Lab 1 - Observing Process Behaviour

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1 Introduction

This lab introduces fundamental operating system concepts by introducing the `/proc` directory – a virtual filesystem that provides access to process states.

2 Objectives

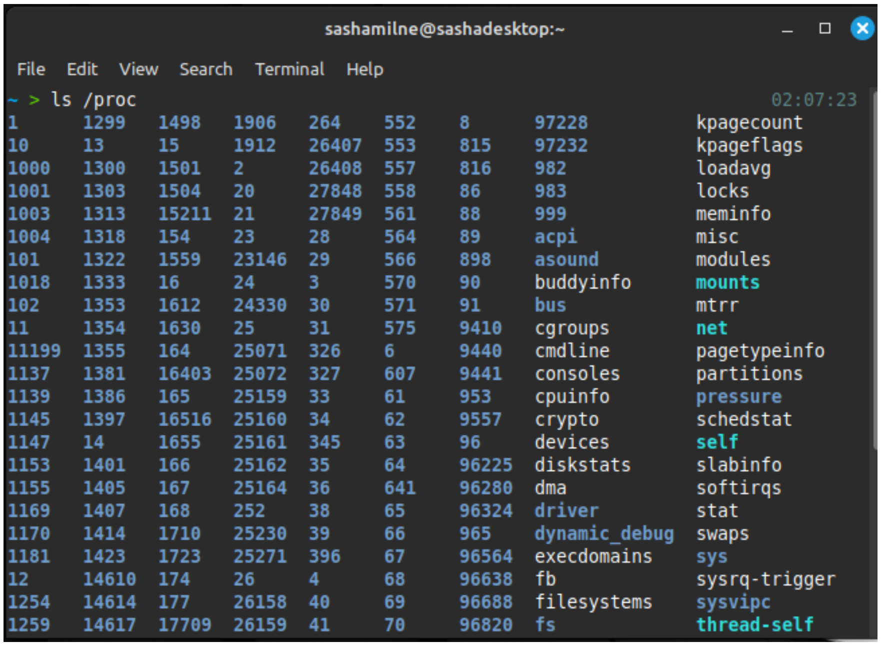
The goals of this lab are as follows:

1. **Process Monitoring via `/proc`:** To examine how a process executes and changes via the `/proc` virtual filesystem by directly inspecting its contents using CLI programs such as `cat`.
2. **Executing POSIX System Calls in C:** To develop and test simple C programs that demonstrate the use of `fork()` and `exec()` system calls for process creation and control.

