1. Explore how processes are handled by the cpu

Using your linux virtual machine, install the following: htop, make, code from ostep.

Install htop:

First things first, I run `sudo apt update` and `sudo apt upgrade` to make sure all packages are up to date. Next, we can install htop by running `sudo apt install build-essential manpages-dev htop strace`.

```
📦[b@ubuntu ~]$ htop --version
htop 3.3.0
```

Looks great, htop is installed with version 3.3.0.

Install make:

Next, I'll run `sudo apt install make`.

```
📦[b@ubuntu ~]$ make --version
GNU Make 4.3
Built for x86_64-pc-linux-gnu
Copyright (C) 1988-2020 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/lice
nses/gpl.html>
This is free software: you are free to change and redistribute
it.
There is NO WARRANTY, to the extent permitted by law.
```

Perfect, we're all set with make as well. Onto ostep.

Install ostep code:

We have to install the ostep code from a github repo, so I'll need to git as well. I already have git installed:

```
📦[b@ubuntu ~]$ git --version
git version 2.43.0
```

Next, I'll navigate to my Github folder, and clone the ostep repo.

```
📦[b@ubuntu GitHub]$ git clone https://github.com/remzi-arpacidusseau/ostep-code.git
Cloning into 'ostep-code'...
remote: Enumerating objects: 316, done.
remote: Counting objects: 100% (155/155), done.
remote: Compressing objects: 100% (54/54), done.
remote: Total 316 (delta 110), reused 101 (delta 101), pack-reused 161 (from 1)
Receiving objects: 100% (316/316), 54.66 KiB | 4.20 MiB/s, done.
Resolving deltas: 100% (148/148), done.
```

Now that we've cloned the repo, I'll cd into /ostep/intro and `make` to compile the intro c programs.

```
📦[b@ubuntu intro]$ make
gcc -o cpu cpu.c -Wall
gcc -o mem mem.c -Wall
gcc -o threads threads.c -Wall -pthread
gcc -o io io.c -Wall
```

Great, we can see multiple programs compiled. The next step is to read through the intro chapter of the book and try out the code listed.

./cpu

The first program is `cpu.c`. Let's examine the contents of this program with `nano cpu.c`:

```c
#include <stdio.h>
#include <stdlib.h>
#include "common.h"

int main(int argc, char *argv[])
{
    if (argc != 2) {
        fprintf(stderr, "usage: cpu <string>\n");
        exit(1);
    }
    char *str = argv[1];

    while (1) {
        printf("%s\n", str);
        Spin(1);
    }
    return 0;
}
```

This program spins up a cpu that repeats the following:

- Check if 1 second has passed

- If one second has passed, print argument
  First, let's test it with `./cpu ben`:

```
📦[b@ubuntu intro]$ ./cpu ben
ben
ben
ben
ben
ben
^C
```

  The program prints my name repeatedly until I kill it with ctrl+c.

Next, let's try running multiple programs at once with `./cpu A & ./cpu B`. & will send the process to the background.

```
📦[b@ubuntu intro]$ ./cpu A & ./cpu B
[1] 8216
B
A
B
A
```

This program repeatedly prints B, then A. This shows how virtualizing a cpu creates the illusion of the cpu doing multiple tasks at once.

While running, we can use `jobs` to see ids of process running and their states.
If I run `ctrl+c`, then `jobs`, we can see ./cpu A is still running:

```
jobs
[1]+  Running                 ./cpu A &
```

This process isn't killed by `ctrl+c` because it's in the background. To kill it, we must bring it to foreground with `fg 1`.

```
fg 1
./cpu A
```

Now, we can kill it with `ctrl+c`.

Question: How many programs can run in the foreground?
A: With one cpu, only one program can run in the foreground.

./mem

Let's open up mem.c:

```
  GNU nano 7.2                                                  mem.c
#include <unistd.h>
#include <stdio.h>
#include <stdlib.h>
#include "common.h"

int main(int argc, char *argv[]) {
    if (argc != 2) {
        fprintf(stderr, "usage: mem <value>\n");
        exit(1);
    }
    int *p;
    p = malloc(sizeof(int));
    assert(p != NULL);
    printf("(%d) addr pointed to by p: %p\n", (int) getpid(), p);
    *p = atoi(argv[1]); // assign value to addr stored in p
    while (1) {
        Spin(1);
        *p = *p + 1;
        printf("(%d) value of p: %d\n", getpid(), *p);
    }
    return 0;
}
```

The mem.c program uses the `malloc` function to manually allocate memory. I've seen this function previously in my Assembly/Computer Architecture course. When running mem.c, the program:

- Allocates memory
- Prints address of allocated memory
- Puts zero into the first slot of the allocated memory.
  This loops every second, and increments the value stored at the saved address, as well as

printing the PID of itself.

