

COMP3000 Exam Review

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1 Environment Variables

Environment variables are constructed in the shell on login. These variables are stored by the shell, and typically provide user-specific context and values to processes.

Some examples of environment variables are:

- **PATH** contains the “path” to different areas on the system where binaries are located. A sample path could look like `/usr/local/bin:/usr/bin:/bin`, each of these three directories are searched by the shell to find programs
- **USER** contains the username of the current user that's logged in.
- **SHELL** contains the shell that the user is using
- etc

You can set environment variables with `export` on bash, and printing them by appending the variable name with a `$`. For example, to set and print a variable called `POOP`

```
export POOP=foo
echo $POOP
```

2 wait()

Wait is used to wait for a change of state in a child process, and to obtain information about the child process whose state has changed.

A state change is considered to be:

- The child terminated
 - In this case, performing a wait allows the system to release the resources associated with the child who terminated. **If a wait is not performed, the child is considered to be a “zombie”**
- The child was stopped by a signal
- The child was resumed by a signal

If the child has already changed states then a call to wait will return immediately. Else they will block until either a child changes state or a signal handler interrupts the call.

3 How2Shell

How a shell works (generally):

- A shell is just another program.
- What happens when a user runs a program:
 - Based on the PATH environment variable, the shell will search for binaries that correspond to the user's request.
 - If the user specified output redirection, the shell will redirect STDOUT / STDIN appropriately (see section on this)
 - Fork the current process, the child process will execute the specified program.
 - The child process sends a signal to the parent process (shell), shell continues execution.

There are exceptions for I/O redirection, piping, and running programs in the background, however the above workflow applies to all of those cases.

4 Working Dir

The working directory represents where your program, or shell, currently is.

- To change the current working directory in bash, use the cd command.
- To change the current working directory in C, use the chdir() function.

5 Globbing and Wildcards

Globbing and wildcard matching is something done by the shell, with logic implemented by the C library glob.h, or the logic can be defined manually. It doesn't really matter as long as it behaves like a normal glob

5.1 How To Glob

Consider the following files:

```
book1 book2 book3 potato1 potato2 potato3
```

To get all books, a few possible wildcard statements would be `b*`, `book*`, etc. If I wanted to get all things with a 3 I could do `*3`. If I wanted to get everything containing the letter o and the number 2, I could do `*o*2`

Globbing isn't understood by a program, so all of these glob statements **expand** out to be a list of files, i.e

```
b* = book1 book2 book3
```

6 I/O Redirection

The I/O redirection we implemented is *ms-dos* style. Because dos could only run one process at a time, the general workflow was something like this

1. Run process A and put the output to some TMP file `A > tmpfile`
2. Run process B with the input redirected from the tmpfile `B < tmpfile`

In a more modern multiprocess system this would not involve writing anything to the disk – however here is how we implemented this in 3000shell:

1. Run process A and put the output to some TMP file `A > tmpfile`
 - (a) **Run process A:** fork the current process, wait for the child to finish.
 - (b) **Put the output to some TMP file:** open the tmpfile, get the file descriptor. Create a copy of the old file descriptor, redirect stdout to the output file.
2. Run process B with the input redirected from the tmpfile B
 - (a) **Run process B:** fork the current process, wait for the child to finish.
 - (b) **Put the output to some TMP file:** open the tmpfile, get the file descriptor. Create a copy of the old file descriptor, redirect stdout to the output file.

7 Umask

Umask, or file mode creation masks, are groupings of bits that define permissions for files.

First, consider the model that is used for file permissions:

- User – permissions for the immediate user
- Group – permissions for users that are in a files group
- Others – permissions for all other users

For each class there corresponds a set of bits that represent the actions that can be applied to the file:

- r – read access to the file.
- w – write access to the file.
- x – permission to execute the file.

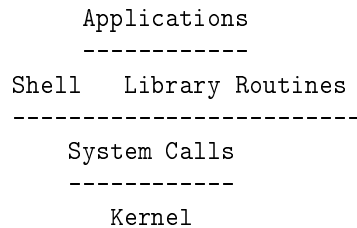
These permissions values can be represented as three bits, in the order RWX. For instance to specify read, write, and not execute, the corresponding value will be 110.

