CS 3502
Operating Systems

Project 1

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https://kevinsuo.github.io/

Outline

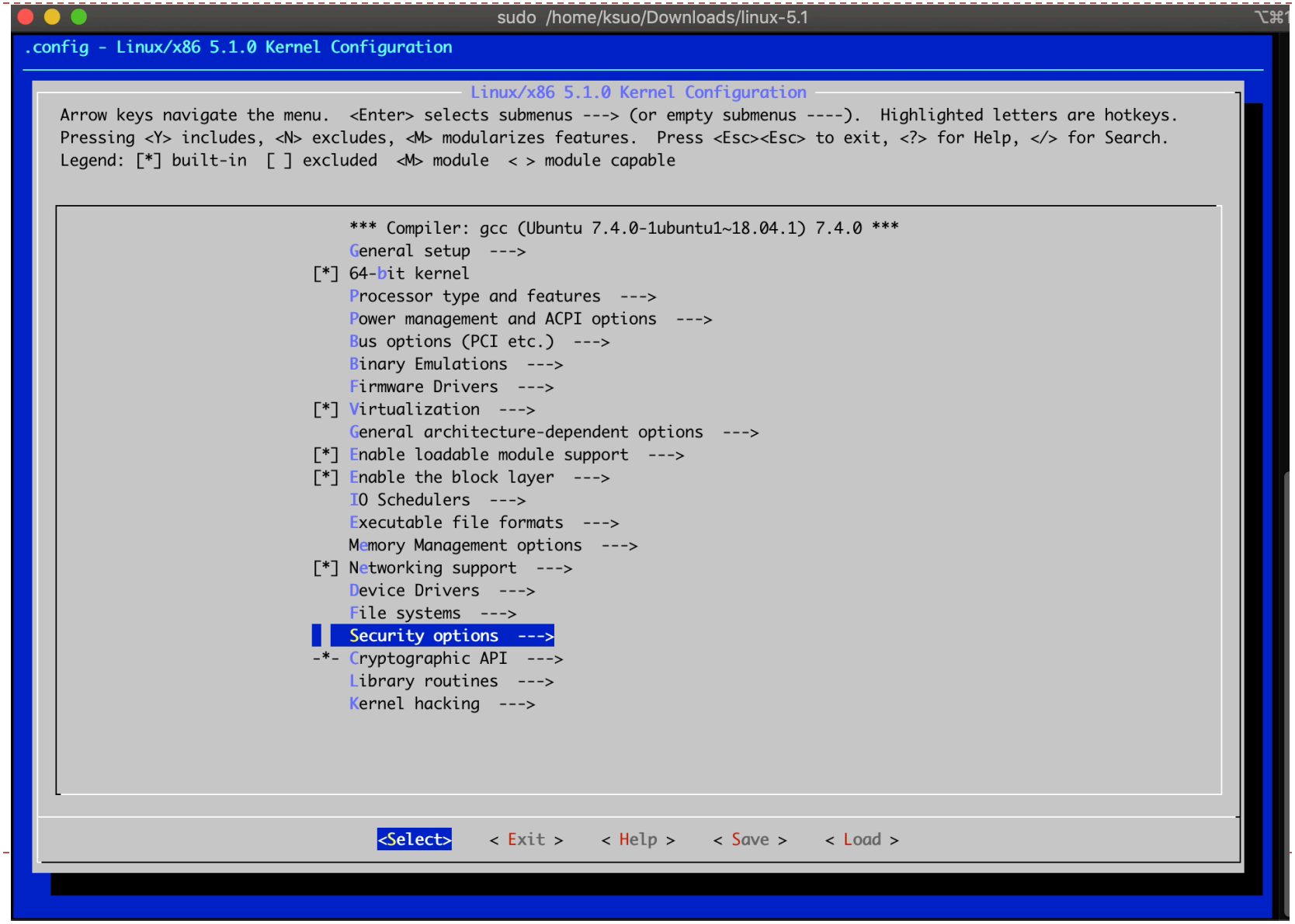
- **Assignment 0: create a VM and compile your kernel**
- Assignment 1: add a new system call into the Linux kernel
- Assignment 2: Extend your new system call to print out the calling process's information
- Assignment 3: Extend your new system call to print out the information of an arbitrary process identified by its PID

How to build one ubuntu VM?

- HostOS
  - Windows 10: https://www.youtube.com/watch?v=QbmRXJJKsvs
  - MacOS: https://www.youtube.com/watch?v=GDoCrfPma2k&t=321s

Project 1: menuconfig

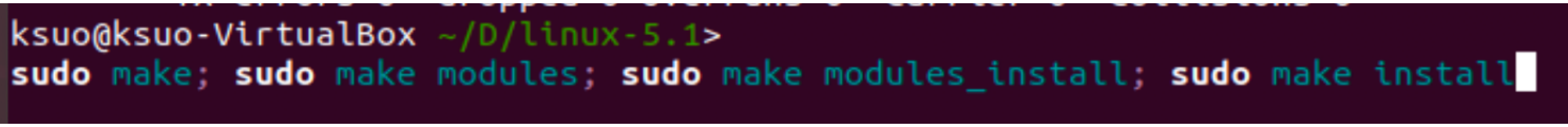
https://youtu.be/UyOGF4UOoR0



Tips

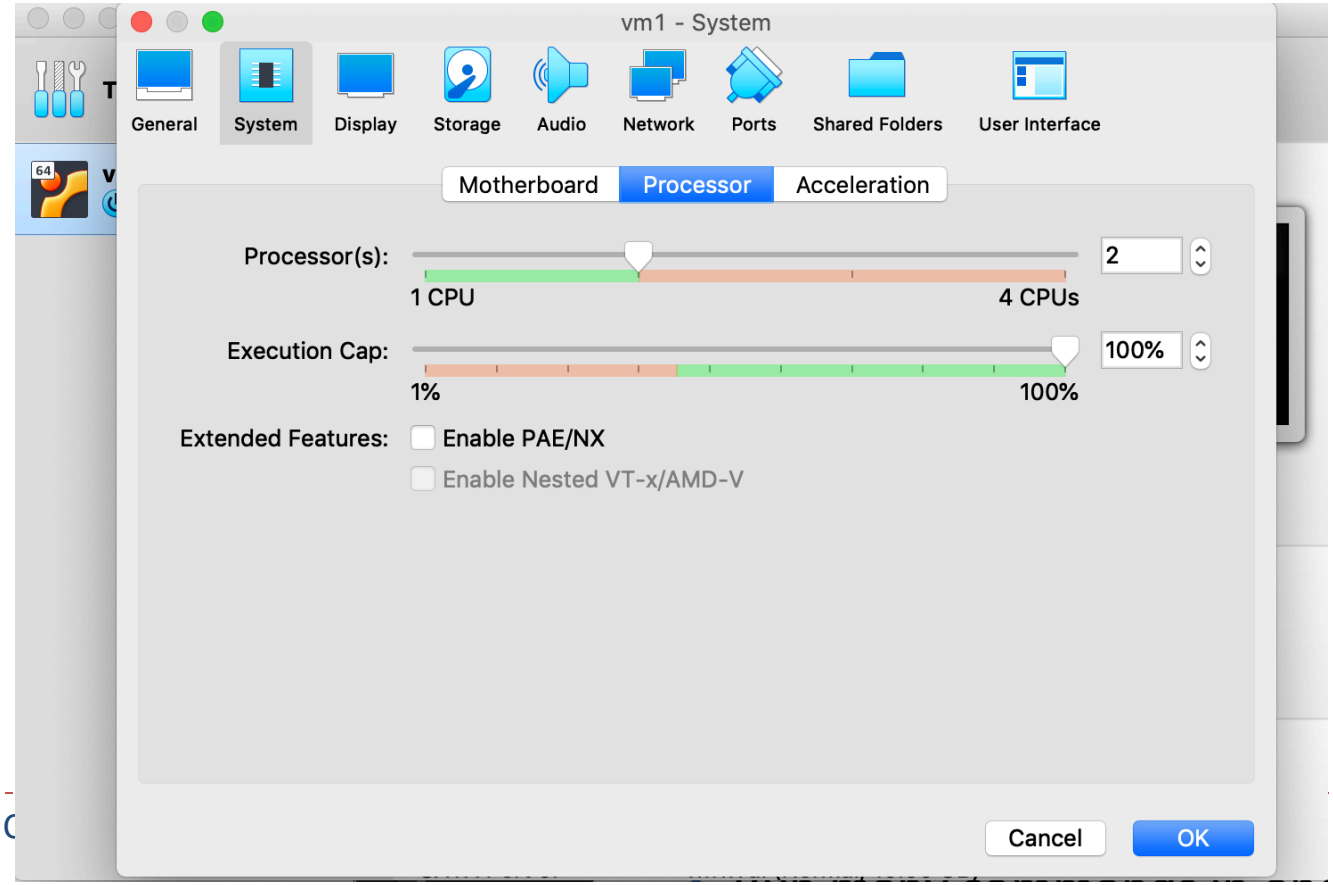
- Compile Linux kernel takes half to many hours, depending on machine speed
- To save the time, you can compile it before you sleep
- Run many commands in one:

  $ sudo make; sudo make modules; sudo make modules_install; sudo make install



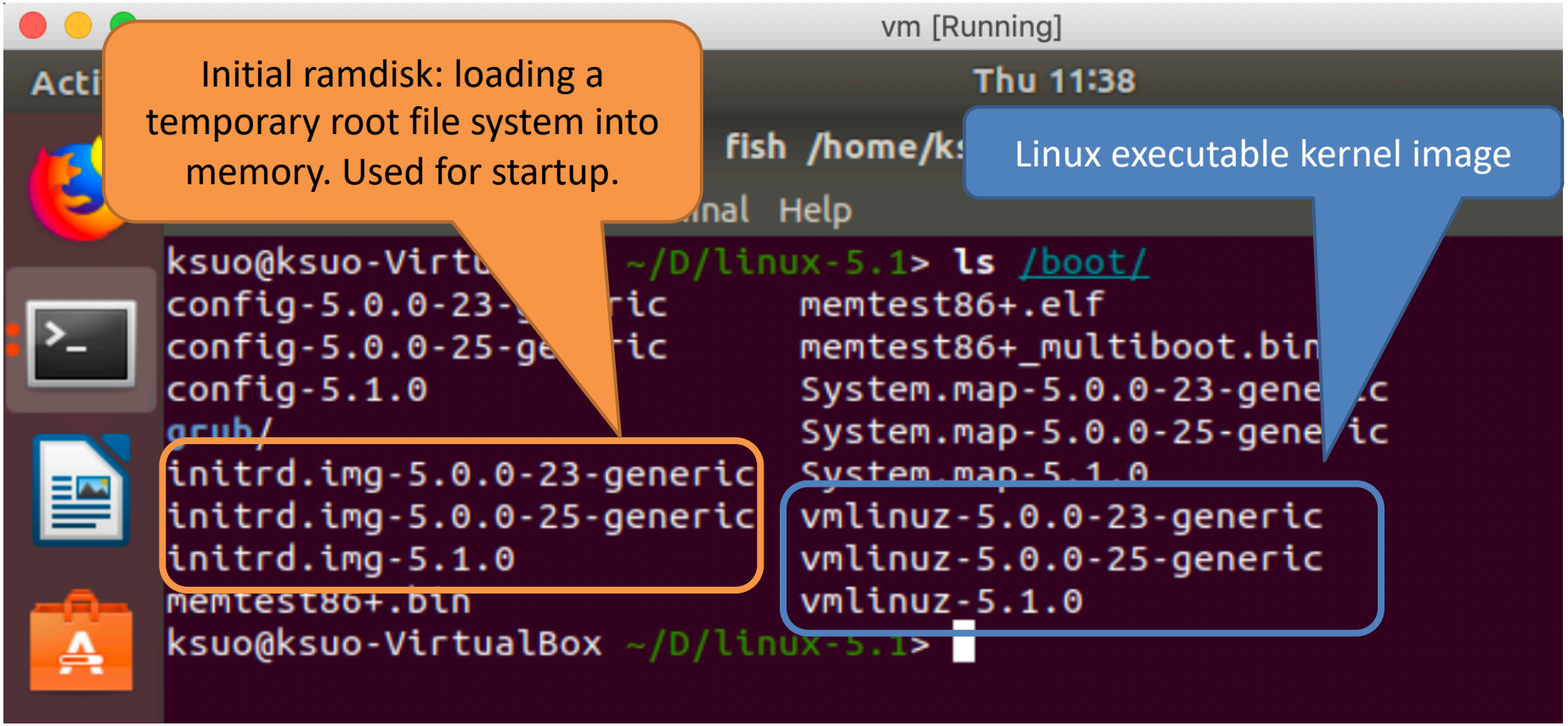
Tips

- Set up more CPUs for VM
- Make –j N, to accelerate compiling



Where is my kernel?

- $ ls /boot/



Which kernel to boot if there are many?

If you are using Ubuntu: change the grub configuration file:

$ sudo vim /etc/default/grub

Make the following changes:

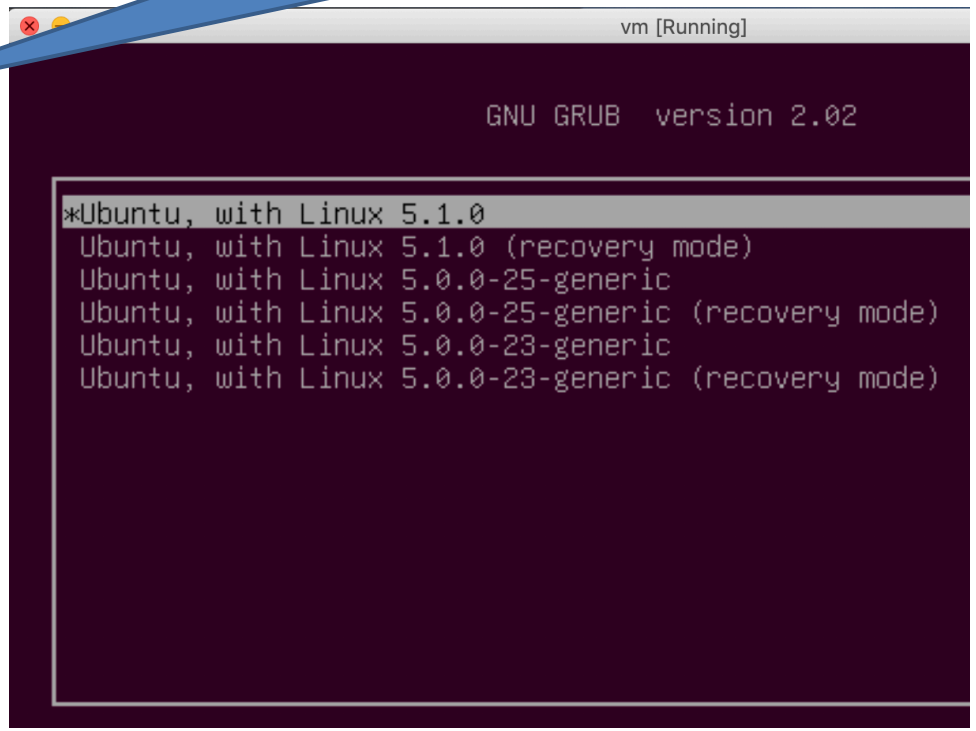
GRUB_DEFAULT=0

GRUB_TIMEOUT=10

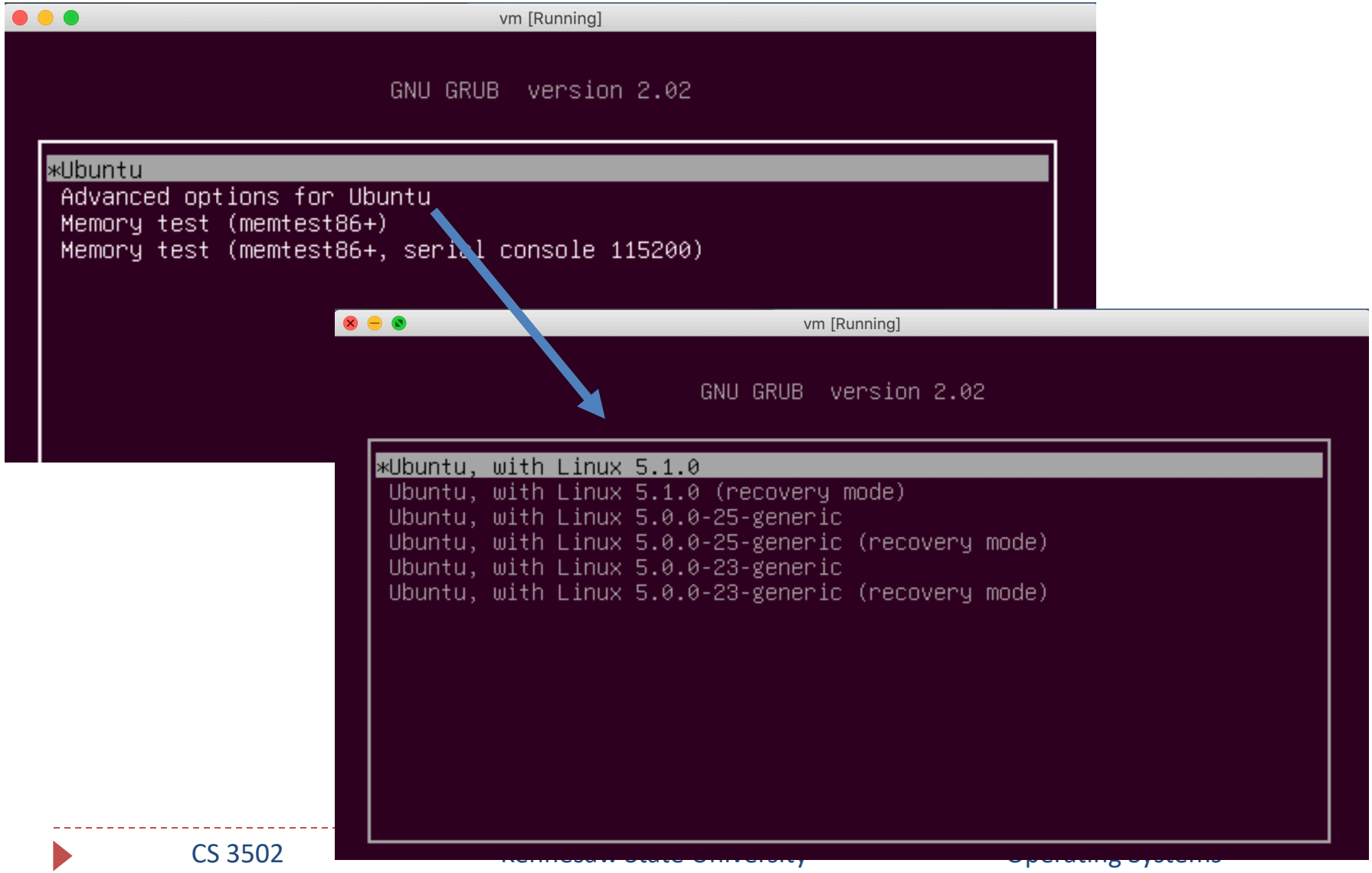
Then, update the grub entry:

$ sudo update-grub2

The OS boots by using the first kernel by default. You have 10 seconds to choose.