Let's test it with `./mem 15`:

```
[b@ubuntu intro]$ ./mem 15
(8271) addr pointed to by p: 0x5620bdc522a0
(8271) value of p: 16
(8271) value of p: 17
(8271) value of p: 18
(8271) value of p: 19
^C
```

We can see the address of the memory we allocated, as well as watch the value of p increment, starting at 15.

What about with `./mem 15 & ./mem 5`?

```
[b@ubuntu intro]$ ./mem 15 & ./mem 5
[1] 8274
(8275) addr pointed to by p: 0x55d35b1b32a0
(8274) addr pointed to by p: 0x55a6f99162a0
(8275) value of p: 6
(8274) value of p: 16
(8275) value of p: 7
(8274) value of p: 17
(8275) value of p: 8
(8274) value of p: 18
^C
```

We can see each instance of mem running has allocated to separate memory, and takes turns incrementing their value.

htop

The first part of this section is to "start up a few cpus and mem in the background, then run htop in another terminal."

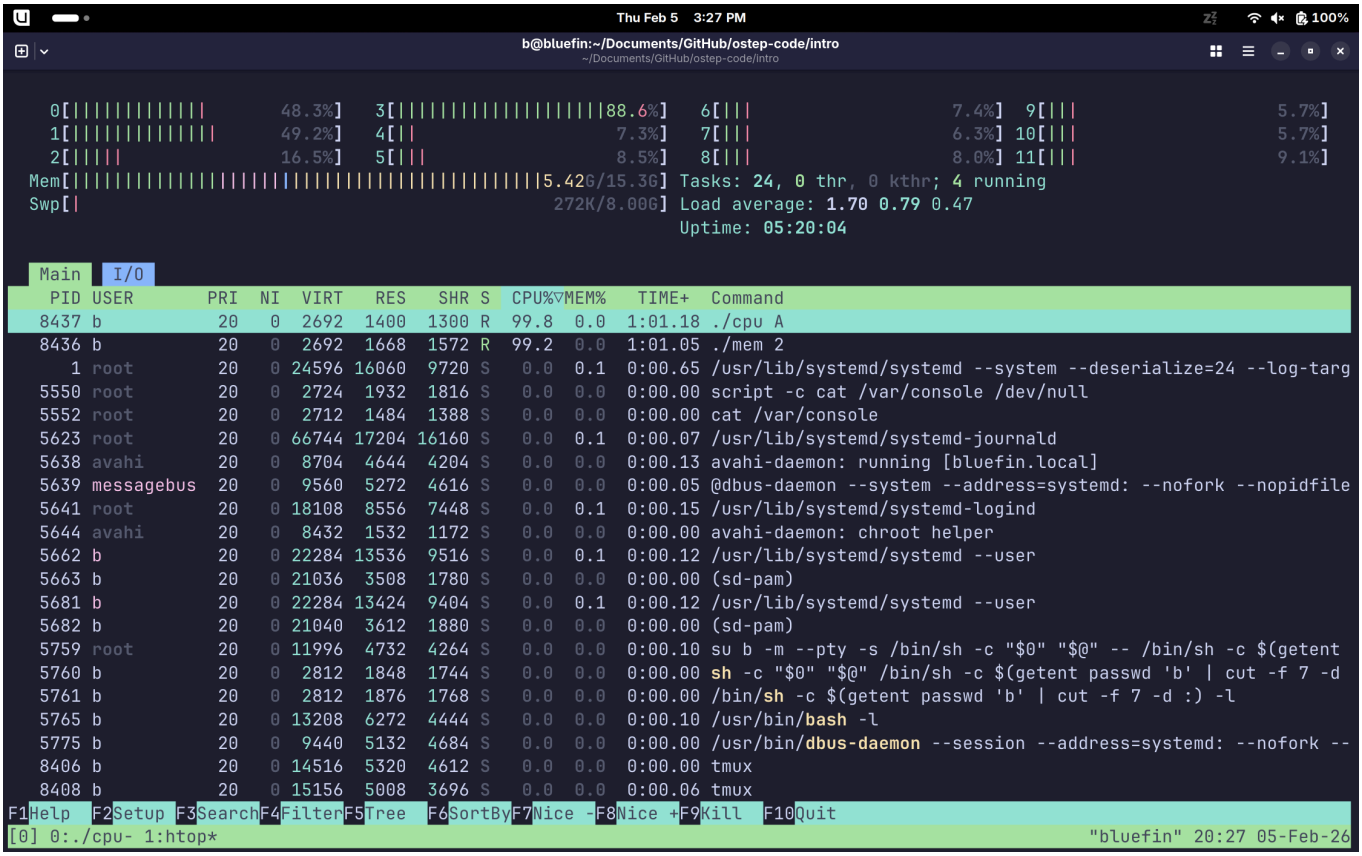
Because I'm running ubuntu in a container, I have to use a terminal multiplexer to have multiple terminal sessions. I'll be using tmux. With tmux, I can create sessions with `ctrl+b` then `c`, and cycle through sessions with `ctrl+b` and `n` for next / `p` for previous. It's pretty cool!