3 Methodology

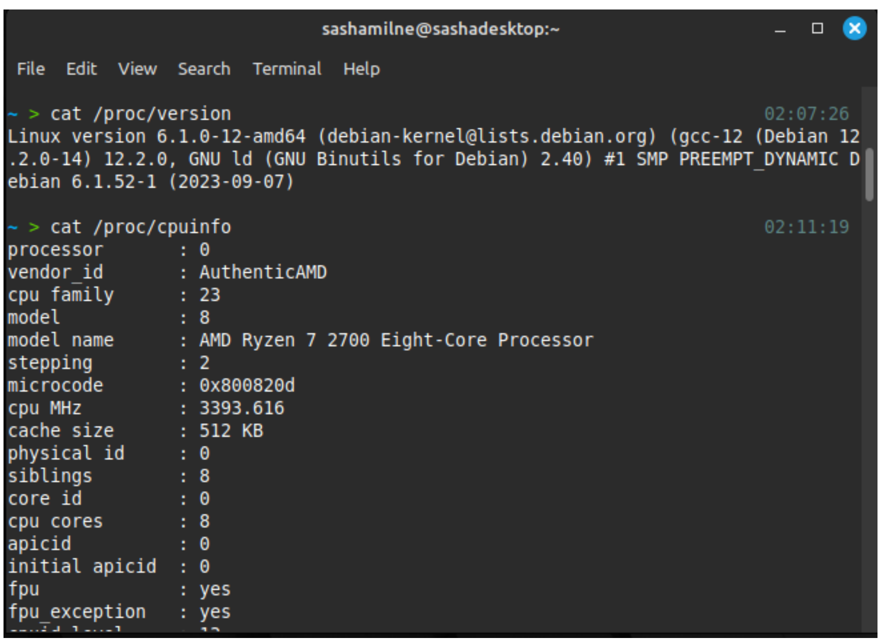
3.1 Initial Setup & Basic Exploration

Since a Linux environment is needed to explore the `/proc` filesystem and for POSIX compliance, the first step was to install a Virtual Machine (VM) and a Linux ISO to run on it. I already had an installation of Debian set up on my PC, so I used this as my testing environment.
I then used basic CLI tools to explore the `/proc` filesystem.



```
sashamilne@sashadesktop:~
File  Edit  View  Search  Terminal  Help
~ > ls /proc                                                    02:07:23
1      1299  1498   1906   264    552  8      97228          kpagecount
10     13    15     1912   26407  553  815    97232          kpageflags
1000   1300  1501   2      26408  557  816    982            loadavg
1001   1303  1504   20     27848  558  86     983            locks
1003   1313  15211  21     27849  561  88     999            meminfo
1004   1318  154    23     28     564  89     acpi           misc
101    1322  1559   23146  29     566  898    asound         modules
1018   1333  16     24     3      570  90     buddyinfo      mounts
102    1353  1612   24330  30     571  91     bus            mtrr
11     1354  1630   25     31     575  9410   cgroups        net
11199  1355  164    25071  326    6    9440   cmdline        pagetypeinfo
1137   1381  16403  25072  327    607  9441   consoles       partitions
1139   1386  165    25159  33     61   953    cpuinfo        pressure
1145   1397  16516  25160  34     62   9557   crypto         schedstat
1147   14    1655   25161  345    63   96     devices        self
1153   1401  166    25162  35     64   96225  diskstats      slabinfo
1155   1405  167    25164  36     641  96280  dma            softirqs
1169   1407  168    252    38     65   96324  driver         stat
1170   1414  1710   25230  39     66   965    dynamic_debug  swaps
1181   1423  1723   25271  396    67   96564  execdomains    sys
12     14610 174    26     4      68   96638  fb             sysrq-trigger
1254   14614 177    26158  40     69   96688  filesystems    sysvipc
1259   14617 17709  26159  41     70   96820  fs             thread-self
```

Figure 1: Exploring `/proc` using `ls`



```
sashamilne@sashadesktop:~
File  Edit  View  Search  Terminal  Help

~ > cat /proc/version                                           02:07:26
Linux version 6.1.0-12-amd64 (debian-kernel@lists.debian.org) (gcc-12 (Debian 12
.2.0-14) 12.2.0, GNU ld (GNU Binutils for Debian) 2.40) #1 SMP PREEMPT_DYNAMIC D
ebian 6.1.52-1 (2023-09-07)

~ > cat /proc/cpuinfo                                           02:11:19
processor       : 0
vendor_id       : AuthenticAMD
cpu family      : 23
model           : 8
model name      : AMD Ryzen 7 2700 Eight-Core Processor
stepping        : 2
microcode       : 0x800820d
cpu MHz         : 3393.616
cache size      : 512 KB
physical id     : 0
siblings        : 8
core id         : 0
cpu cores       : 8
apicid          : 0
initial apicid  : 0
fpu             : yes
fpu_exception   : yes
```

Figure 2: Further exploration of `/proc` using `cat`

In *Figure 1*, the CLI output of `ls /proc` can be observed. This command lists all the contents of the `/proc` directory to `stdout`. Each folder with a number contains information about a process referenced by its Process ID (PID). There are other miscellaneous files which contain critical system info which can be observed.
In *Figure 2*, two such files are examined, `version` and `cpuinfo`, using `cat`. Here, information

is displayed onto the CLI about what version of `proc` is being used and information about the CPU. For example, I allocated 8 of my 16 threads in my Ryzen 7 2700, and we can observe the system seeing 8 CPU cores available.

3.2 Finding Process Info

The goal of the next activity was to find the PID of the shell and explore its process status. We used `bash` as the shell and `ps` to get the PID.

