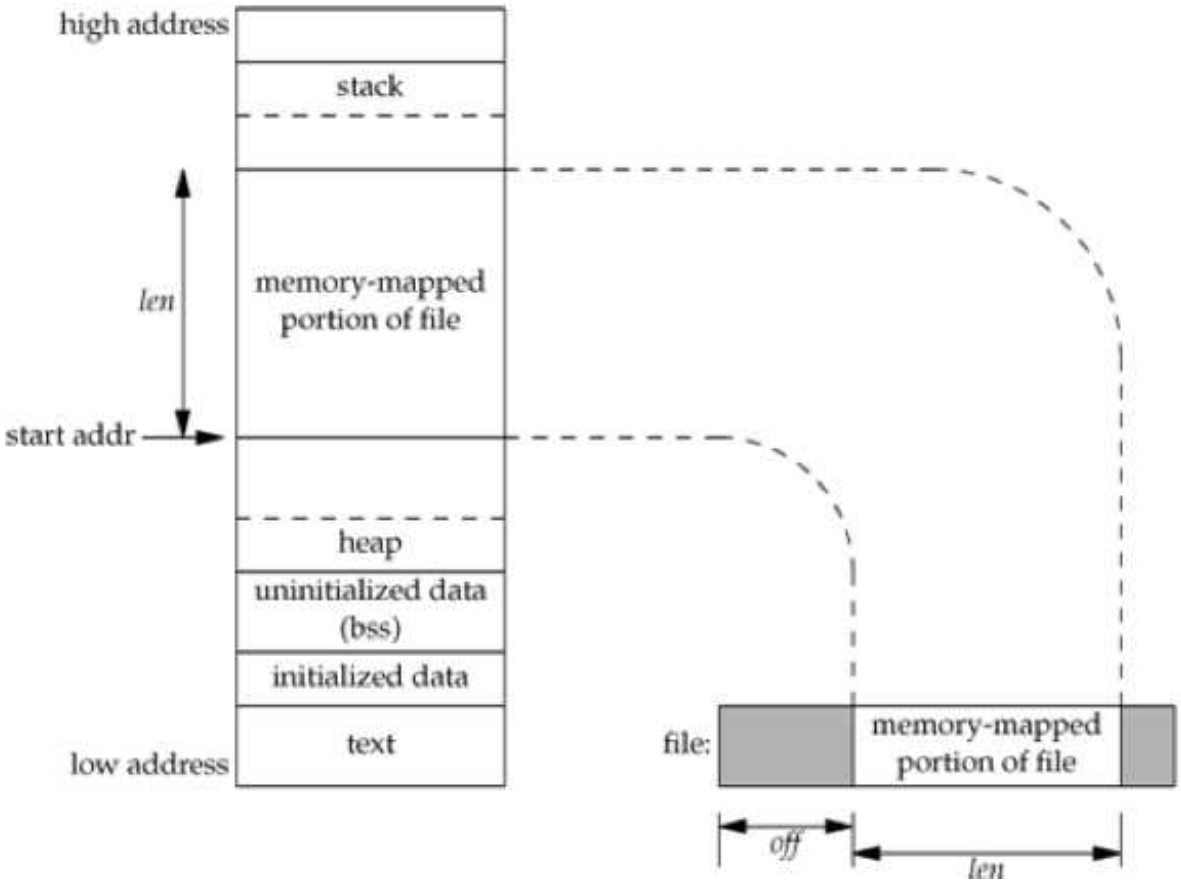
- `PROT_READ` – region can be read
- `PROT_WRITE` – region can be written
- `PROT_EXEC` – region can be executed
- `PROT_NONE` – region can not be accessed

*flag* needs to be one of

- `MAP_SHARED`
- `MAP_PRIVATE`
- `MAP_COPY`

which may be OR'd with other flags (see `mmap(2)` for details).

# Memory Mapped I/O



# Memory Mapped I/O

| Operation | Linux 2.4.22 (Intel x86) | | | Solaris 9 (SPARC) | | |
|---|---|---|---|---|---|---|
| | User | System | Clock | User | System | Clock |
| `read/write` | 0.04 | 1.02 | 39.76 | 0.18 | 9.70 | 41.66 |
| `mmap/memcpy` | 0.64 | 1.31 | 24.26 | 1.68 | 7.94 | 28.53 |

Exercise: write a program that benchmarks this performance and run it on the systems you have access to.

# Memory Mapped I/O

`http://cvsweb.netbsd.org/bsdweb.cgi/src/bin/cp/utils.c?rev=HEAD`

# Final Project

Final project: write a simple web server.

`http://www.cs.stevens.edu/~jschauma/631/f13-final-project.html`

# HTTP

Hypertext Transfer Protocol

RFC2616

# HTTP

HTTP is a request/response protocol.