Start up a few cpus and mem in the background

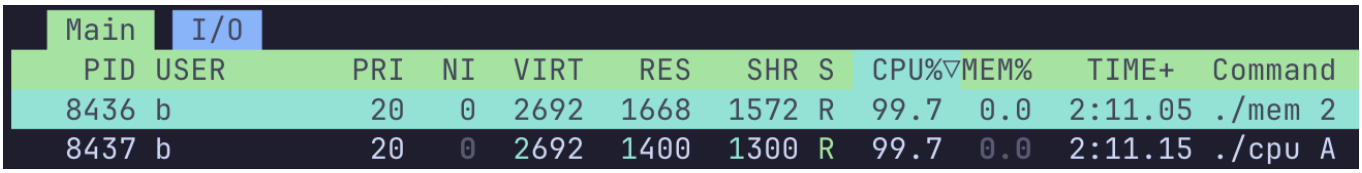
I'll run `./mem 2 & ./cpu A`, then jump into `htop` in my other session.

```
[b@ubuntu intro]$ ./mem 2 & ./cpu A
[1] 8436
A
(8436) addr pointed to by p: 0x55afa48ce2a0
A
(8436) value of p: 3
```

`htop` opens us into a TUI that is a bit overwhelming at first glance:

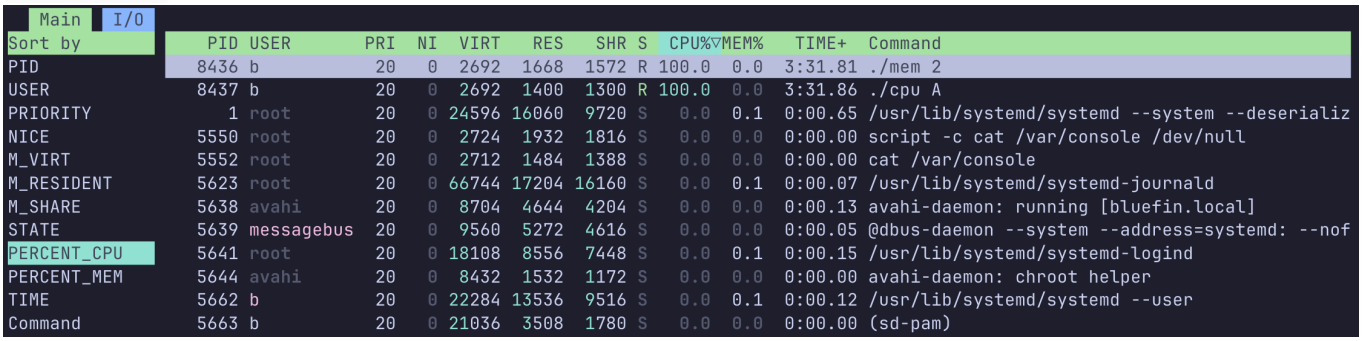


We can see `./mem and ./cpu` are sitting at the top of our process list.



