Processes

processes practice for CSC420 Operating Systems Spring 2024 Lyon College

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README

- This file accompanies lectures on the shell and `bash(1)`. To gain practice, you should type along in your own Org-mode file. You have to have Emacs and my `.emacs` file installed on your PC or the Pi you're working with.

- This section is based on chapter 10 of Shotts, The Linux Command Line (2e), NoStarch Press (2019).

- To make this easier, use the auto expansion (`<s`). This will only work if you have my `.emacs` file (from GDrive) installed.

- Add the following two lines at the top of your file, and activate each line with `C-c C-c` (this is confirmed in the echo area as `Local setup has been refreshed`)):

  ```
  #+PROPERTY: header-args:bash :results output
  ```

- Remember that `C-M-\` inside a code block indents syntactically (on Windows, this may only work if you have a marked region - set the mark with `C-SPC`).

Overview

- Modern operating systems are *multitasking*, which means they create an illusion of doing more than one thing at once.

- They do this by rapidly switching from one executing program to another.
- The **kernel** manages this through clever **process management**, which really is clever **memory management**.
- This is illustrated in the figure 1. The simple program is all over the computer's memory.

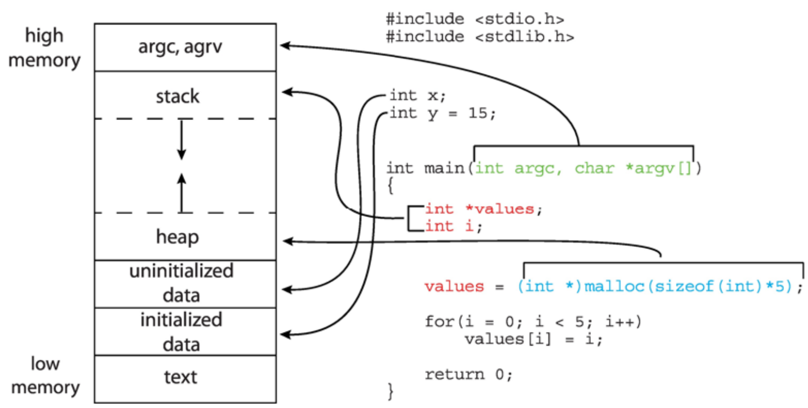


Figure 1: Memory Layout of a C Program (Source: Silberschatz et al)

- The diagram illustrates the typical memory layout of a process in a C program:
    1. **High Memory to Low Memory:** The top represents high memory addresses and the bottom low memory addresses in the process's address space.
    2. **Text:** Contains the compiled code of the program (`.out`).
    3. **Uninitialized Data:** Holds uninitialized global and static variables (values unknown at start) - `int x;`
    4. **Initialized Data:** Contains initialized global and static variables - `int y = 15;`
    5. **argc, argv:** Located on the stack; used to pass command-line arguments into the program. `argc` is the argument count, and `*argv[]` is an pointer array of argument strings.

6. **Stack:** Used for function call management; contains local variables and function parameters - `int *values` (pointer to `values`), `int i`.
7. **Heap:** For dynamically-allocated memory during runtime - `malloc` allocates memory for 5 integers, assigned to `values`.

x

- As always, let's focus on stuff we can do ourselves. This includes a bunch of new shell commands:

COMMAND	MEANING
`ps`	Report a snapshot of current processes
`top`	Display tasks
`jobs`	List active jobs
`bg`	Place a job in the background
`fg`	Place a job in the foreground
`kill`	Send a kill signal to process
`killall`	Kill processes by name
`shutdown`	Shut down or reboot the system

How a process works

- When the OS starts up, the **kernel** launches the `init` program, which in turn runs a series of shell scripts (in `/etc`) that start all the system services.
- Check `/etc` out now - you find e.g. the directory `/etc/cups`, which contains scripts for the Common UNIX Printing System (CUPS).
- Many of the services are *daemon* programs - they just sit in the background and do their thing without a user interface (UI).
- `init` itself is a `daemon`, also called `systemd`. The shell program `systemctl` allows indirect access to all services.
- **Grab a daemon!**

  In the code block **??**,

  1. run the command `systemctl status`,
  2. `tee` its output to a text file `systemctl.txt`

3. `grep` for the login daemon program `logind`

```
systemctl status | tee systemctl.txt | grep logind
```

```
       86093 grep logind
  systemd-logind.service
    874 /lib/systemd/systemd-logind
```

- If a program (like `init`) can launch other programs, it's a *parent process* producing a *child process*.
- **How does the kernel maintain control?** By assigning a *process ID* (PID) to every process.
- Processes are assigned in ascending order beginning with `init`, which has PID 1.
- Processes are assigned in ascending order beginning with `init`, which has PID 1: run `px ax`, `grep` for `init`, and print the first line:

```
ps ax | grep init | head -n 1
```

```
1 ?        Ss     0:05 /sbin/init splash
```

- The **kernel** also tracks process memory and readiness to resume execution. Like files, processes have owners and userIDs.