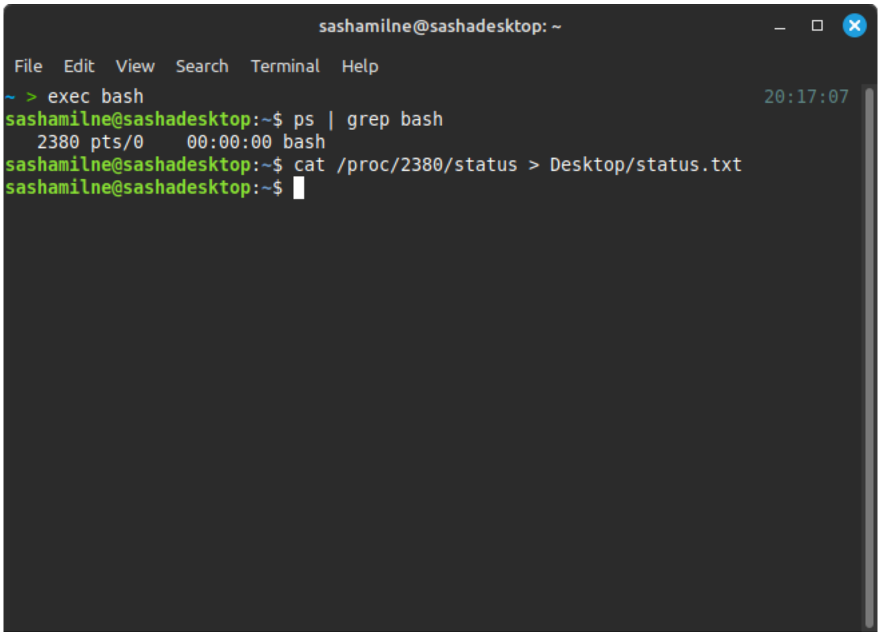


Figure 3: Finding the PID of the shell and getting its status

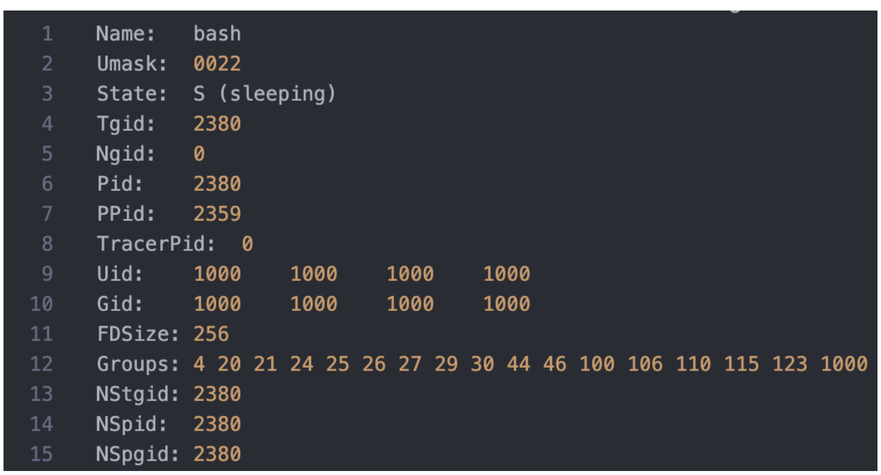


Figure 4: Viewing the output file

In *Figure 3*, the shell PID is obtained using `ps`. We then output the contents of `/proc/PID/status`, redirecting it into status.txt. The full contents of this file can be found in `logs/status.log`, however, a screenshot is provided in *Figure 4*. From this figure, we can see that the process was sleeping at the time of execution of `cat` along with many other details.

3.3 Preparing Experiments & Understanding Tools

The goal of this section is to explore the state changes of processes using specially created programs. Using the provided `lab1.tar`, we will launch and observe other, more interesting programs.

Figure 5: Extracting lab1 tar file

After extracting the contents of `lab1.tar`, I moved everything to my workspace directory and reorganized the project structure for neatness. Inside the `lab1` directory, there are three compiled binaries: `procmon`, `calcloop`, and `cploop`.

3.3.1 Analysis of Binaries

The purpose of the `procmon` program is to monitor the status of a process given its PID. The program accepts an argument `PID` which it then monitors using the `proc` filesystem.

`cploop` is a program that creates a file named *fromfile* containing 500 thousand `"x"` characters and runs ten iterations of a loop that sleeps for 10 seconds and copies the contents of *fromfile* to a new file named *tofile*.