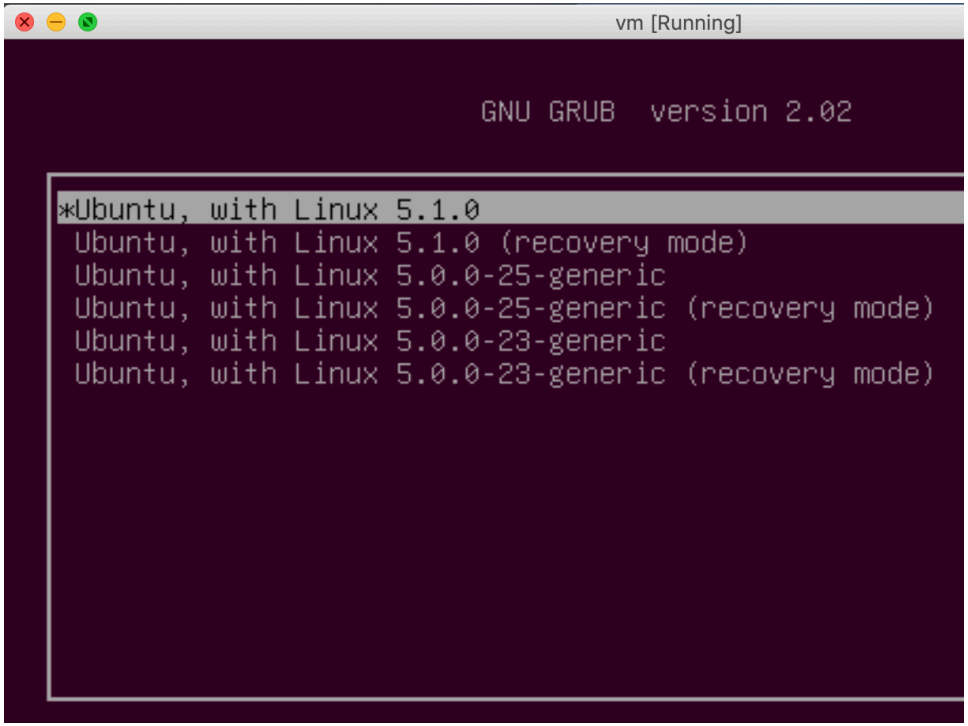
Which kernel to boot if there are many?



What if my kernel crashed?

- Your kernel could crash because you might bring in some kernel bugs

- In the menu, choose the old kernel to boot the system
- Fix your bug in the source code
- Compile and reboot



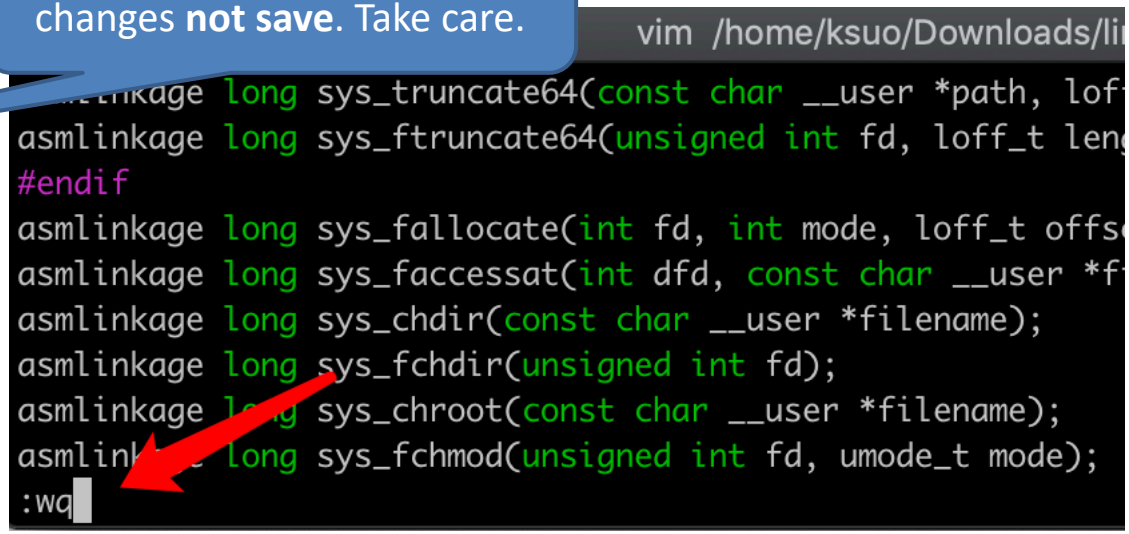
Project 1: No IDE, please use vim

- Open a file
  - $ vim test.c

- Close a file
  - Inside vim (after opening), press :q!
  - Inside vim (after opening), press :wq, changes saved

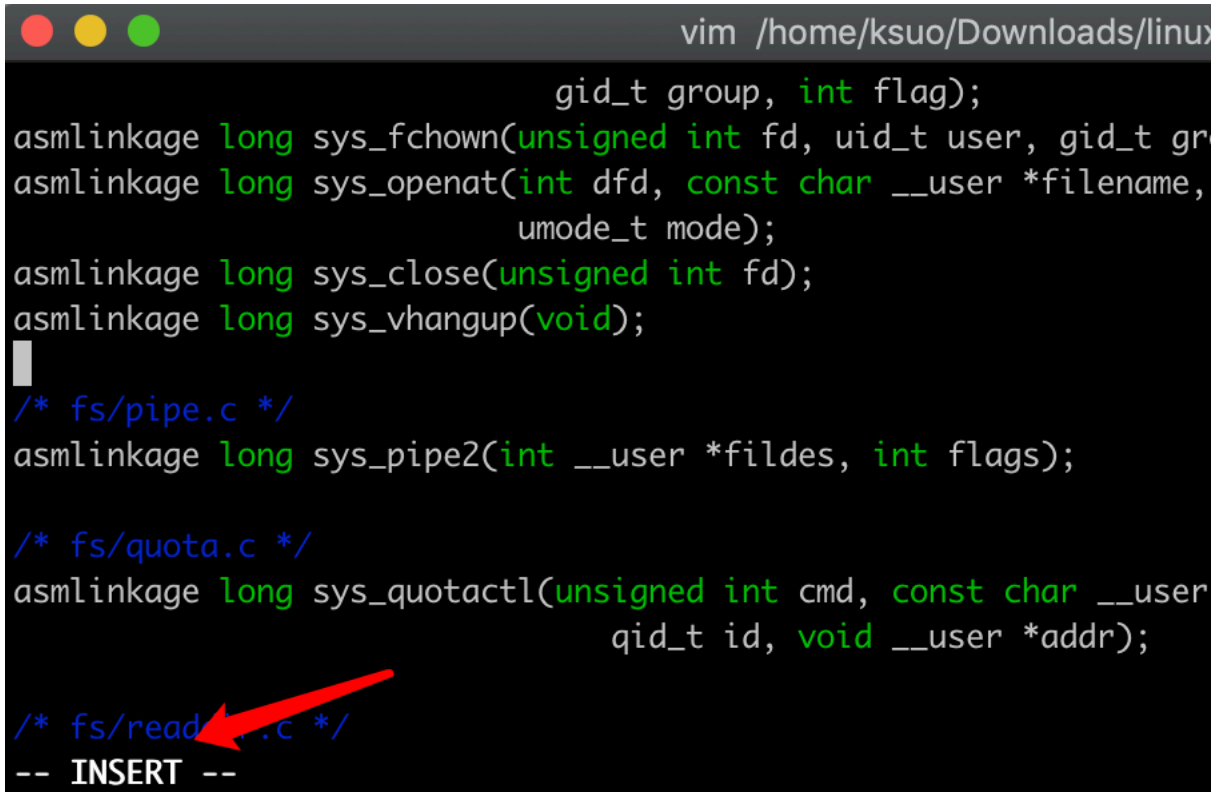
colon mark means menu.

Exclamation mark means changes **not save**. Take care.