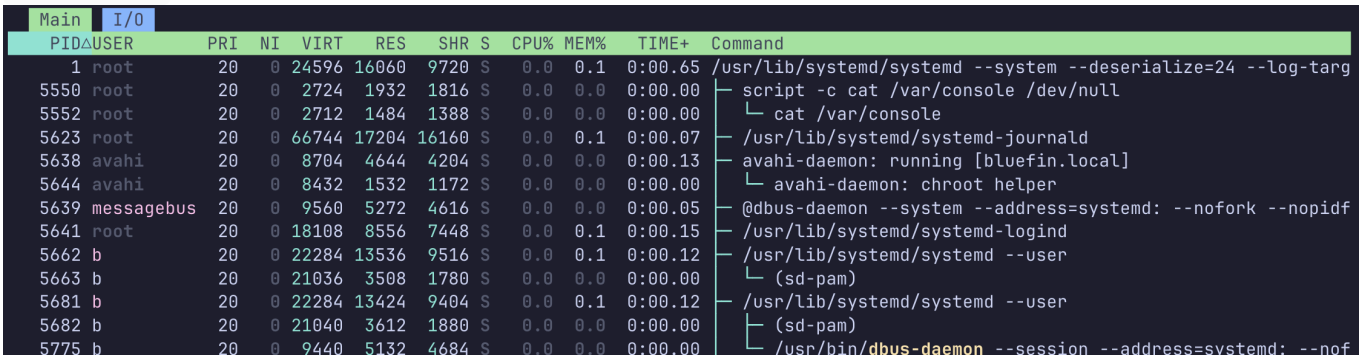
Let's try a few functions:

`sort (f6)`



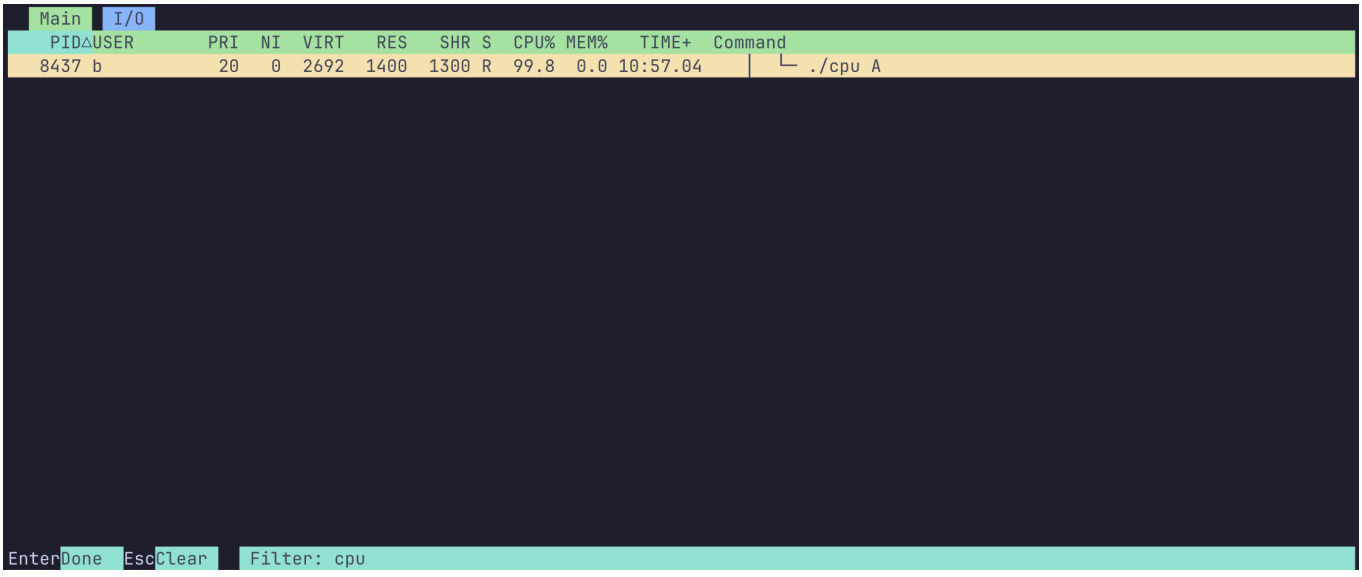
We can see a nice menu of presets to sort by. Personally, I like keeping it on PERCENT_CPU.

`tree (f5)`



`tree` shows us a parent/child tree of which processes spawned which.

`filter (f4)`



`filter` gives us the option to filter by keywords. I filtered for "cpu", and we can see `.cpu` is the sole display.

We're instructed to filter for ssh, because most people doing this assignment are using an Ubuntu VM. Because I'm using a distrobox container, not a VM, we actually don't have an ssh daemon running in the container.

Next, I use `Kill (f9)` to send SIGTERM 15s to both cpu and mem, killing the programs without messing with `fg` and `jobs` .