Translation to octal: each set of these bits is effectively an octal value (base 7). So all of these binary values can be represented as octal, for example

- RWX-RWX-RWX = 111 111 111 = 777 permissions
- RW-RW-R- = 110 110 100 = 664 permissions

8 System and Library Calls

System calls are one layer above the kernel – all a system call does is asks the kernel to do something. They are very low level. Library calls consist of system calls, so library calls can be thought of as an *abstraction* of system calls



9 TTY's And Proc

TTY's are text input / output environments. Typically these

TODO: Add more here

10 Signal Handlers

10.1 How To Define and Register

Typically a signal handler is defined in a method, and looks like this:

```

1 void signal_handler(int the_signal)
2 {
3     int pid, status;
4
5     if (the_signal == SIGHUP) {
6         fprintf(stderr, "Received SIGHUP.\n");
7         return;
8     }
9
10    if (the_signal != SIGCHLD) {
11        fprintf(stderr, "Child handler called for signal %d?!\n",
12                the_signal);
13        return;
14    }
15
16    pid = wait(&status);
17
18    if (pid == -1) {
19        /* nothing to wait for */
20        return;
21    }
22
23    if (WIFEXITED(status)) {
24        fprintf(stderr, "\nProcess %d exited with status %d.\n",
25                pid, WEXITSTATUS(status));
26    } else {
27        fprintf(stderr, "\nProcess %d aborted.\n", pid);

```

```

28 }
29 }

```

In the above example we have a generic method that takes an int (since that's all a signal is) and then we provide logic depending on the signals we want to handle.

Signal handlers are typically registered when a program starts up, in the main method.

```

1  int main(int argc, char *argv[], char *envp[])
2  {
3      // A struct for signal handlers
4      struct sigaction signal_handler_struct;
5
6      // Fill the struct with 0s
7      memset (&signal_handler_struct, 0, sizeof(signal_handler_struct));
8
9      // Assuming we have a signal_handler method
10     signal_handler_struct.sa_handler = signal_handler;
11
12     // Provide behavior compatible with BSD signal semantics by making
        certain system calls restartable across signals.
13     signal_handler_struct.sa_flags = SA_RESTART;
14
15     // Now we can register our signals to our signal handler.
16     if (sigaction(SIGCHLD, &signal_handler_struct, NULL)) {
17         fprintf(stderr, "Couldn't register SIGCHLD handler.\n");
18     }
19
20     if (sigaction(SIGHUP, &signal_handler_struct, NULL)) {
21         fprintf(stderr, "Couldn't register SIGHUP handler.\n");
22     }
23
24     // ... rest of your program
25 }

```

11 UNIX Pipes

The unix pipeline redirects the standard output of one program to the standard input of another program.

NOTE in assignment 1 we implemented a MS-DOS style pipe command which is different from what happens in UNIX. MS-DOS, because it could only run one program at a time, would do the following

- Run program A, redirecting stdout to a temporary file A > tmp.txt
- Run program B, redirecting stdin from a temporary file B < tmp.txt
- This would happen seamlessly when the user types A | B

12 Hard Links vs Symlinks

12.1 Hard Links

A hard link can be thought of as a second filename. For example, inode x can have filename blah.txt when it's created, but if I hardlink blah.txt to notblah.txt I'm just updating that inode's record with two names: blah.txt and notblah.txt

Hard linking is done by `ln source dest`. A hardlink appears as a copy of a file, but editing it edits both filenames (since they link to the same inode).