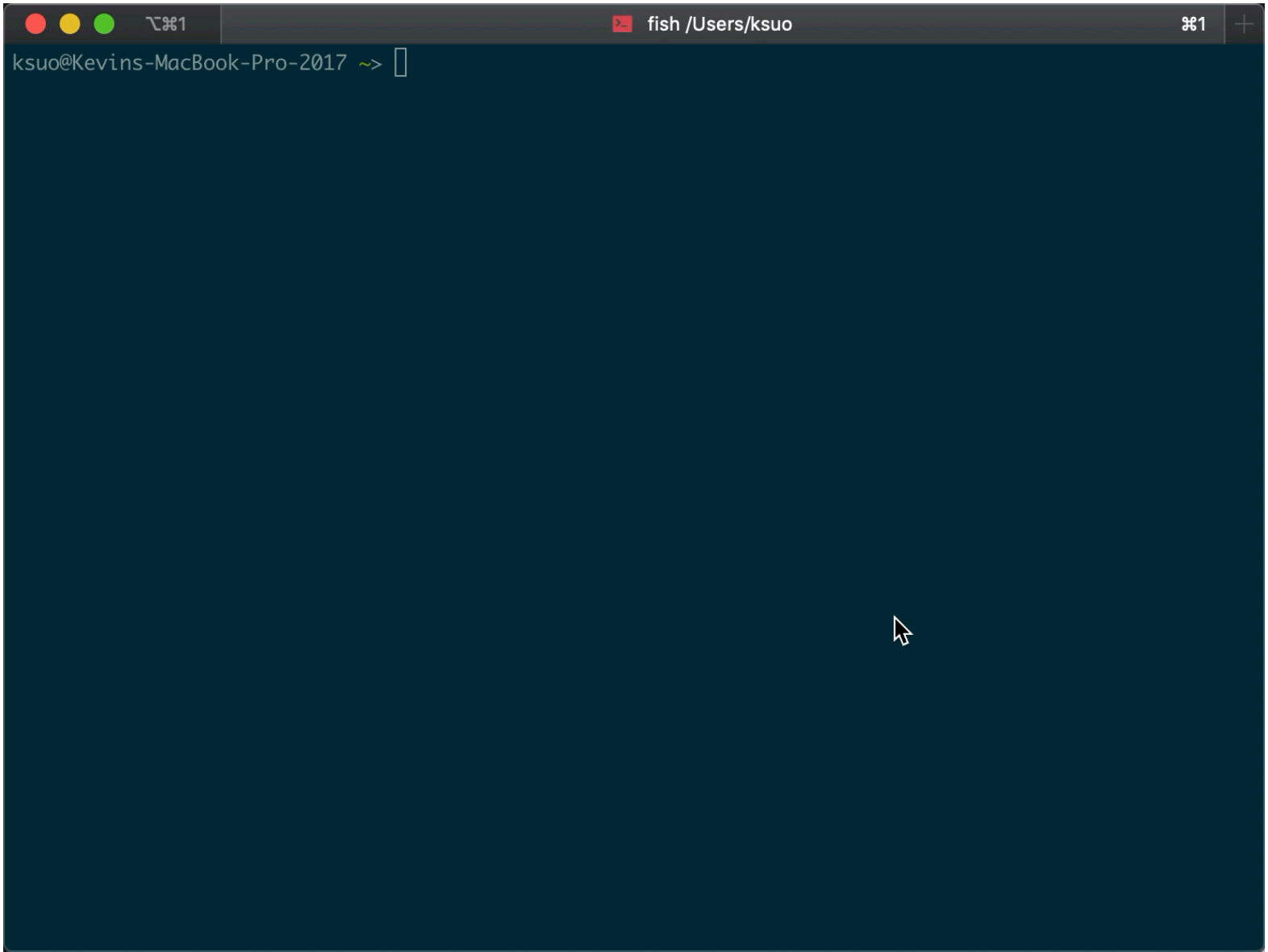
Project 1: No IDE, please use vim

- Edit a file
  - Open a file
  - Press i (means enter the insert mode). then input your code
  - Press ESC to exit the insert mode
  - Close a file (:wq)



Project 1: No IDE, please use vim

https://youtu.be/rS0XZpLtVlo



Edit a file with vim

- step 1: $ vim file
- step 2: press i, enter insert mode; move the cursor to position and edit the context
- step 3: after editing, press ESC to exit the insert mode to normal mode
- step 4: press :wq to save what you edit and quit. If you do not want to save, press :q!

More about vim

- A quick start guide for beginners to the Vim text editor
  - https://eastmanreference.com/a-quick-start-guide-for-beginners-to-the-vim-text-editor
- Vim basics:
  - https://www.howtoforge.com/vim-basics
- Learn the Basic Vim Commands [Beginners Guide]
  - https://www.youtube.com/watch?time_continue=265&v=ZEGqkam-3Ic

Compile the kernel

1. download the kernel source code
2. unzip the file
3. use *make menuconfig* to create a config file
4. use *make/make modules* to compile the code
5. use *make modules_install/make install* to install the kernel
6. reboot the VM

Outline

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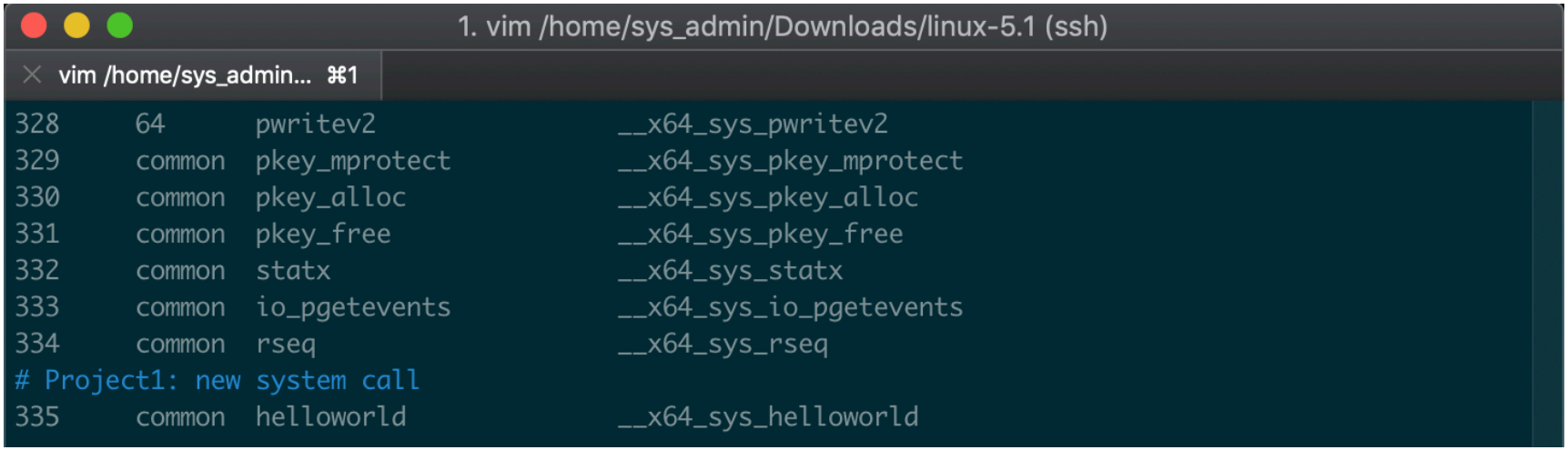
- Assignment 2: Extend your new system call to print out the calling process's information
- Assignment 3: Extend your new system call to print out the information of an arbitrary process identified by its PID

Define your system call

- Step 1: register your system call
- Step 2: declare your system call in the header file
- Step 3: implement your system call
- Step 4: write user level app to call it

Step 1: register your system call

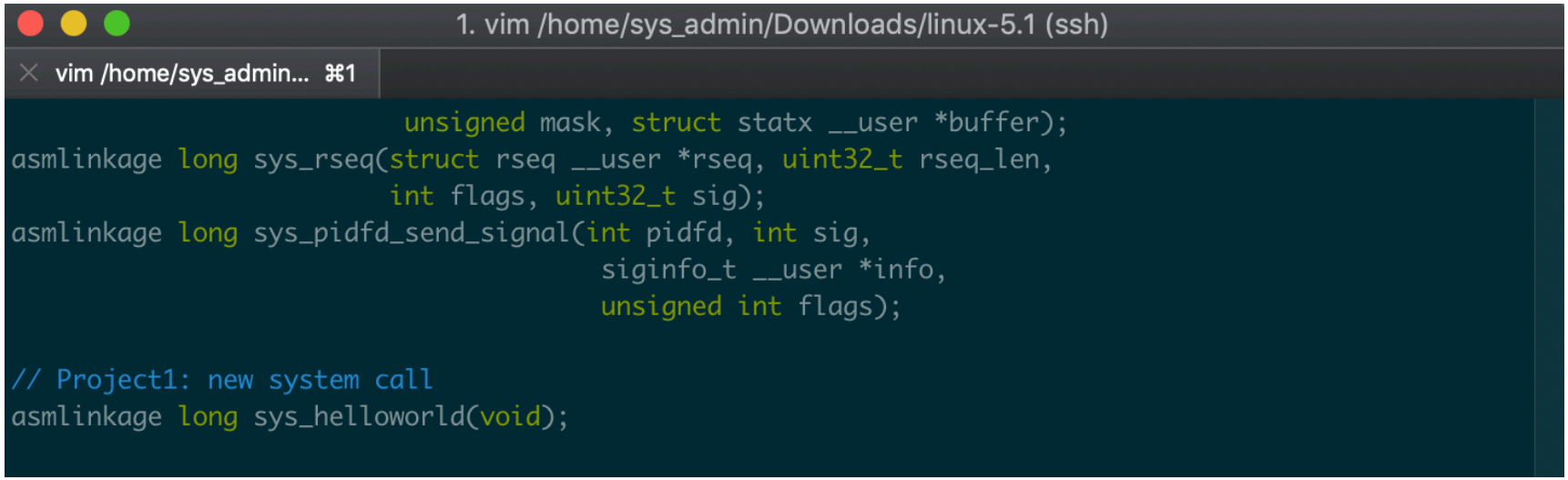
arch/x86/entry/syscalls/syscall_64.tbl



https://elixir.bootlin.com/linux/v5.0/source/arch/x86/entry/syscalls/syscall_64.tbl#L346