./Fork

Now, we'll take a look at fork.c.

```
  GNU nano 7.2                                                  fork.c
#include <stdio.h>
#include <unistd.h>
#include <sys/types.h>

int main() {
    pid_t pid = fork();

    if (pid < 0) {
        perror("fork failed");
        return 1;
    } else if (pid == 0) {
        // Child
        printf("Child: PID = %d, Parent PID = %d\n", getpid(), getppid());
    } else {
        // Parent
        printf("Parent: PID = %d, Child PID = %d\n", getpid(), pid);
    }
    return 0;
}
```

We can see this is a simple program to fork a process, and display child/parent PIDs.

gcc fork.c -o fork && ./fork

```
📦[b@ubuntu Downloads]$ gcc fork.c -o fork && ./fork
Parent: PID = 8500, Child PID = 8501
Child: PID = 8501, Parent PID = 8500
📦[b@ubuntu Downloads]$ gcc fork.c -o fork && ./fork
Parent: PID = 8507, Child PID = 8508
Child: PID = 8508, Parent PID = 1
📦[b@ubuntu Downloads]$ gcc fork.c -o fork && ./fork
Parent: PID = 8514, Child PID = 8515
Child: PID = 8515, Parent PID = 1
```

We can see after the first run, the children show a Parent PID of 1, meaning the parent has been terminated.

./fork_exec

Let's take a look at `fork_exec`.

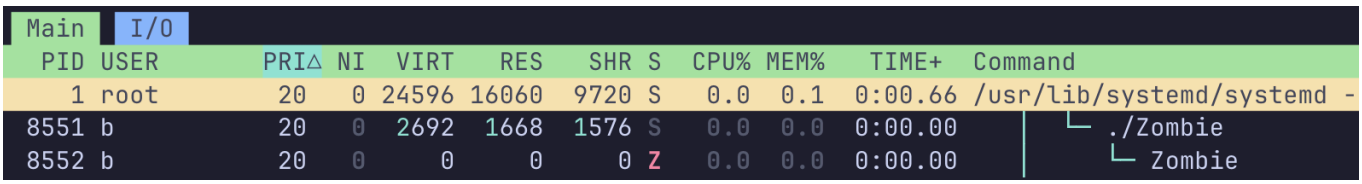
```c
#include <stdio.h>
#include <unistd.h>
#include <sys/wait.h>

int main() {
    pid_t pid = fork();

    if (pid == 0) {
        // Child replaces itself with ls
        printf("Child (PID %d) about to exec ls...\n", getpid());
        execl("/bin/ls", "ls", "-l", NULL);
        perror("execl failed");  // only reached if exec fails
        _exit(1);
    } else if (pid > 0) {
        wait(NULL);  // parent waits for child
        printf("Parent: child finished.\n");
    }
    return 0;
}
```

We can see this will repeatedly spawn a child that calls `ls -l`, and the parent prints `Parent: child finished` once `ls -l` runs successfully.

Let's use `zombie.c` to look for zombie processes in htop.

```
📦[b@ubuntu Downloads]$ gcc Zombie.c -o Zombie
📦[b@ubuntu Downloads]$ ./Zombie
Parent (PID 8549) sleeping for 60 seconds...
Child (PID 8550, parent 8549) exiting now...
```

In htop:



We can see that the child has a "Z" state, showing that it's a zombie child. Eventually, the zombie process gets cleaned up.

Now, let's observe an orphan process get reparented:

```
Child starting (PID 8561, initial parent 8560)
📦[b@ubuntu Downloads]$ Child waking up (PID 8561, new parent now 1)
Child exiting.
```

```
Main  I/O
  PID USER       PRI△ NI  VIRT   RES   SHR S  CPU% MEM%   TIME+  Command
 5639 messagebus  20   0  9560  5272  4616 S   0.0  0.0  0:00.05 ├─ @dbus-daemon --system --address=systemd: --nofork --nopidf
 5775 b           20   0  9440  5132  4684 S   0.0  0.0  0:00.00 │  └─ /usr/bin/dbus-daemon --session --address=systemd: --nof
 8561 b           20   0  2692  1004   904 S   0.0  0.0  0:00.00 └─ ./orphan
```

./cpu_burn

- Detects how many CPU cores you have
- Spawns one pthread per core
- Each thread runs a tight infinite loop doing math