Hard links, because of how they're created, are hard to tell from regular files (since they are also regular files). In the below example I created `file.txt`, and `ass.txt` which hardlinks to `file.txt`

```
$ ls -al
total 8
drwxr-xr-x 1 conner users 30 Oct 12 16:08 .
drwxr-xr-x 1 conner users 52 Oct 12 16:07 ..
-rw-r--r-- 2 conner users 15 Oct 12 16:10 ass.txt
-rw-r--r-- 2 conner users 15 Oct 12 16:10 file.txt
```

Hmm, these appear to be the same. A simple way to tell if a hardlink exists is to look at the **inode** that it corresponds to. This can be done with `ls -li`

```
$ ls -li
total 8
1471517 -rw-r--r-- 2 conner users 15 Oct 12 16:10 ass.txt
1471517 -rw-r--r-- 2 conner users 15 Oct 12 16:10 file.txt
```

Because the inodes for those two files are the same, we know that they are hardlinked together.

12.2 Soft Links

A soft link, or symlink, can be thought of as a pointer to an inode. The difference between a symlink and a hard link is that this **not** another name added to an existing file, rather, it's a new file that points to the inode of another file. This means that the source file has to exist in order for the symlink to be valid.

Symlinks are created by `ln -s source dest`, and `dest` will have a new inode that points to the source file. See below for an example

Here, I created `link` which points to `file.txt`

```
$ ls -al
drwxr-xr-x 1 conner users 24 Oct 12 16:16 .
drwxr-xr-x 1 conner users 52 Oct 12 16:07 ..
-rw-r--r-- 1 conner users 15 Oct 12 16:10 file.txt
lrwxrwxrwx 1 conner users  8 Oct 12 16:16 link -> file.txt
```

We know right away that it's an symlink because of the arrow in `ls`, and we can verify the symlink resides on another inode from `ls -li`

```
$ ls -li
total 8
1471517 -rw-r--r-- 1 conner users 15 Oct 12 16:10 file.txt
1471741 lrwxrwxrwx 1 conner users  8 Oct 12 16:16 link -> file.txt
```

13 Object Files vs Executable Files

When a source file gets compiled, an object file gets created. This object file is mostly ready to be ran, however, there are unresolved references to external libraries that need to be included. After these references have been resolved, we have a binary that's not useless!

14 Process Memory Map

From the lowest to the highest address:

- **Text segment:** contains executable instructions, this is placed below the heap or stack in order to prevent heaps and stack overflows from overwriting it.
- **Initialized data:** above the text segment, contains global variables and static
- **Uninitialized data / BSS:** BSS = block started by symbol. Data in this segment is initialized by the kernel before the program starts executing.
- **Heap:** begins after the BSS segment, grows upwards towards the stack. Data in the heap is managed by malloc et al.
- **Stack:** Sits at a high address, grows down towards the heap. the stack holds automatic variables, and *stack frames* – data about function calls and contexts. In general, we want to use the heap more than the stack because the stack ideally is used for execution-level stuff (frames)

15 Process Creation

Unix processes have PID's, an important concept to grasp in context of the following functions:

- **fork** – creates a child process off of the parent, essentially a clone of the parent that runs alongside it. The UNIX equivalent of getting pregnant.
- **execve** – Executes an arbitrary binary. This executes in the current process, so if one wants a different PID for the binary to be ran the process should be **fork'd** beforehand.
- **exit** – Returns an exit status to the parent process.
- **wait** – Waits for PID to change state.

16 3000Copy Sequence of Operations

In all cases, we perform the following initialization steps:

1. Parse the source and destination args
2. Open the source and dest files, get the file descriptors

16.1 RW Implementation

```
1 done = 0;
2 while (!done) {
3     len = read(source_fd, buf, BUFSIZE);
4     if (len == -1) {
5         report_error("reading source", strerror(errno));
6     }
7
8     if (len > 0) {
9         if (write(dest_fd, buf, len) == -1) {
10             report_error("writing dest", strerror(errno));
11         }
```



```

12         } else {
13             done = 1;
14         }
15     }

```

1. Read in a maximum of BUFSIZE bytes into our buffer, take note of how many bytes we read
2. If we have bytes, write them to the destination file
3. Else we are done! Close file descriptors.