`calcloop` is a program that runs 10 iterations of a loop that sleeps for 3 seconds then increments a variable 400 million times

3.4 Running Provided Scripts

The next step is to run the scripts `tstcalc` and `tstcp` provided in the `lab1` directory. I moved the scripts to a `scripts` subdirectory and slightly modified the scripts to output the log files to a `logs` subdirectory for cleanliness.

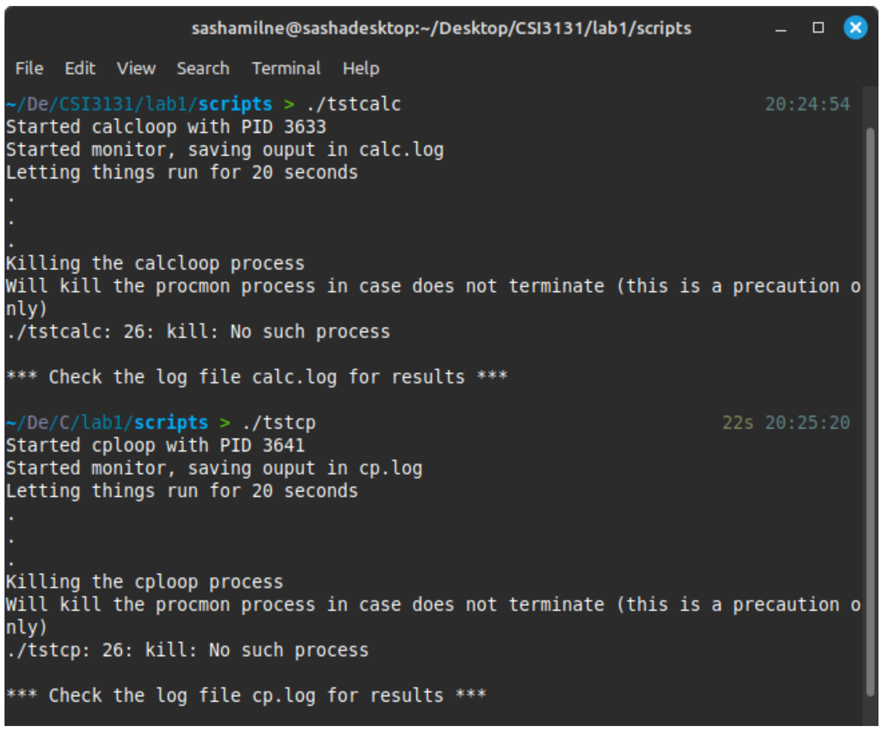


Figure 6: Running tstcalc and tstcp

Figure 7: Confirming generation of `log` files using `ls`

I forgot to take screenshots of the verification that the `log` files were generated using `ls`, so I had to do it after the fact using a cloned version of `lab1` on my Macbook Air, which is why the filepaths are not consistent.

3.5 Programming mon.c

The program `mon.c` is intended to take the name of another program as an argument. Using this argument, it launches the other program and monitors it using procmon. The first challenge of this spec was to convert the relative path passed in through `argv` to an absolute path accessible by `execlp`.

```c
    const char* program = argv[1];

    char path[PATH_MAX];
    ssize_t len = readlink("/proc/self/exe", path, sizeof(path) - 1);
    if(len == -1)
    {
        perror("readlink");
        exit(EXIT_FAILURE);
    }
    path[len] = '\0';


    char* last_slash = strrchr(path, '/');
    if(last_slash != NULL)
    {
        *(last_slash+1) = '\0';
    }


    char program_path[PATH_MAX];
    char procmon_path[PATH_MAX];

    snprintf(program_path, sizeof(program_path), "%s%s", path, program);
    snprintf(procmon_path, sizeof(procmon_path), "%s%s", path, "procmon");
```

Figure 8: Finding the absolute path

```c
    // 1. launch the program specified by the variable 'fileName' and get its pid
    pid_t child_pid = fork();

    if (child_pid == 0) {
        execlp(program_path, program, NULL);
        perror("Failed to exec program");
        exit(-1);
    }

    if (child_pid < 0) {
        perror("Failed to fork");
        exit(-1);
    }

    // 2. launch 'procmon pid' where pid is the pid of the program launched in step 1
    char pid_str[20];
    sprintf(pid_str, "%d", child_pid);

    pid_t procmon_pid = fork();
    if (procmon_pid == 0) {
        execlp(procmon_path, "procmon", pid_str, NULL);
        perror("Failed to exec program");
        exit(-1);
    }
    if (procmon_pid < 0) {
        perror("Failed to fork");
        exit(-1);
    }
```