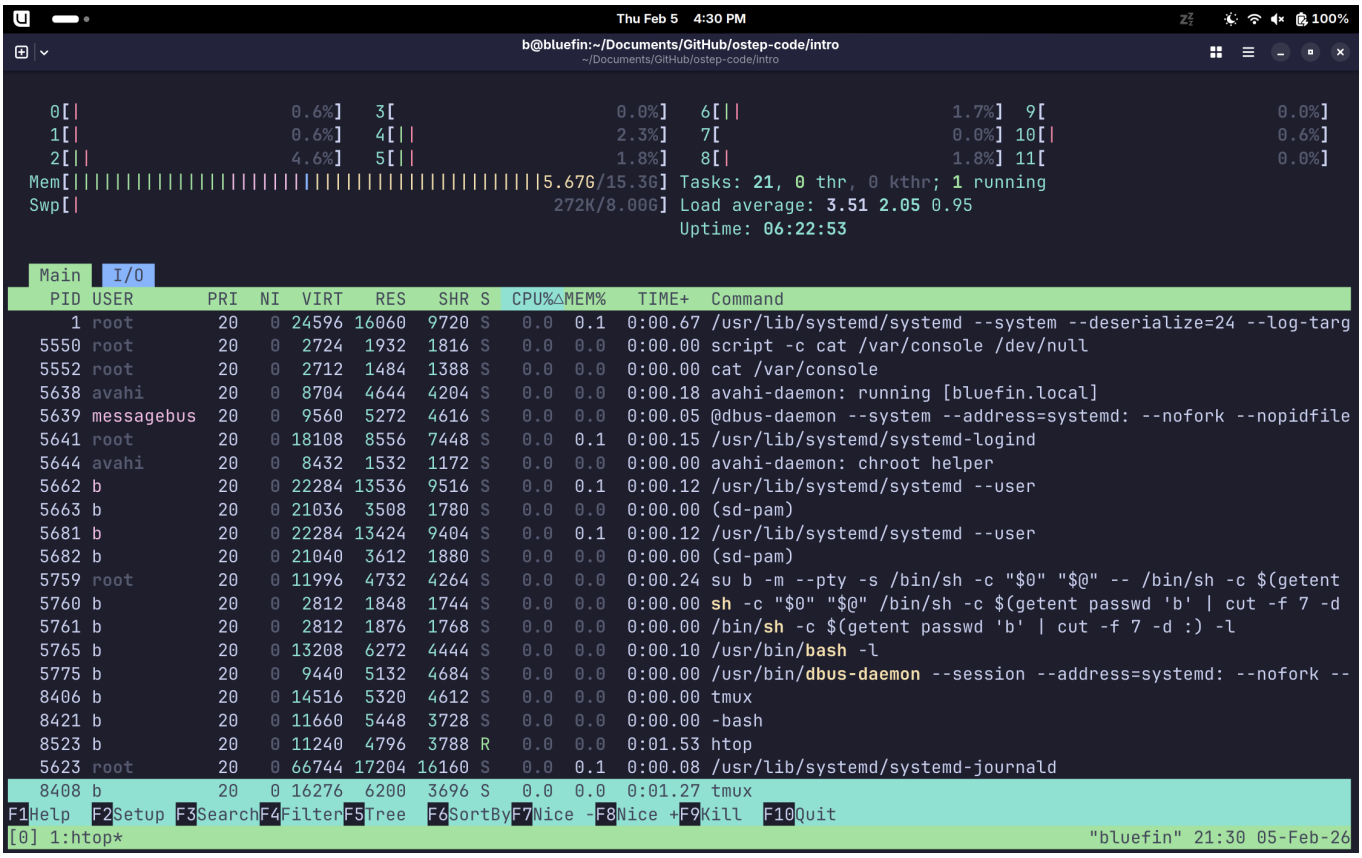
```
📦[b@ubuntu Downloads]$ gcc cpu_burn.c -o cpu_burn -pthread -lm
📦[b@ubuntu Downloads]$ ./cpu_burn
Starting 12 CPU burner threads
```

Here we go....