16.2 MMAP Implementation

```

1     len = statbuf.st_size;
2     source_map = (char *) mmap(NULL, len,
3                               PROT_READ, MAP_SHARED, source_fd, 0);
4
5     if (source_map == MAP_FAILED) {
6         report_error("source map", strerror(errno));
7     }
8
9     if (stat(dest_fn, &statbuf) == -1) {
10        printf("%s does not exist, creating\n", dest_fn);
11    } else {
12        printf("%s exists, overwriting\n", dest_fn);
13    }
14
15    //... repeat the above for the dest FD
16
17    printf("Copying bytes...\n");
18
19    for (i = 0; i < len; i++) {
20        dest_map[i] = source_map[i];
21    }

```

1. Open the source and dest file, get the file descriptors.
2. Get the length of the source file. Create a mapping the size of the source file into virtual memory using the FD we got from opening the source file.
3. Get the length of the dest file. Create a mapping of the size of the dest file into virtual memory using the FD we got from opening the dest file.
4. Iterate over the source map, transferring its values to the destination map.
5. Close the file descriptors

17 Assembly RBP, RSP

RBP is the base pointer, and RSP is the stack pointer.

- RSP memory address at the top of the stack
- RBP memory address of any stack frame, moves around the stack.

18 I/O

18.1 File I/O

- `open` / `openat`, the `open` system call opens a file, if the file does not exist it will be created if the `O_CREAT` flag is set.
- `read`, system call to read bits from a file descriptor
- `write`, system call to write bits to a file descriptor
- `lseek`, system call to reposition the file offset of an open file descriptor
 - `lseek` past the end of the file and write for a good time
- `mmap`, map or unmap files into memory, `mmap` creates a mapping into the virtual address space of the calling process.
- `close`, ass.

18.2 Directory I/O

- `opendir/open`, opens a directory, returns a `DIR` stream / struct.
- `readdir/getdents64`, `readdir` is older and is superseded by `getdents64`, used for getting a directories entries.
- `closedir/close` self explanatory.

19 mmap

What is this for??

From what we've used it for, file-backed mapping. If I had a file of size n and I wanted to read it, my general algorithm would be allocate a buffer to read the file, read file, play with file, life is great. However, if my file is size n and my memory is size k where $n > k$, we have a problem.

`mmap` is handy because we never have to `malloc` anything - `mmap` will "map" the file into memory without explicitly reading it. Now, when you play with that memory area `mmaped_file[i]`, those memory operations will **transparently** act on the file. It lets you map files into memory that are larger than the available memory on the system using the OS's available paging mechanism.

There are a few ways of using `MMAP`:

- `PROT_EXEC` – used for loading executable code
- `R/W mmap, shared` – used for writing to and modifying files on disk
- `R/W mmap, private` – used for copying the file into memory and modifying the memory
- `R/W mmap, anonymous + shared` – used for allocating memory that's shared between processes
- `R/W mmap, anonymous + private` – allocate memory to this process.

20 Process Memory Map

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21 DD high level and Syscalls

DD is a advanced file copy utility. It takes an input file from the `if` paramater and writes to an output file given by the `of` paramater

21.1 Syscalls of DD

TODO: Get DD syscall output

22 File Systems

22.1 Filesystem Commands

- `sudo` – you will want to be root in order to mount and unmount filesystems.
- `mount file path` – mounts filesystem at file to path.
- `umount path` – unmounts filesystem at location path.
- `rsync SRC DEST` – advanced copy / sync utility. Uses a delta transfer algorithm to only transfer what is new / updated between the SRC and DEST.
 - `-a` "archive" flag corresponds to `-rlptgoD`
 - `-r` recursive
 - `-l` preserve symlinks
 - `-p` preserve permissions
 - `-t` preserve modification times
 - `-g` preserve group info
 - `-o` preserve owner info
 - `-D` corresponds to `--devices` and `--specials`, which preserve device and special files
- `df` "disk free", gives a report on disk usage. `df -h` is a very common command
- `chown OWNER[:[GROUP]] FILE` changes the ownership and group ownership info of a file, can be used recursively
- `mkfs.ext4` – formats a file with a ext4 filesystem

22.2 Truncate and DD

22.3 Filesystem Holes

22.4 Superblocks

22.5 Logical and Physical

22.6 Userspace Filesystem Restrictions

23 SSH and SSHFS

23.1 Key based Authentication

SSH does support password authentication, but key based authentication is more secure as it utilizes a private/public key combination that is **much** harder to crack than a password.