Step 2: declare your system call in the header file

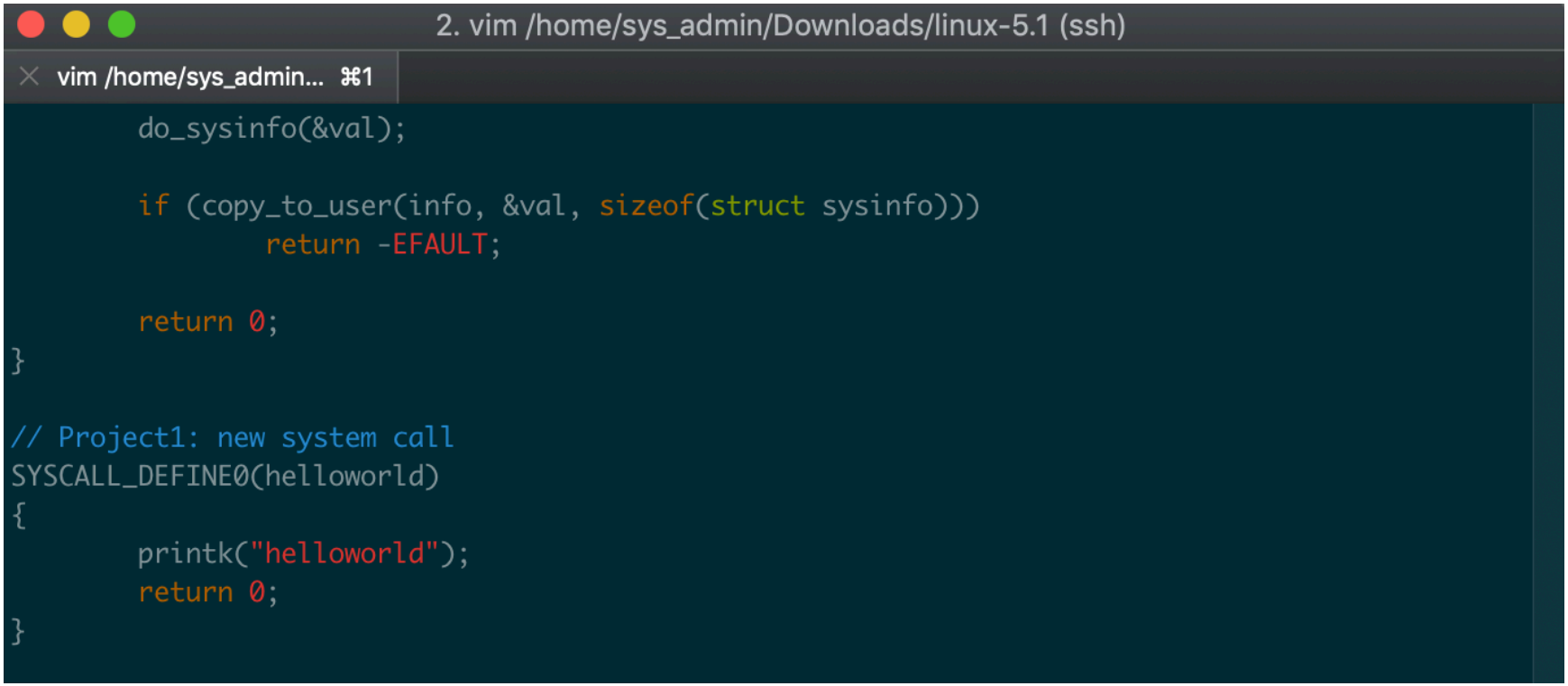
include/linux/syscalls.h



https://elixir.bootlin.com/linux/v5.0/source/include/linux/syscalls.h

Step 3: implement your system call

kernel/sys.c



https://elixir.bootlin.com/linux/v5.0/source/kernel/sys.c#L402

Step 4: write user level app to call it

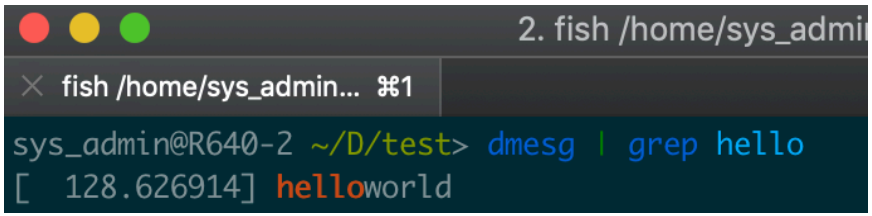
test_syscall.c：

```
****************************************
#include <linux/unistd .h>
#include <sys/syscall .h>
#include <sys/types .h>
#include <stdio .h>
#define __NR_helloworld 335

int main(int argc, char *argv[])
{
    syscall (__NR_helloworld) ;
    return 0 ;
}
****************************************

//If syscall needs parameter, then：
//syscall (__NR_helloworld，a，b，c) ;
```

Compile and execute：

```
$ gcc test_syscall.c -o test_syscall
$ ./test_syscall
```

The test program will call the new system call and output a helloworld message at the tail of the output of dmesg (system log).



Put it all together

User space

Kernel space

Step 4: user call it

test_syscall.c:

```
*****************************************
#include <linux/unistd .h>
#include <sys/syscall .h>
#include <sys/types .h>
#include <stdio .h>
#define __NR_helloworld 335

int main(int argc, char *argv[])
{
    syscall (__NR_helloworld) ;
    return 0 ;
}
*****************************************
```

Step 1: register

1. vim /home/sys_admin/Downloads/linux-5.1 (

vim /home/sys_admin... ⌘1

```
328     64      pwritev2                __x64_sys_pwritev2
329     common  pkey_mprotect           __x64_sys_pkey_mprotect
330     common  pkey_alloc              __x64_sys_pkey_alloc
331     common  pkey_free               __x64_sys_pkey_free
332     common  statx                   __x64_sys_statx
333     common  io_pgetevents           __x64_sys_io_pgetevents
334     common  rseq                    __x64_sys_rseq
# Project1: new system call
335     common  helloworld              __x64_sys_helloworld
```

Step 2: declare

1. vim /home/sys_admin/Downloads/linux-5.1 (ssh

vim /home/sys_admin... ⌘1

```
                        unsigned mask, struct statx __user *buffer);
asmlinkage long sys_rseq(struct rseq __user *rseq, uint32_t rseq_len,
                         int flags, uint32_t sig);
asmlinkage long sys_pidfd_send_signal(int pidfd, int sig,
                                      siginfo_t __user *info,
                                      unsigned int flags);

// Project1: new system call
asmlinkage long sys_helloworld(void);
```

2. vim /home/sys_admin/Downloads/linux

vim /home/sys_admin... ⌘1

```
        do_sysinfo(&val);

        if (copy_to_user(info, &val, sizeof(struct sysinfo)))
                return -EFAULT;

        return 0;
}

// Project1: new system call
SYSCALL_DEFINE0(helloworld)
{
        printk("helloworld");
        return 0;
}
```

Step 3: implementation

2. fish /home/sys_admi

fish /home/sys_admin... ⌘1

```
sys_admin@R640-2 ~/D/test> dmesg | grep hello
[  128.626914] helloworld
```

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Assignment 2:
step 1&2:register and declare

arch/x86/entry/syscalls/syscall_64.tbl

1. vim /home/sys_admin/Downloads/linux-5.1 (ssh)

vim /home/sys_admin... ⌘1

```
328     64      pwritev2                __x64_sys_pwritev2
329     common  pkey_mprotect           __x64_sys_pkey_mprotect
330     common  pkey_alloc              __x64_sys_pkey_alloc
331     common  pkey_free               __x64_sys_pkey_free
332     common  statx                   __x64_sys_statx
333     common  io_pgetevents           __x64_sys_io_pgetevents
334     common  rseq                    __x64_sys_rseq
# Project1: new system call
335     common  helloworld              __x64_sys_helloworld
```

include/linux/syscalls.h

1. vim /home/sys_admin/Downloads/linux-5.1 (ssh)

vim /home/sys_admin... ⌘1

```
                        unsigned mask, struct statx __user *buffer);
asmlinkage long sys_rseq(struct rseq __user *rseq, uint32_t rseq_len,
                         int flags, uint32_t sig);
asmlinkage long sys_pidfd_send_signal(int pidfd, int sig,
                                      siginfo_t __user *info,
                                      unsigned int flags);

// Project1: new system call
asmlinkage long sys_helloworld(void);
```

Assignment 2:
step 3: implementation

- print out the following information of the calling process:
  - Process id, running state, and program name
  - Start time and virtual runtime
  - Its parent processes until init (first system process)

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https://elixir.bootlin.com/linux/v5.1/source/include/linux/sched.h#L739

Assignment 2:
step 3: implementation

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  - Process id, running state, and program name
  - Start time and virtual runtime
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https://elixir.bootlin.com/linux/v5.1/source/include/linux/sched.h#L594

Assignment 2:
step 3: implementation

- print out the following information of the calling process:
  - Process id, running state, and program name
  - Start time and virtual runtime
  - Its parent processes until init (first system process)

https://elixir.bootlin.com/linux/v5.1/source/include/linux/sched.h#L840

Assignment 2:
step 3: implementation

- print out the following information of the calling process:
  - Process id, running state, and program name
  - Start time and virtual runtime
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https://elixir.bootlin.com/linux/v5.1/source/include/linux/sched.h#L808

Assignment 2:
step 3: implementation

- print out the following information of the calling process:
  - Process id, running state, and program name
  - Start time and virtual runtime
  - Its parent processes until init (first system process)

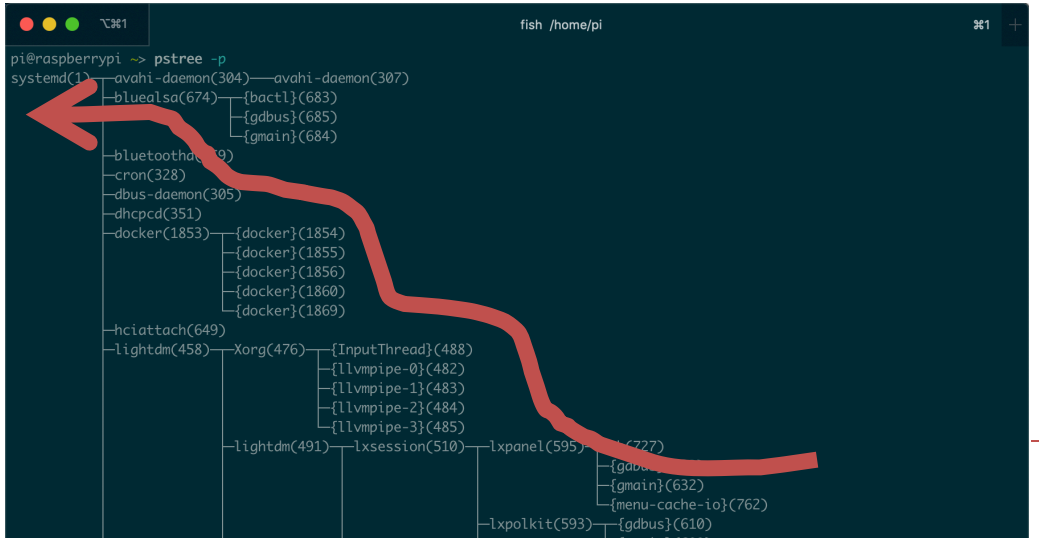
https://elixir.bootlin.com/linux/v5.1/source/include/linux/sched.h#L637

https://elixir.bootlin.com/linux/v5.1/source/include/linux/sched.h#L440

Task_struct
→ sched_entity
→ vruntime

Assignment 2:
step 3: implementation

- print out the following information of the calling process:
  - Process id, running state, and program name
  - Start time and virtual runtime
  - Its parent processes until init (first system process)