We can see almost immediately, my CPU usage hits ~100% for each process for `./cpu_burn`

```
Thu Feb 5  4:29 PM                                                    100%
b@bluefin:~/Documents/GitHub/ostep-code/intro
~/Documents/GitHub/ostep-code/intro

  0[||||||||||||||||||||97.0%]   3[||||||||||||||||||||96.9%]   6[||||||||||||||||||||97.7%]  9[||||||||||||||||||||97.8%]
  1[||||||||||||||||||||96.9%]   4[||||||||||||||||||||97.8%]   7[||||||||||||||||||||97.7%] 10[||||||||||||||||||||97.7%]
  2[||||||||||||||||||||97.7%]   5[||||||||||||||||||||97.7%]   8[||||||||||||||||||||98.5%] 11[||||||||||||||||||||97.7%]
Mem[|||||||||||||||||||||||||||||||||||||5.61G/15.3G] Tasks: 23, 12 thr, 0 kthr; 12 running
Swp[|                                      272K/8.00G] Load average: 6.70 2.08 0.89
                                                       Uptime: 06:21:58

  Main  I/O
    PID USER       PRI  NI  VIRT   RES   SHR S  CPU%△MEM%   TIME+  Command
   5761 b           20   0  2812  1876  1768 S   0.0  0.0  0:00.00 /bin/sh -c $(getent passwd 'b' | cut -f 7 -d :) -l
   5765 b           20   0 13208  6272  4444 S   0.0  0.0  0:00.10 /usr/bin/bash -l
   5775 b           20   0  9440  5132  4684 S   0.0  0.0  0:00.00 /usr/bin/dbus-daemon --session --address=systemd: --nofork --
   8406 b           20   0 14516  5320  4612 S   0.0  0.0  0:00.00 tmux
   8408 b           20   0 16416  6284  3696 S   0.0  0.0  0:01.25 tmux
   8409 b           20   0 12308  6128  3760 S   0.0  0.0  0:00.07 -bash
   8421 b           20   0 11660  5448  3728 S   0.0  0.0  0:00.00 -bash
   8523 b           20   0 11316  4796  3788 R   0.0  0.0  0:01.47 htop
   8568 b           20   0 99.5M  2124  1912 S   0.0  0.0  0:00.00 ./cpu_burn
   8569 b           20   0 99.5M  2124  1912 R  98.7  0.0  0:48.70 ./cpu_burn
   8570 b           20   0 99.5M  2124  1912 R 100.3  0.0  0:48.70 ./cpu_burn
   8571 b           20   0 99.5M  2124  1912 R 101.8  0.0  0:48.72 ./cpu_burn
   8572 b           20   0 99.5M  2124  1912 R 101.8  0.0  0:48.74 ./cpu_burn
   8573 b           20   0 99.5M  2124  1912 R 101.8  0.0  0:48.68 ./cpu_burn
   8574 b           20   0 99.5M  2124  1912 R 101.0  0.0  0:48.70 ./cpu_burn
   8576 b           20   0 99.5M  2124  1912 S 101.0  0.0  0:48.82 ./cpu_burn
   8577 b           20   0 99.5M  2124  1912 R 100.3  0.0  0:48.77 ./cpu_burn
   8575 b           20   0 99.5M  2124  1912 R 100.3  0.0  0:48.75 ./cpu_burn
   8578 b           20   0 99.5M  2124  1912 R 101.0  0.0  0:48.69 ./cpu_burn
   8579 b           20   0 99.5M  2124  1912 R 100.3  0.0  0:48.74 ./cpu_burn
   8580 b           20   0 99.5M  2124  1912 R 101.8  0.0  0:48.72 ./cpu_burn
F1Help  F2Setup F3SearchF4FilterF5Tree  F6SortByF7Nice -F8Nice +F9Kill  F10Quit
[0] 0:./cpu_burn- 1:htop*                                    "bluefin" 21:29 05-Feb-26
```

After letting cpu_burn run for a bit, I sent SIGTERM 15s to ./cpu_burn, and my usage returned to normal.



Now modify the code to run with:

- *Less threads than cores*
- *Number varies based on your vm setup, ex. You have 5 cores and set to 2*
- *An overload of threads*
- *int cores = sysconf(SC_NPROCESSORS_ONLN)*

Let's open up cpu_burn.c:

```
  GNU nano 7.2                                                cpu_b
int main() {
    int cores = sysconf(_SC_NPROCESSORS_ONLN);
    printf("Starting %d CPU burner threads\n", cores);

    pthread_t* threads = malloc(sizeof(pthread_t) * cores);

    for (int i = 0; i < cores; i++) {
        pthread_create(&threads[i], NULL, burn, NULL);
    }

    // Prevent main thread from exiting
    for (int i = 0; i < cores; i++) {
        pthread_join(threads[i], NULL);
    }

    free(threads);
    return 0;
}
```