Viewing processes statically

- The `ps` program has a lot of options (check `ps(1)`)
- Run `ps` without options.

```
ps | head -n 10
```

```
 PID TTY          TIME CMD
1313 ?        00:00:00 systemd
1314 ?        00:00:00 (sd-pam)
1323 ?        00:00:00 pipewire
1324 ?        00:47:15 pulseaudio
```

```
1325 ?        00:00:01 cinnamon-sessio
1343 ?        00:00:04 dbus-daemon
1541 ?        00:00:01 gnome-keyring-d
1552 ?        00:00:03 csd-media-keys
1553 ?        00:00:00 at-spi-bus-laun
```

- The result is confusing because you're inside another program now.
- Open a shell (in Emacs with `M-x shell` or a terminal) and type `ps`. You should see something like this:

```
  PID TTY          TIME CMD
12254 pts/1    00:00:00 bash
12257 pts/1    00:00:00 ps
```

- **What this means:**
  - You see two `PID` - the shell program and the `ps` program
  - `TTY` ("teletype") is the *controlling terminal* for the process
  - `TIME` is the amount of CPU time consumed by the process
- Run `ps` again, this time add the option `x`

```
ps x | head -n 10
```

```
 PID TTY      STAT   TIME COMMAND
1313 ?        Ss     0:00 /lib/systemd/systemd --user
1314 ?        S      0:00 (sd-pam)
1323 ?        S<sl   0:00 /usr/bin/pipewire
1324 ?        S<sl  47:15 /usr/bin/pulseaudio --daemonize=no --log-target=journal
1325 ?        Ssl    0:01 cinnamon-session --session cinnamon
1343 ?        Ss     0:04 /usr/bin/dbus-daemon --session --address=systemd: --nofo
1541 ?        SLl    0:01 /usr/bin/gnome-keyring-daemon --start --components=pkcs1
1552 ?        Sl     0:03 csd-media-keys
1553 ?        Sl     0:00 /usr/libexec/at-spi-bus-launcher --launch-immediately
```

- `ps x` (no dash!) shows all processes regardless of what terminal they are controlled by. `?` indicates no terminal (like daemons).
- How many processes that you own that have no terminal?

```
ps x | grep ? | wc -l
```

```
112
```

- List only the first 5 lines of the `ps x` listing.

```
ps x | head -5
```

```
 PID TTY      STAT   TIME COMMAND
1313 ?        Ss     0:00 /lib/systemd/systemd --user
1314 ?        S      0:00 (sd-pam)
1323 ?        S<sl   0:00 /usr/bin/pipewire
1324 ?        S<sl  47:15 /usr/bin/pulseaudio --daemonize=no --log-target=journal
```

- The column `STAT` reveals the current status of the process, see table .

STATE	MEANING
R	Running or ready to run
S	Sleeping, waiting for an event (e.g. keystroke)
D	Uninterruptible sleep, waiting for I/O (e.g. disk)
T	Stopped, received instruction to stop
Z	Zombie child process, abandoned by parent
$<$	High priority (not *nice* - more CPU time)
N	Low priority (*nice*) - served once $<$ are done

There may be more characters denoting exotic process characteristics (see `ps(1)`). E.g. `s` is a *session leader*, `+` is a *foreground* process, and `l` is multi-threaded.

- Check if you have any running processes (`R`) or Zombie processes (`Z`):

```
ps x | grep -cE [RZ]
```

```
6
```

- You get even more information with the option `aux`. Redirect the output of `ps aux` to a file `psaux.txt`, and print only the first 5 lines.

```
ps aux  | tee psaux.txt | head -5
```

```
USER         PID %CPU %MEM    VSZ   RSS TTY      STAT START   TIME COMMAND
root           1  0.0  0.1 166500  8892 ?        Ss   Apr19   0:05 /sbin/init spla
root           2  0.0  0.0      0     0 ?        S    Apr19   0:00 [kthreadd]
root           3  0.0  0.0      0     0 ?        I<   Apr19   0:00 [rcu_gp]
root           4  0.0  0.0      0     0 ?        I<   Apr19   0:00 [rcu_par_gp]
```

- You should see `PID 1`, the `init` program. The `splash` options means that you can see a splash screen during boot.
- Table shows some header definitions