For loop until it reaches the init

```
{
        printk(...)
}
```

Assignment 2:
step 3: implementation

kernel/sys.c

ssh ⌥⌘3

```
SYSCALL_DEFINE0(print_self)
{


        for (task = current; task != &init_task; task = task->parent) {
                printk("%s %s\n %s %d\n %s %ld\n %s %lld\n %s %lld\n\n",









        }

        return 0;
}
```

Assignment 2:
Step 4: write user level app to call it

```c
#include <linux/unistd.h>
#include <sys/syscall.h>
#include <sys/types.h>
#include <stdio.h>
#include <unistd.h>

#define __NR_print_self 336

int main(int argc, char *argv[])
{
    syscall (__NR_print_self);
    return 0;
}
```

Compile and execute:

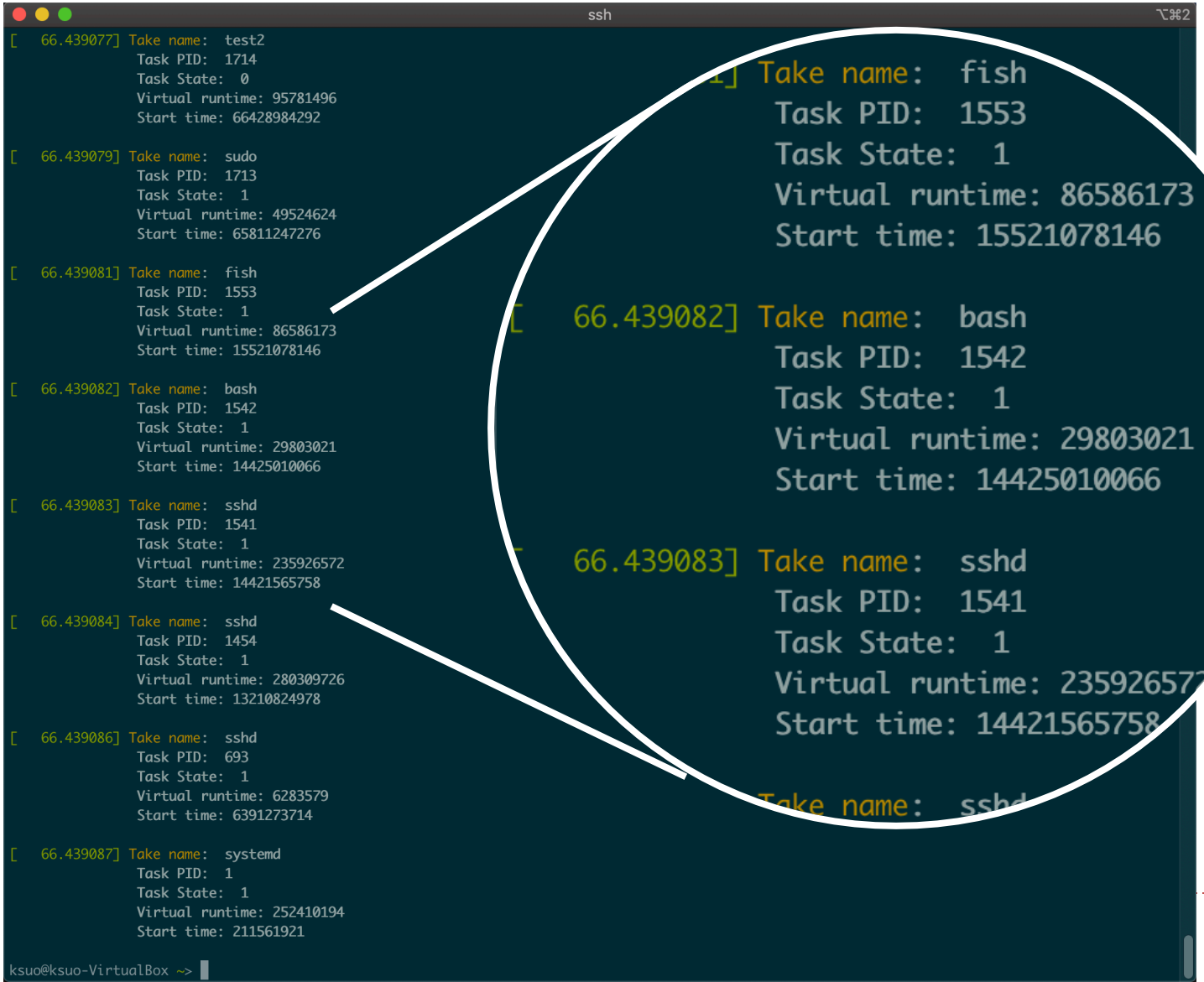
$ gcc test_syscall2.c -o test_syscall2

$ ./test_syscall2

The test program will call the new system call and output message at the tail of the output of dmesg (system log).

$ dmesg

At the end of output of $dmesg



Put it all together

User space

Step 4: user call it

syscall (336)

Step 1: register

arch/x86/entry/syscalls/syscall_64.tbl

336 …. …. ….

Kernel space

Step 2: declare

include/linux/syscalls.h

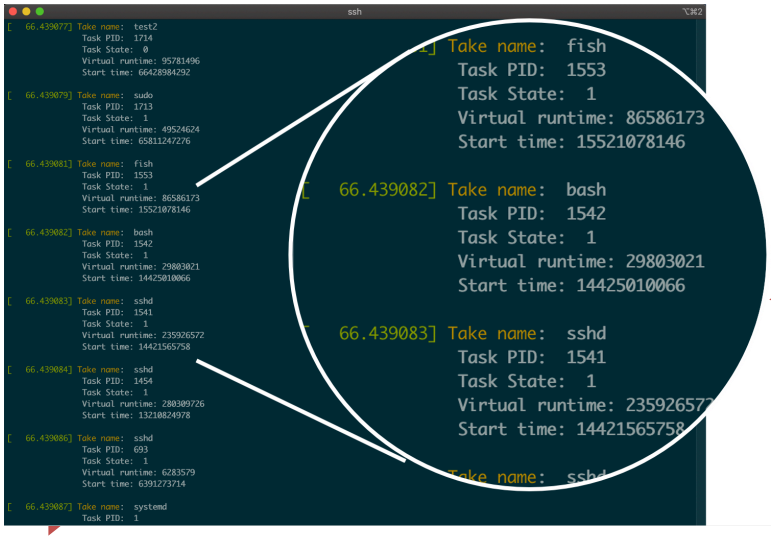
asmlinkage long …

kernel/sys.c

```
SYSCALL_DEFINE0(…)
{
   //print current process pid,
state, time, parent id, …
}
```

Step 3: implementation

$ dmesg



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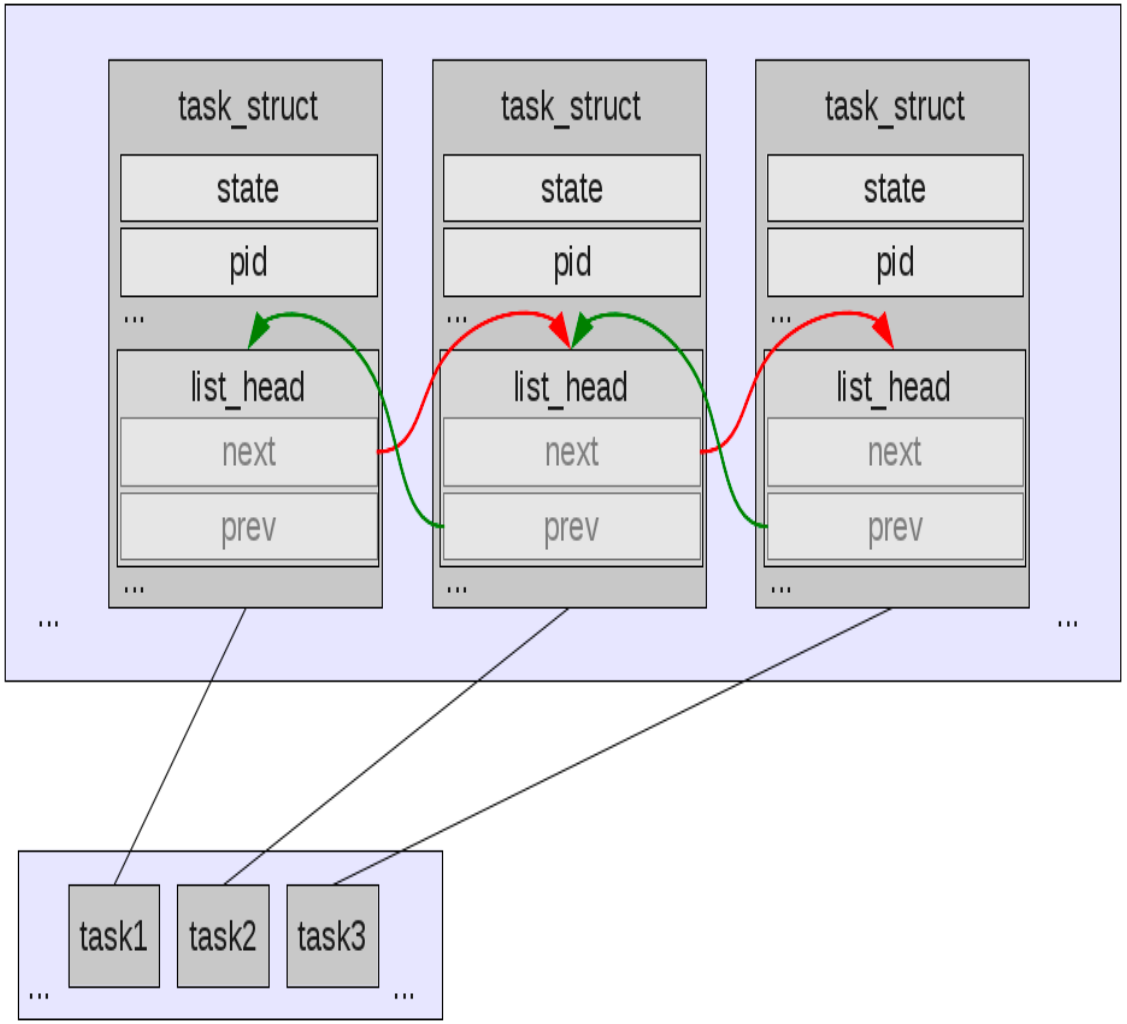
Assignment 3

- print_other to print the information for an arbitrary process. The system call takes a process pid as its argument and outputs the above information of this process.