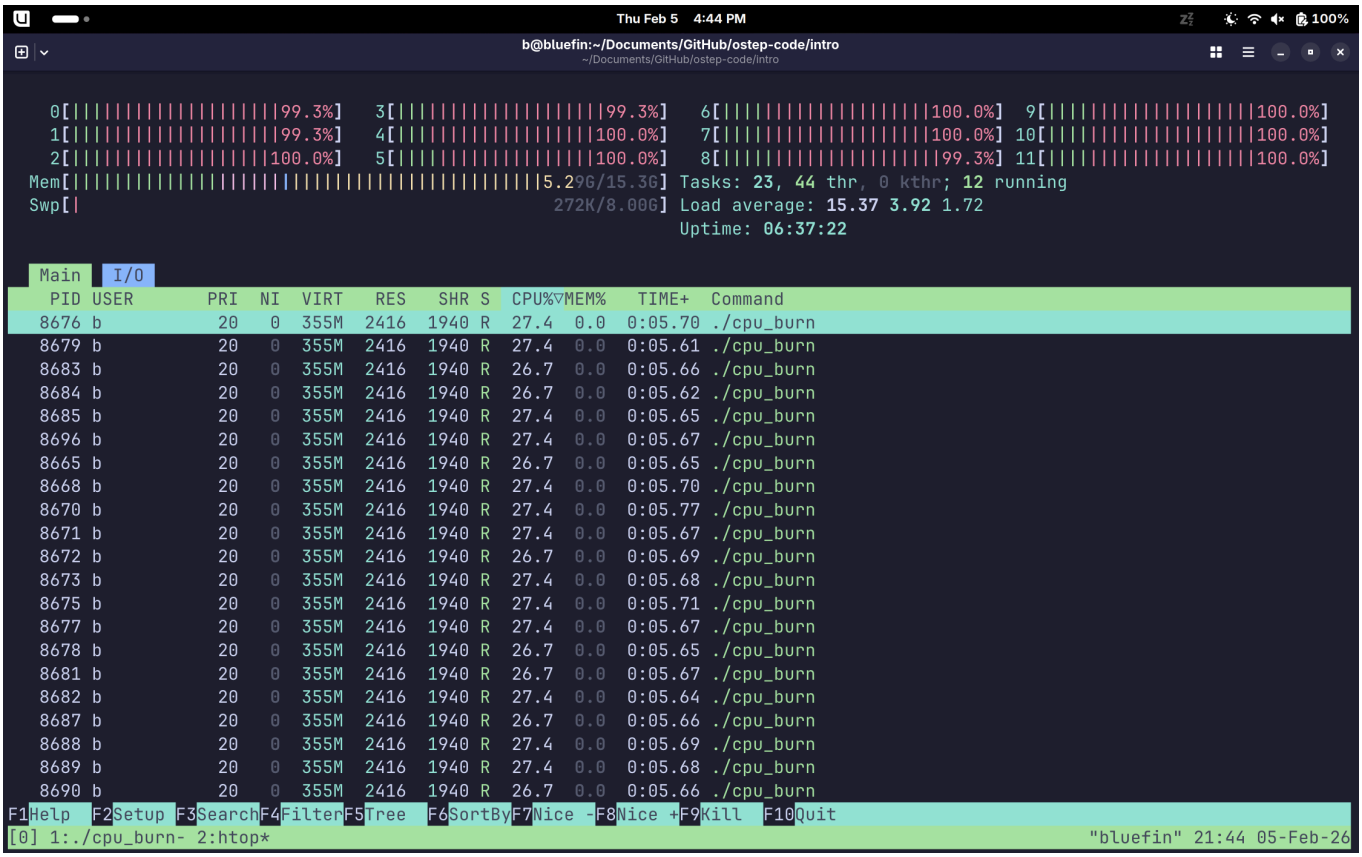
For *less threads than cores*, I'll simply change the for loop to execute 4 less times than the amount of cores we have.

```
for (int i = 0; i < cores - 4; i++) {
    pthread_join(threads[i], NULL);
}
```

Next, for *overload of threads* i'll change:

```
int main() {
    int cores = sysconf(_SC_NPROCESSORS_ONLN) * 4;
```

So, we're creating more threads than cores we have available. Let's run cpu_burn again!



This time, each instance of `./cpu_burn` is only taking up ~27% of CPU, but we can see at the top all 12 of my cores are maxed out with usage. This means that even if you distribute high workload across many threads, you can still burn through resources quickly if your cores are limited.

Conclusion

Overall, this was a great way to get some experience with htop, and get a glimpse into what goes on under the hood with processes, threads, and cores.