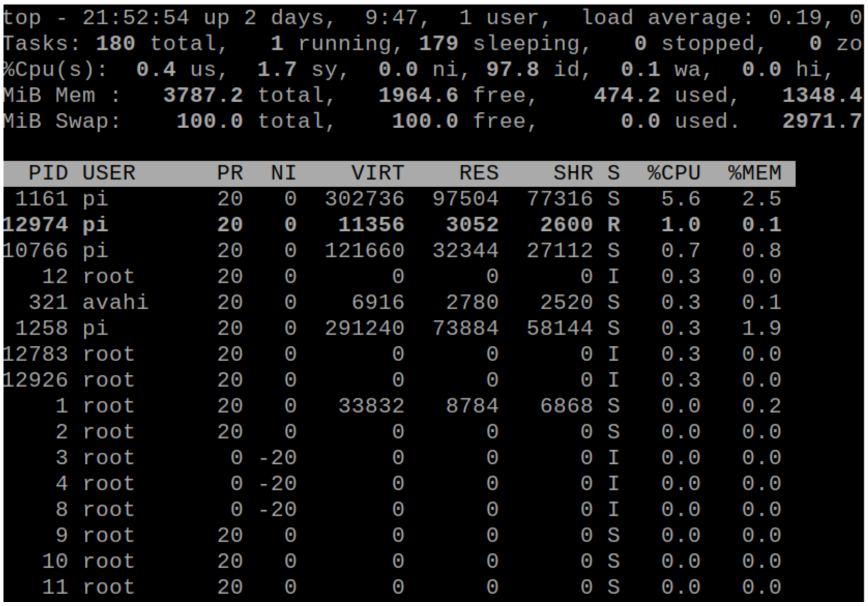
HEADER	MEANING
USER	User ID - this is the process owner
%CPU	CPU usage in percent
%MEM	Memory usage in percent
VSZ	Virtual memory size (kB)
RSS	Resident set size - RAM use in kB
START	Process starting time and date

- Why is the CPU usage of `init` zero, while the Memory usage is non-zero? How much RAM does the program actually use?

  ANSWER: The `init` program only runs during the booting process, but as part of the **kernel** it is loaded into the central memory. It occupies 8MB.

Viewing processes dynamically

- `ps` provides a snapshot, but `top` provides a real-time view.
- Open a terminal (in or outside of Emacs) and run `top`. You can stop the command with `C-c` or `q`.
- `top` refreshes every three seconds and shows the top system processes. It includes a summary at the top and a table sorted by CPU activity at the bottom.
- The system summary contains a lot of good stuff. Table gives a rundown.
- `top` accepts some keyboard commands like `h` (help) and `q` (quit).



```
top - 21:52:54 up 2 days,  9:47,  1 user,  load average: 0.19, 0
Tasks: 180 total,   1 running, 179 sleeping,   0 stopped,   0 zo
%Cpu(s):  0.4 us,  1.7 sy,  0.0 ni, 97.8 id,  0.1 wa,  0.0 hi,
MiB Mem :   3787.2 total,   1964.6 free,    474.2 used,   1348.4
MiB Swap:    100.0 total,    100.0 free,      0.0 used.   2971.7

  PID USER      PR  NI    VIRT    RES    SHR S  %CPU  %MEM
 1161 pi        20   0  302736  97504  77316 S   5.6   2.5
12974 pi        20   0   11356   3052   2600 R   1.0   0.1
10766 pi        20   0  121660  32344  27112 S   0.7   0.8
   12 root      20   0       0      0      0 I   0.3   0.0
  321 avahi     20   0    6916   2780   2520 S   0.3   0.1
 1258 pi        20   0  291240  73884  58144 S   0.3   1.9
12783 root      20   0       0      0      0 I   0.3   0.0
12926 root      20   0       0      0      0 I   0.3   0.0
    1 root      20   0   33832   8784   6868 S   0.0   0.2
    2 root      20   0       0      0      0 S   0.0   0.0
    3 root       0 -20       0      0      0 I   0.0   0.0
    4 root       0 -20       0      0      0 I   0.0   0.0
    8 root       0 -20       0      0      0 I   0.0   0.0
    9 root      20   0       0      0      0 S   0.0   0.0
   10 root      20   0       0      0      0 S   0.0   0.0
   11 root      20   0       0      0      0 S   0.0   0.0
```

Figure 2: Top view

ROW	FIELD	MEANING
1	top	Program name
	21:52:54	Current time of day
	up 2 days 9:49	*uptime* since last boot
	1 user	No. of users logged in
	load average	No. of processes waiting to run
		Values $<$ 1.0 means not busy
2	Tasks:	No. of processes and their states
		total, running, sleeping, stopped
3	Cpu(s):	Activities that the CPU performs:
		us: user processes (not kernel)
		sy: system processes (kernel)
		ni: nice (low prio) processes
		id: idle processes
		wa: waiting for I/O
4	Mem:	Physical RAM used
5	Swap:	Swap space (virtual memory) used

- `top` is better than any graphical application (e.g. the Task Manager that you have on your Pi) - it is faster and consumes far less resources.

