Course Title: Kernel Programming & Device Drivers

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LTTS GLOBAL ENGINEERING ACADEMY

Agenda

- Introduction to Kernel
- Building Custom Kernel
- Kernel Modules
- Static and Dynamic Modules
- Kconfig entries
- Adding System Calls
- Summary

Version

Version	Reviewed by	Approved by	Remarks
1.0			

Learning Outcome of the Course

- Understanding Linux Kernel in depth
- Build Custom Kernel
- Writing Kernel Modules
- Adding new system calls

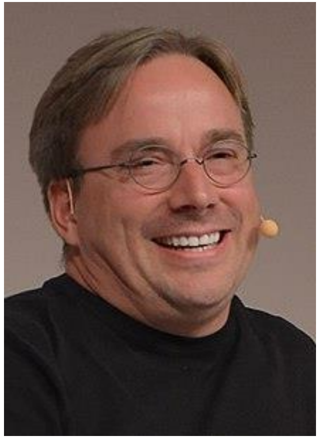
Pre-Requites

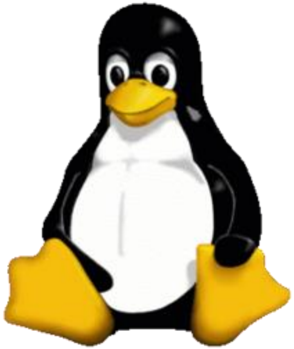
- Linux Command Line Basics
- Programming in Linux Environment
- Knowledge of Makefiles
- Awareness on Kernel
- Awareness on System Call

Introduction to Kernel

History & Introduction

- Initiated by Linus Torvalds as a hobby project in 1991
- Inspired by Minix OS designed by Andrew S Tanenbaum
- Driven by large and dynamic community
- Popular kernel for Free and Open Source Operating Systems, e.g. GNU Linux
- Licensed under GPLv2 terms





Linux Kernel - Highlights

- Scalable for wide range of architectures and configurations – tiny embedded devices to powerful super computers
- Standardized and interoperable programming interface (system calls, std compliance)
- Secure, Stable and Reliable
- Rich set of generic drivers
- Rich set of networking drivers & protocol stacks
- Upstream (mainline) vs Downstream kernel

Kernel Versions

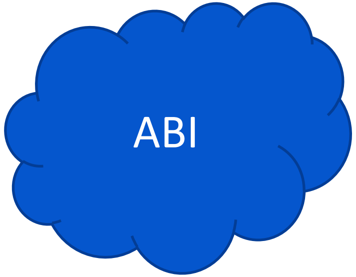
- a.b.c-d format
  - a.b represents major version
  - c represents release version
  - d represents local version
- Older convention of kernel versions (major, minor, release versions)
- Patch set, optional fourth digit
- Key changes between 2.4.x – 2.6.x
- LTS versions – Long Term Support
- 5.11.x is latest stable version (As on March 2021)

Architecture

- Dual Mode operations of modern CPUs
- Components of OS
  - Kernel
  - Drivers
  - Libraries
  - Utilities
- User mode and Kernel Mode
- User space and Kernel space
- Linux Kernel – Modular Architecture
- Access to kernel space
  - System Calls
  - Pseudo file systems – device files, procfs, sysfs, debugfs etc.

System Calls

- Interface between kernel space and userspace
- Defined in kernel, part of kernel core (static part)
- Invoked from user space and executed in kernel space
- Mode switching , Trap instruction
- Identified by unique number
- Passing system call number
- Passing parameters
- Handling return values
- Application Binary Interface (ABI)
- System call wrappers in user space, workflow behind
- System call workflow in kernel space
- Additional Ref:- https://courses.linuxchix.org/kernel-hacking-2002/09-understanding-system-calls.html



Programming Paradigm in Kernel

- Supported Languages – C and Assembly
- No libraries, but similar APIs for most purposes
- Avoid floating point operations
- ANSI/C89 standard
- Sensitive Memory Access Issues
- System call interface is stable , e.g., POSIX standard
- Volatile changes in kernel internal code & APIs

Kernel Source - Highlights

- Large proportion of architecture independent code
- Small amount of architecture dependent code
- Drivers – major stake in kernel source
- Top level directories in KSRC
  - Refer your kernel source or online LXR
  - Additional Ref:- https://courses.linuxchix.org/kernel-hacking-2002/08-overview-kernel-source.html

Qemu Based Emulation

Clean Workspace

- Choose a clean directory for all the work,
- You may choose directory like workspace/eworkspace/kworkspace/ebuildws/ews or with any sensible name under home directory
- Don’t use Desktop, Downloads, Documents, Music, Videos, Pictures etc, which are meant for other purpose.
- Avoid spaces or special symbols in path names
- Under this workspace keep different sub directories for downloaded packages, extracted source to build, configuration files, examples etc.