Figure 9: Starting `program` and `procmon` processes

Figure 9 demonstrates the usage of `fork` and `exec` to start new processes. `Fork` creates a copy of the existing process (child process) and returns the PID of the child in the parent process while returning 0 for the child process. `Exec` replaces the existing process with a new one. Using these two functions, we can start two new processes, `procmon` and the process given in `argv[1]`

3.6 Compiling mon.c

When it comes to compiling from source in C, I believe it is almost always worth the effort to create a `Makefile` instead of manually calling `gcc` everytime you want to compile a binary. I also took the time to reorganize the project structure for cleanliness.

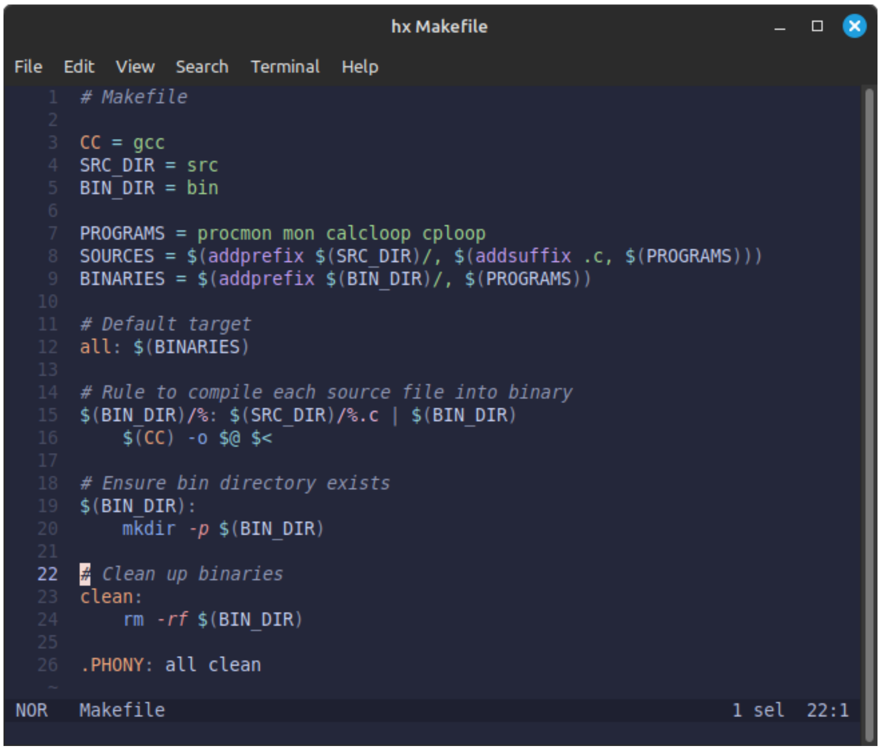


Figure 10: Creating a Makefile to automate compilation process

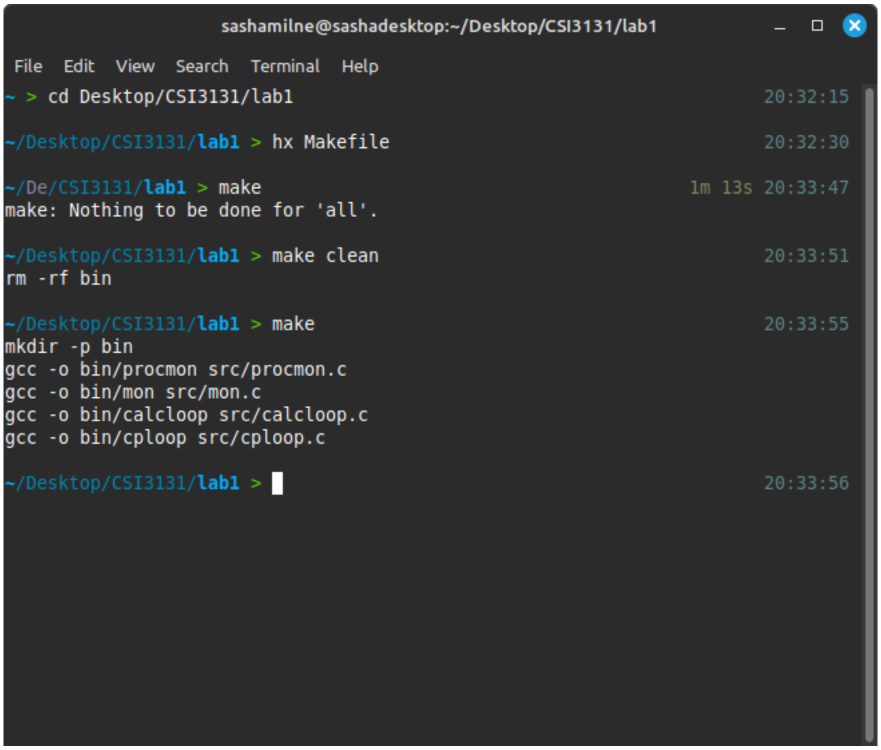


Figure 11: Running Makefile to recompile binaries

As demonstrated in *Figure 9*, the result is the same as manually calling `gcc -o bin/mon src/mon.c` except it is cleaner and more organized.

4 Results

4.1 Analysis of Log Files

4.1.1 calc.log

```

        Monitoring /proc/3633/stat:

Time        State           SysTm    UsrTm
  0     Sleeping(memory)      0        0
  1     Sleeping(memory)      0        0
  2     Sleeping(memory)      0        0
  3     Running               0        0
  4     Sleeping(memory)      0       89
  5     Sleeping(memory)      0       89
  6     Sleeping(memory)      0       89
  7     Running               0      108
  8     Sleeping(memory)      0      177
  9     Sleeping(memory)      0      177
 10     Sleeping(memory)      0      177
 11     Running               0      225
 12     Sleeping(memory)      0      266
 13     Sleeping(memory)      0      266
 14     Sleeping(memory)      0      266
 15     Running               0      333
 16     Sleeping(memory)      0      355
 17     Sleeping(memory)      0      355
 18     Sleeping(memory)      0      355
 19     Running               0      440