- Input: pid
- Output:
  - Process id, running state, and program name
  - Start time and virtual runtime
  - Its parent processes until init (first system process)

Assignment 3



List_head

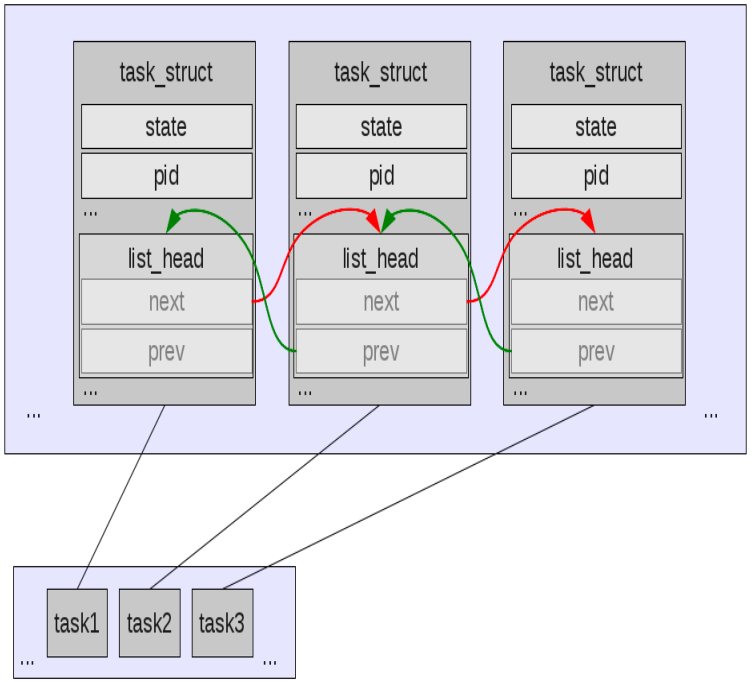
https://elixir.bootlin.com/linux/v5.1/source/include/linux/sched.h#L674

Next, prev

https://elixir.bootlin.com/linux/v5.1/source/include/linux/types.h#L186

Assignment 3

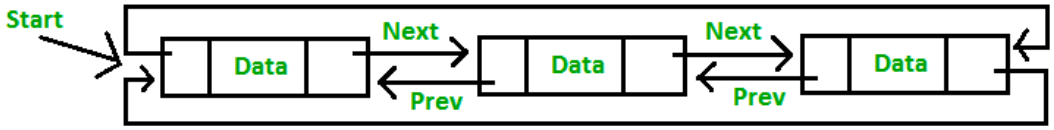
```
SYSCALL(int targetpid)
{
        //search pid from the list
        For loop
        {
                if (task->pid == targetpid)
                {
                        …
                }
        }

        //if the pid exists, then print information
        if (exist)
        {
                For loop until it reaches the init
                {
                        printk(…)
                }
        }
}
```



Assignment 3

```c
struct task_struct *p;
struct list_head *lh;

for (lh = &init_task->tasks->next; lh != &init_task->tasks; lh = lh->next) {
        p = list_entry(lh, struct task_struct, tasks);

        //search by pid
}

//if found pid, do something
//if not found, do something else
```

```
SYSCALL(int targetpid)
{
        //search pid
        For loop
        {
                if (task->pid == targetpid)
                {
                        …
                }
        }

        //if the pid exists, then print information
        if (exist)
        {
                For loop until it reaches the init
                {
                        printk(…)
                }
        }
}
```



Assignment 2

Syscall input with parameters

```
SYSCALL_DEFINE0(getpid)
{
        return task_tgid_vnr(current);
}
```

```
SYSCALL_DEFINE1(getpgid, pid_t, pid)
{
        return do_getpgid(pid);
}
```

```
SYSCALL_DEFINE2(sethostname, char __user *, name, int, len)
{
        int errno;
        char tmp[__NEW_UTS_LEN];
```

```
SYSCALL_DEFINE3(setpriority, int, which, int, who, int, niceval)
{
        struct task_struct *g, *p;
        struct user_struct *user;
        const struct cred *cred = current_cred();
        int error = -EINVAL;
```

Step 4: write user level app to call it

```c
#include <linux/unistd.h>
#include <sys/syscall.h>
#include <sys/types.h>
#include <stdio.h>
#include <unistd.h>

#define __NR_print_other 337

int main(int argc, char *argv[])
{
    int pid = 30;
    syscall (__NR_print_other, pid);
    return 0;
}
```

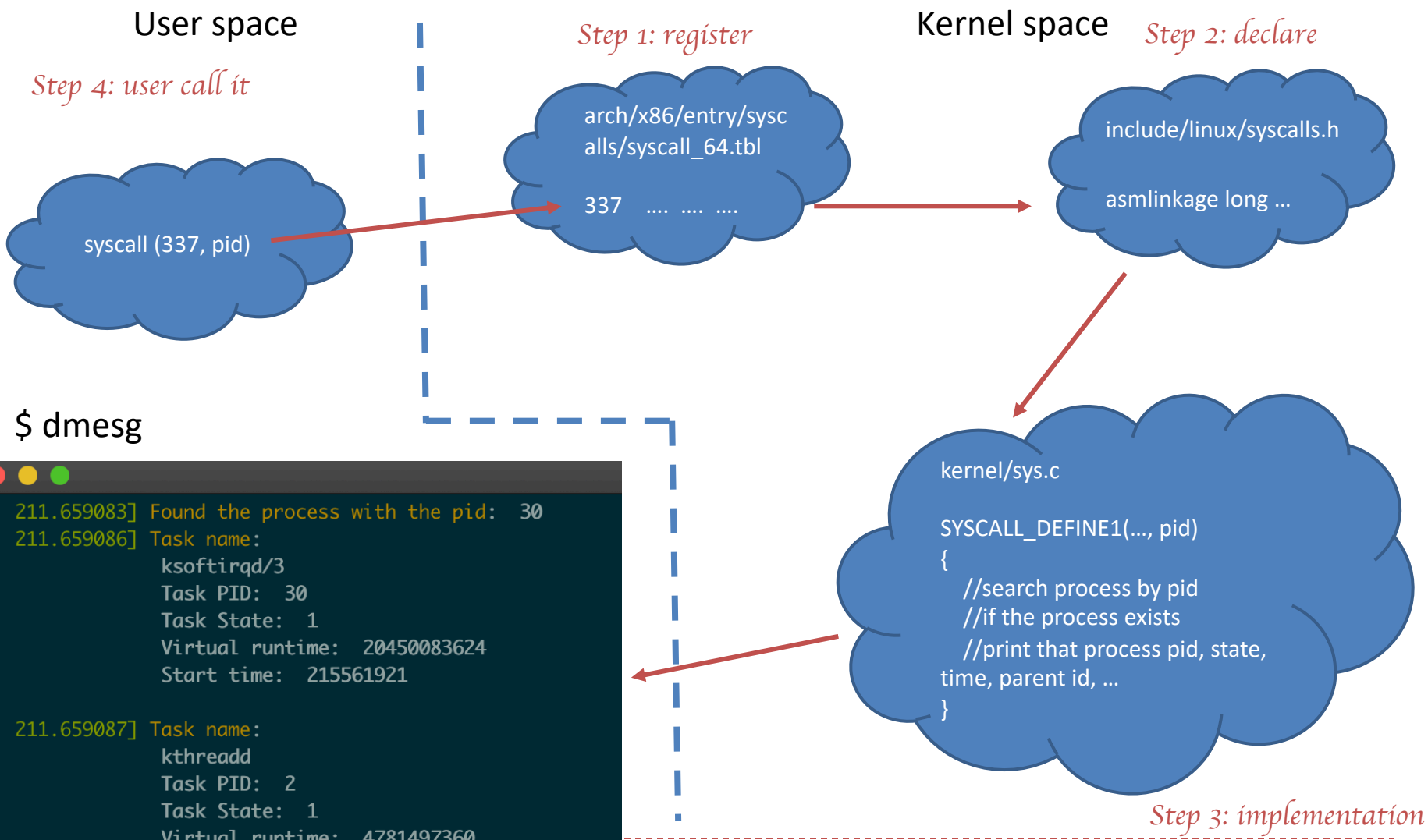
Compile and execute:

```
$ gcc test_syscall3.c -o test_syscall3
$ ./test_syscall3
```