Controlling processes

Interrupting a process

- As a guinea pig program, we use `emacs`.
- Open a terminal (inside Emacs after splitting the screen with `C-x 2` or outside of Emacs), and enter `emacs` at the prompt. A new Emacs editor window appears. Notice that the terminal prompt does not return.
- Close the new Emacs editor manually by clicking on the `X` in the upper right corner. The prompt in the Shell returns.
- Enter `emacs` again in the shell, and interrupt it with CTRL-C (outside of Emacs, or with `C-c C-c` on the Emacs `*shell*`).
- Many programs can be interrupted this way by sending an **interrupt** signal to the **kernel**.

Putting a process in the background

- The terminal has a *foreground* and a *background*. To launch a program so that it is immediately placed into the background, follow it with an ampersand `&` character
- Start Emacs from the shell in the background. An Emacs window should open. Look at the terminal.
- The message that appeared is part of shell *job control*. It means that we have started job number 1 with the PID 13899. If you check the process table with `ps`, you should see the process

  ```
  [1] 13899
  ```

- `grep` the `emacs` process from the process table using the PID.

  ```
  13928 pts/1    00:00:04 emacs
  ```

- The `jobs` command lists the jobs that were launched from our terminal. Try it. You should see something like this:

```
[1]+  Running                 emacs &
```

Returning a process to the foreground

- A process in the background is immune from keyboard input - you cannot interrupt it with `CTRL-C`. To return it to the foreground, use the `fg` command.
- On the shell where you started it, return the process to the foreground with the command `fg %1`. The `1` is the `jobspec`.
- Kill the Emacs process with `C-c C-c` or `CTRL-C` on the shell where you started it.
- If you enter `jobs` you get no response, and `fg` tells you there's no job.

Stopping or pausing a process

- Start an `emacs` process in a terminal (NOT in an Emacs shell) - it's now in the foreground. If you press `CTRL-z` in the shell, the process is stopped.

```
pi@raspberrypi:~ $ emacs
^Z
[1]+  Stopped                 emacs
pi@raspberrypi:~ $
```

- To bring the process back, you can either bring it into the foreground with `fg %1`, or resume the process in the background with `bg %`. Try both.
- **Why would you launch a graphical program from the shell?**
  - The program may not be listed in the GUI
  - You see error messages that otherwise are invisible
  - Some graphical programs have useful command line options

Killing a process

- `kill` is used to terminate processes using the PID. Start Emacs from the shell *in the background* (inside or outside of emacs), and then kill it with `kill PID`.

  Tip: you get the PID with `ps`*, or right after executing the background command.*

- `kill` does actually not "kill" the process, it sends it a signal. We have already used some of these signals:

SIGNAL	MEANING
INT	CTRL-C - interrupt process
TSTP	CTRL-Z - terminal stop
HUP	Hang up (used by daemons)
KILL	Kill without cleanup
TERM	Terminate with `kill`
STOP	Stop without delay

- Some of these signals are sent to the target program (identified by PID) while others are sent straight to the kernel.

More process commands

Some fun commands to play with and explore. We already looked at `pstree`. You may have to install these.

COMMAND	MEANING
pstree	Process list arranged as tree pattern
vmstat	System usage snapshot
xload	Draws a graph showing system load over time
tload	Draws graph in terminal

Summary

- Multitasking by rapidly switching tasks, managed by the kernel.
- Memory layout in processes includes compiled code, initialized/uninitialized data, stack, and heap.

- Useful shell commands for process management: `ps`, `top`, `jobs`, `bg`, `fg`, `kill`, `shutdown`.
- Kernel starts with `init` program to launch system services.
- Services typically run as background daemons, managed via `systemctl`.
- Processes are tracked via Process IDs (PID).
- Snapshot of processes using `ps`, dynamic view with `top`.
- Process statuses include running, sleeping, stopped, and zombie states.
- Interrupt, background, and foreground control of processes with commands like `CTRL-C`, `&`, `fg`, `bg`.
- `kill` command for sending signals to processes.
- Additional tools: `vmstat`, `xload`, `tload` for system performance analysis.
- Offers enhanced control and visibility, crucial for system optimization and troubleshooting.

References

- Silberschatz, Galvin and Gagne (2018). Operating System Concepts - 10th edition, Wiley.
- Shotts, The Linux Command line (2019). NoStarch.