procmon: Cannot open /proc/3633/stat, the monitored process is not running any more.
```

Figure 12: Output of calc.log

The output of this log file shows a pattern of the process sleeping for three seconds and then running for one. This follows the behaviour of the code exactly as `calcloop` is programmed to sleep for three seconds before each iteration. `SysTm` stays at 0 for the entirety of the execution which is also expected as the program does not operate in kernel mode at any point. Finally, we see fairly intensive increases in `UsrTm` when the program is running. This is due to CPU-intensive looping (400 million increments) each iteration which uses exclusively user-space computation.

4.1.2 cp.log

```

        Monitoring /proc/7005/stat:

Time        State           SysTm    UsrTm
  0     Running               0        0
  1     Sleeping(memory)      0        0
  2     Sleeping(memory)      0        0
  3     Running               0        0
  4     Sleeping(memory)     30       11
  5     Sleeping(memory)     30       11
  6     Sleeping(memory)     30       11
  7     Sleeping(memory)     65       19
  8     Sleeping(memory)     65       19
  9     Sleeping(memory)     65       19
 10     Running              87       23
 11     Sleeping(memory)     99       27
 12     Sleeping(memory)     99       27
 13     Sleeping(memory)     99       27
 14     Sleeping(memory)    130       38
 15     Sleeping(memory)    130       38
 16     Sleeping(memory)    130       38
 17     Sleeping(memory)    161       49
 18     Sleeping(memory)    161       49
 19     Sleeping(memory)    161       49
procmon: Cannot open /proc/7005/stat, the monitored process is not running any more.
```

Figure 13: Output of cp.log

4.2 Testing mon.c

The output of this process shows

5 Discussion

Interpret your results. Compare with theoretical expectations. Explain discrepancies.

6 Conclusion

References

- Author, *Title*, Journal Name, Year.
- Author, *Title*, Book Name, Publisher, Year.