Generating a public / private key pair is a simple process: run `ssh-keygen`.

todo: add output

23.1.1 Transferring the Hard Way

Anil likely wanted us to do it the "hard way" so we see how key based auth is set up. It is **not** how anybody should do this in practice

```
# Append our public key to a file called authorized keys
$ cat ~/.ssh/id_rsa.pub >> authorized_keys
# Move the authorized keys file to other@localhost's home directory
$ scp authorized_keys other@localhost:.
# Delete our copy of authorized keys file
$ rm authorized_keys
```

Then as the other user

```
# Log in as the other user over ssh
$ ssh other@localhost
# Make an ssh config directory
$ mkdir ~/.ssh
# Make the directory private
$ chmod 700 ~/.ssh
# Move the authorized keys file to .ssh
$ mv ~/authorized_keys ~/.ssh
# Make the authorized keys file private
$ chmod 600 ~/.ssh/authorized_keys
```

Some problems with this approach: we overwrite the authorized keys file on the client side, we should be appending to the client's authorized keys file.

23.1.2 Transferring The Easy Way

After making a key, just use `ssh-copy-id user@host` to copy your key to some user at some host.

23.2 SSHFS Performance

Slow. Because of the encryption ssh uses, the performance is going to be decently bad compared to other networked filesystems like nfs and samba.

23.3 SSHFS inodes

SSHFS abstracts inodes, so the inodes that would be displayed on the actual client FS would be different than those displayed over sshfs.

24 eBPF

BPF, for Berkeley Packet Filter, is a technology used to monitor network traffic. eBPF is an *extended* BPF, it can be used beyond tracing network traffic and is able to trace pretty much anything at the kernel level.

24.1 eBPF internals

eBPF is a framework that lets us write small programs that get injected into the kernel and respond to certain events (disk IO, syscalls, etc). Think of eBPF acting on linux like JavaScript acting on HTML. JS lets us attach event listeners to a variety of HTML elements and respond on events, we can rewrite the HTML DOM using JS, we can do all sorts of stuff to monitor and manipulate the underlying webpage. The interpreter that powers JS is similar to eBPF, not in how it works but what it enables us to do.

You could also write kernel modules to accomplish what eBPF is doing, however modules are complicated, eBPF is much safer since it runs in a virtual machine (see more on this below), and eBPF abstracts away alot of the complexity meaning using it is much easier.

eBPF security: the BPF does not have a way to load code into the kernel. eBPF's solution to loading arbitrary code in the kernel is to use a bytecode (interpreted) language that gets compiled on runtime in the kernel – this is similar to how Java and the JVM works. eBPF also has a sanity verifier that sanity tests whatever you pass to it.

[Great resource if you want more info](#)