# The Hypertext Transfer Protocol

HTTP is a request/response protocol:

1. client sends a request to the server
2. server responds

# The Hypertext Transfer Protocol

HTTP is a request/response protocol:

1. client sends a request to the server
   - request method
   - URI
   - protocol version
   - request modifiers
   - client information
2. server responds

# HTTP: A client request

```
$ telnet www.google.com 80
Trying 2607:f8b0:400c:c02::93...
Connected to www.google.com.
Escape character is '^]'.
GET / HTTP/1.0
```

# The Hypertext Transfer Protocol

HTTP is a request/response protocol:

1. client sends a request to the server
   - request method
   - URI
   - protocol version
   - request modifiers
   - client information
2. server responds
   - status line (including success or error code)
   - server information
   - entity metainformation
   - content

# HTTP: a server response

```
HTTP/1.0 200 OK
Date: Mon, 22 Oct 2012 03:08:18 GMT
Content-Type: text/html; charset=ISO-8859-1
Server: gws

<!doctype html><html itemscope="itemscope"
itemtype="http://schema.org/WebPage"><head><meta content="Search the
world's information, including webpages, images, videos and more. Google
has many special features to help you find exactly what you're looking
for." name="description"><meta content="noodp" name="robots"><meta
itemprop="image"
content="/images/google_favicon_128.png"><title>Google</title><script>
window.google={kEI:"oriEUNmMGMX50gH6kYGwBw",getEI:function(a){var
b;while(a&&!(a.getAttribute&&(b=a.getAttribute("eid"))))a=a.parentNode;return
b||google.kEI},https:function(){return
window.location.protocol=="https:"},kEXPI:"25657,30316,39523,39977,40362
```

# The Hypertext Transfer Protocol

Server status codes:

- 1xx – Informational; Request received, continuing process
- 2xx – Success; The action was successfully received, understood, and accepted
- 3xx – Redirection; Further action must be taken in order to complete the request
- 4xx – Client Error; The request contains bad syntax or cannot be fulfilled
- 5xx – Server Error; The server failed to fulfill an apparently valid request

# HTTP: A client request

```
$ telnet www.cs.stevens.edu 80
Trying 155.246.89.84...
Connected to tarantula.srcit.stevens-tech.edu.
Escape character is '^]'.
GET / HTTP/1.0

HTTP/1.1 200 OK
Date: Mon, 04 Apr 2011 02:16:14 GMT
Server: Apache/2.2.9 (Debian) DAV/2 SVN/1.5.1 PHP/5.2.6-1+lenny9 with Suhosin-Patch m
Last-Modified: Wed, 17 Nov 2010 19:25:54 GMT
Content-Type: text/html

<!DOCTYPE HTML PUBLIC "-//W3C//DTD HTML 4.0 Transitional//EN">
<html>
<head>
<title>SRCIT wiki page</title>
<meta http-equiv="REFRESH"
content="0;url=http://www.srcit.stevens.edu/wiki"></HEAD>
<BODY>
</BODY>
</HTML>
```

# HTTP - more than just text

HTTP is a *Transfer Protocol* – serving *data*, not any specific text format.

- `Accept-Encoding` client header can specify different formats such as *gzip*, *Shared Dictionary Compression over HTTP (SDCH)* etc.
- corresponding server headers: `Content-Type` and `Content-Encoding`

# HTTP - more than just static data

HTTP is a *Transfer Protocol* – what is transferred need not be static; resources may generate different data to return based on many variables.

- CGI – resource is *executed*, needs to generate appropriate response headers
- server-side scripting (ASP, PHP, Perl, ...)
- client-side scripting (JavaScript/ECMAScript/JScript,...)
- applications based on HTTP, using:
  - AJAX
  - RESTful services
  - JSON, XML, YAML to represent state and abstract information

# Writing a *simple* HTTP server

- parse command-line options, initialize world, ...
- open socket
- run as a dæmon, loop forever
  - accept connection
  - fork child to handle request
- upon `SIGHUP` re-read configuration, restart

# Writing a *simple* HTTP server

Processing requests consists of:

- reading request from socket
- parsing request
  - valid syntax?
  - type of request (GET, HEAD, POST)?
  - determine pathname
    - $\sim$ translation
    - translate relative into absolute pathname
- generate server status response
- handle request

# Writing a *simple* HTTP server

Processing requests consists of:

- handling regular file request
  - `stat(2)` file
  - `open(2)` file
  - `read(2)` file
  - `write(2)` to socket
  - `close(2)` file
  - terminate connection
  - exit child handler
- handling CGI execution
  - setup environment
  - setup filedescriptors (stdin/stdout)
  - fork-exec executable

# Homework

Be able to explain how the shell executes the following statement:

```
( ./a.out | cat >/dev/null ) 2>&1 | more
```

HW#3: webserver framework

`http://www.cs.stevens.edu/~jschauma/631/f13-hw3.html`

Final project: write a simple web server.

`http://www.cs.stevens.edu/~jschauma/631/f13-final-project.html`