The test program will call the new system call and output message at the tail of the output of dmesg (system log).

```
[  211.659083] Found the process with the pid:  30
[  211.659086] Task name:
               ksoftirqd/3
               Task PID:  30
               Task State:  1
               Virtual runtime:  20450083624
               Start time:  215561921

[  211.659087] Task name:
               kthreadd
               Task PID:  2
               Task State:  1
               Virtual runtime:  4781497360
               Start time:  211561921
```

Put it all together



$ dmesg

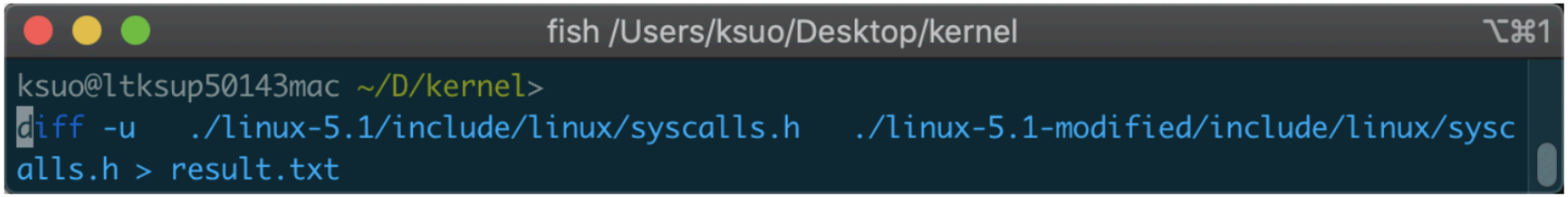
```
[  211.659083] Found the process with the pid:  30
[  211.659086] Task name:
               ksoftirqd/3
               Task PID:  30
               Task State:  1
               Virtual runtime:  20450083624
               Start time:  215561921

[  211.659087] Task name:
               kthreadd
               Task PID:  2
               Task State:  1
               Virtual runtime:  4781497360
               Start time:  211561921
```

Submission

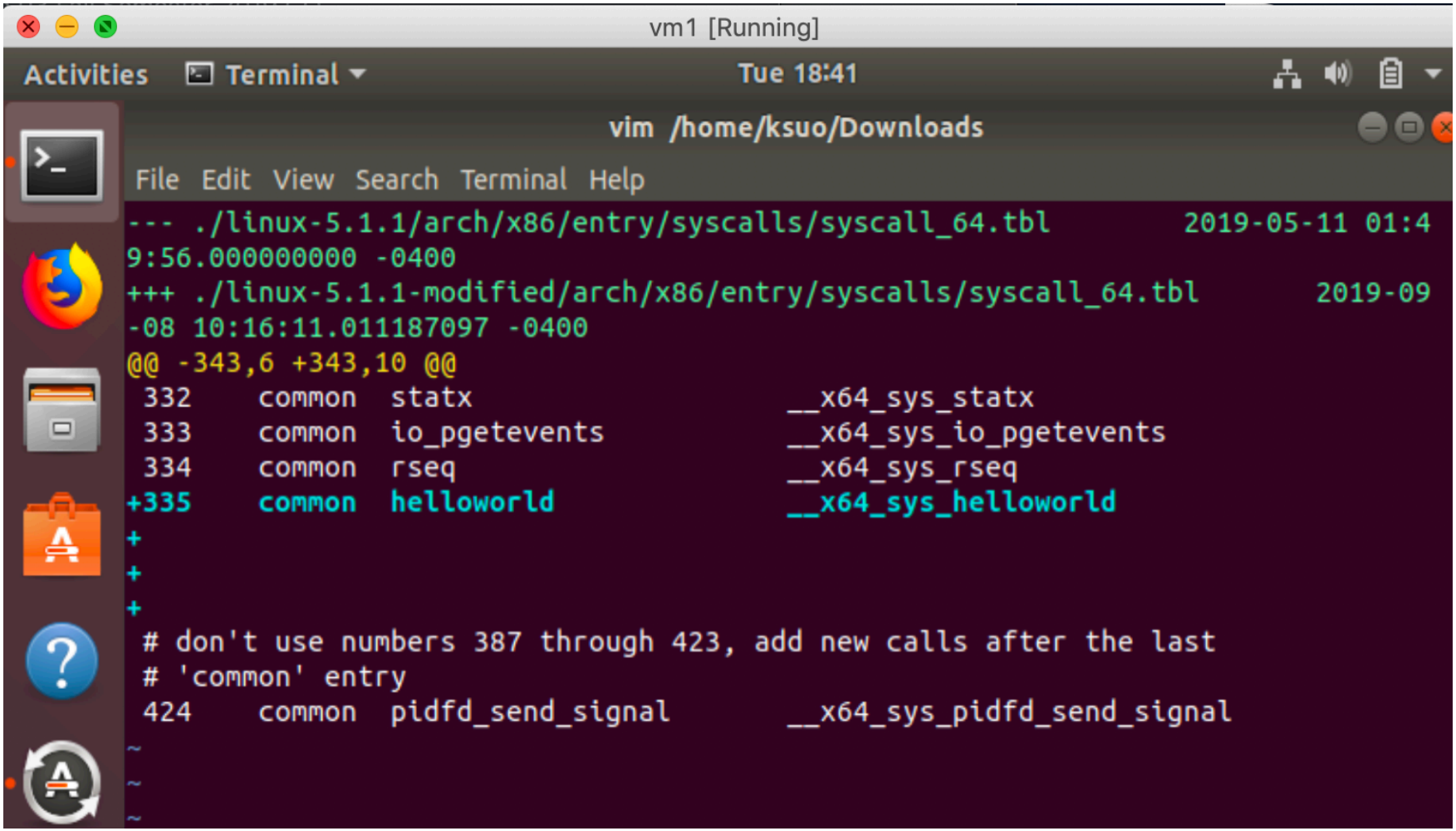
Please use diff command to highlight your modification:

$ diff -u original_file.c modified_file.c > result.txt

For example, to show the difference between file include/linux/syscalls.h, just use the command below:



result.txt content

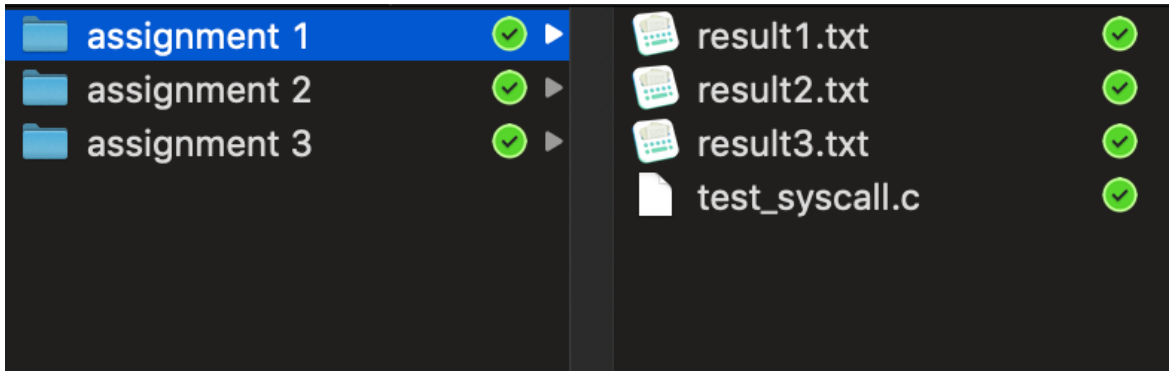


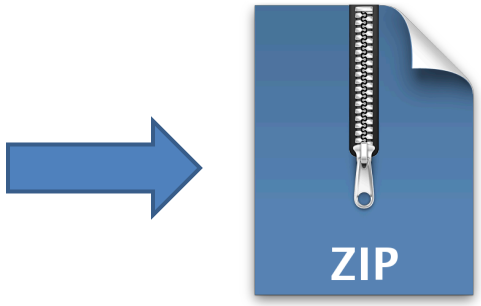
Submission

Please use diff command to highlight your modification:

$ diff -u original_file.c modified_file.c > result.txt

```
fish /Users/ksuo/Desktop/kernel                                    ⌥⌘1
ksuo@ltksup50143mac ~/D/kernel>
diff -u   ./linux-5.1/include/linux/syscalls.h   ./linux-5.1-modified/include/linux/sysc
alls.h > result.txt
```





CS3502_D2Lname.zip

Questions

- T/Th 3-4pm, J-318

- Send me emails or make appointments

Print in C

- User space
  - printf("%d", variable);
  - printf("%d", 1234);
- Kernel space
  - printk("%d", 1234);

Print in C

%c	character
%d	decimal (integer) number (base 10)
%f	floating-point number
%s	a string of characters
%u	unsigned decimal (integer) number
…	…

```
printk("%d", 1234);
printk("%c",  a);
printk("%f", -1.234);
printk("%s", “helloworld”);
…
```

Print in C

If variable is of Type,	use printk format specifier:
int	%d or %x
unsigned int	%u or %x
long	%ld or %lx
unsigned long	%lu or %lx
long long	%lld or %llx
unsigned long long	%llu or %llx
size_t	%zu or %zx
ssize_t	%zd or %zx
s32	%d or %x
u32	%u or %x
s64	%lld or %llx
u64	%llu or %llx

https://elixir.bootlin.com/linux/v5.1/source/include/linux/sched.h#L808

```
printk("%llu", start_time);
```

Print in C

If variable is of Type,	use printk format specifier:
int	%d or %x
unsigned int	%u or %x
long	%ld or %lx
unsigned long	%lu or %lx
long long	%lld or %llx
unsigned long long	%llu or %llx
size_t	%zu or %zx
ssize_t	%zd or %zx
s32	%d or %x
u32	%u or %x
s64	%lld or %llx
u64	%llu or %llx

https://elixir.bootlin.com/linux/v5.1/source/include/linux/sched.h#L594

printk("%ld", state);