24.2 Trace Command

TODO: make some spicy examples

Sample Questions

1. What system call is used to load a program binary in Linux? Does this system call create a new process?
`execve`, and no – `fork` is used to create a process.
2. Dynamically linked programmes generally make many `mmap` calls at the start of program execution that a statically linked version of the program doesn't do. What are those `mmap` system calls for?
Because the program is *dynamically linked* the `mmap` calls are to map libraries into the process's address space
3. Symbolic links map filenames to filenames. What do hard links map filenames to?
`inodes`
4. What are two standard uses of signals in Linux? Do not list application specific signals like `SIGUSR1`
Some examples that can be used are `SIGTERM`, `SIGKILL`, `SIGINT`, `SIGCHILD`.
`SIGINT` – keyboard interrupt, `SIGTERM` – termination signal, `SIGKILL` – kill signal (most deadly), `SIGCHILD` – child stopped or terminated.
5. Do pointers in C contain virtual or physical addresses? Why?
Pointers contain virtual addresses, because the kernel abstracts the physical memory and users only have access to virtual memory
6. Does a process make a system call to allocate memory? Why?
A process must make a system call like `mmap()` in order to allocate memory. Memory is a physical resource, and the kernel controls all system resources, including the virtual-to-physical mapping of memory address spaces. Because of all of this a system call has to be made, since system calls are how we talk to the kernel.
7. At the prompt of a shell, a user types `something > output.txt`. What programs the file `output.txt` – the `shell`, or `something`? Why?
`shell` opens `output.txt`. The shell will parse the prompt string, get the filename, open the file and gets a file descriptor for it.
After forking, the child process that shell forked will replace its own file descriptor for `STDOUT` with the output file's FD with a function like `dup2()`. Finally, the child process will `execve something` and then the modified FD for `STDOUT` will persist through the call to `execve()`
`execve()` preserves file descriptors so a running program can do I/O in a generic way that allows programs to be combined together into larger solutions.
8. Is it possible for two or more filenames to refer to the same inode? Explain.
HARD. LINK.
9. How can a process send a signal?
By using the `kill` system call.
10. How can a process change what happens when a signal is received?
By registering a signal handler for a particular signal, this is done with a `sigaction` system call.
11. Can a process change what happens when any signal is received?
No, some signals such as `KILL` and `STOP` have predefined signal handlers that can't be overwritten.
12. When a process receives a signal, what happens to the function that the process was already running?
The function is paused and its execution context is pushed onto the function call stack, the signal handler fucks shit up, and it resumes from where it left off once the signal handler finishes.
13. Consider the following code from `3000shell`:

```
1 if (background) {  
2     fprintf(stderr, ``running in background``);  
3 } else {  
4     pid = wait(&ret_status);  
5 }
```

- (a) What does 3000shell.c call before this in order to create a child process?
`fork()`
- (b) What does the call to `wait()` above do?
It waits for the child process to exit, it returns the PID that exited, and `ret-status` is a variable being passed-by-reference, so if the return status is non-null `wait` will put it into the `ret_status` variable
- (c) When does 3000shell also call `wait()`?
It also calls `wait` in the `SIGCHLD` signal handler. The kernel sends 3000shell a `SIGCHLD` signal when a child process terminates. The signal handler code is necessary to take care of background processes (i.e., prevent them from becoming zombies).
- (d) Does the process that executes the above code also run the program the user has typed in at the command prompt? Explain briefly.
It does not. The above code runs in the main 3000shell process. Commands are `execve`'d in child processes. Only the child processes can call `execve` because otherwise 3000shell would effectively terminate by running `execve`.

14. `MMAP` is declared as follows:

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

- (a) At a high level, what does `mmap` do?
`mmap` associates (or maps) the contents of a file with a range of memory addresses without reading the entire file into memory – very cool stuff! If we don't specify a file it will just allocate us memory to fap around with.
- (b) What's the difference between setting flags to be `MAP_SHARED` versus `MAP_PRIVATE` in the context of child processes?
With `MAP_SHARED`, all child processes will share the same memory, changes made by one will be visible to all. Also, if a file descriptor was specified, its contents will be changed when the corresponding memory is changed. With `MAP_PRIVATE`, all changes to memory are private. Every process has its own unique copy (with its contents being copied on fork like all other regular memory). Further, the opened file is not changed to reflect the changes to the mapped copy.
- (c) If we open a file and `mmap` it, setting `prot=PROT_READ`—`PROT_WRITE` and `flags=MAP_PRIVATE`, can we modify the memory that is returned by `mmap`? If we modify this memory, will it modify the file as well? Explain briefly.
If we set `PROT_READ` and `PROT_WRITE`, we can indeed modify the returned memory. Any changes, however, will be private if `MAP_PRIVATE` is specified, so the opened file will not be changed; the initial contents of memory will be the same as the file, but subsequent changes will be private to the process.