Setup Qemu

- Install Qemu, a full system emulator for ARM target architecture

```
sudo apt install qemu-system-arm
qemu-system-arm –v
qemu-system-aarch64 -v
```

- Alternative – Build from sources

```
Download latest stable version of Qemu source from
https://www.qemu.org/download/#source
tar –xvf qemu-5.x.y.tar.xz # replace 5.x.y by suitable version
cd qemu-5.x.y
./configure --targetlist=armsoftmmu, armlinuxuser
                              -–enable-sdl  --prefix=/opt/qemu-5.x.y
make && make install
export PATH=/opt/qemu-4.x.y/bin:$PATH # you may add this to ~/.bashrc
```

Rootfs

- Download core-image-minimal-qemuarm.ext4 from

  http://downloads.yoctoproject.org/releases/yocto/yocto-2.5/machines/qemu/qemuarm/

- Rename core-image-minimal-qemuarm.ext4 as rootfs.img
- Align the size of rootfs

```
e2fsck -f rootfs.img
resize2fs rootfs.img 16M
```

- Alternative

```
# Download core-image-minimal-qemuarm.tar.bz2 from same link
qemu-img create - f raw rootfs.img 64M
mkfs.ext4 rootfs.img
mount –o loop,rw,sync rootfs.img /mnt/image   # mkdir for first time
tar –jxvf core-image-minimal-qemuarm.tar.bz2 –C /mnt/image
umount /mnt/image
```

Toolchain

- Install linaro toolchain from ubuntu package manager

```
sudo apt install gcc-arm-linux-gnueabi                    # soft float
sudo apt install gcc-arm-linux-gnueabihf                  # hard float
```

  - We'll go for soft float for now, due rootfs compatibility

- Alternatively, download latest pre-built linaro toolchain from as per host architecture
  - From https://releases.linaro.org/components/toolchain/binaries/latest-7/arm-linux-gnueabi/, say v7.5.0

```
tar –xvf gcc-linaro-7.5.0-2019.12-x86_64_arm-linux-gnueabi.tar.xz –C /opt
export PATH=/opt/gcc-linaro-linux-gnueabi-7.5.0-2019.12_linux/bin:$PATH
```

  - Similarly gcc-linaro-7.5.0-2019.12-x86_64_arm-linux-gnueabihf.tar.xz for hard float

Your First Boot (Emulation)

- Collect prebuilt zImage, vexpress-v2p-ca9.dtb from faculty
- Ensure rootfs.img is also in same location
- Emulate using Qemu – sdcard approach

```
qemu-system-arm -M vexpress-a9 -m 1024 -serial stdio \
        -kernel zImage -dtb vexpress-v2p-ca9.dtb \
        -sd rootfs.img -append "console=ttyAMA0 root=/dev/mmcblk0 rw"
```

- Emulate using Qemu – initrd approach

```
qemu-system-arm -M vexpress-a9 -m 1024 -serial stdio \
        -kernel zImage -dtb vexpress-v2p-ca9.dtb \
        -initrd rootfs.img -append "console=ttyAMA0 root=/dev/ram0 rw"
```

First Steps on Target

```
uname -r
uname -v
uname -a
cat /proc/cpuinfo
free -m
df -kh
mount
dmesg
```

Building Custom Kernel (Qemu)

Download Kernel Source

- Download any recent LTS version of kernel source
- Let’s go with 4.14.x for now, for better compatibility with Qemu

```
wget https://cdn.kernel.org/pub/linux/kernel/v4.x/linux-4.14.202.tar.xz
tar –xvf linux-4.14.202.tar.xz
```

- Or you can checkout kernel source from git.kernel.org, and switch to desired branch

```
git clone https://git.kernel.org/pub/scm/linux/kernel/git/torvalds/linux.git
cd linux
git checkout tags/v4.14 –b v4.14
```

- Let’s call extracted content (or) checked out content as KSRC

Obtain Configuration File

- Locate default config available in KSRC/arch/arm/configs, we'll refer vexpress_defconfig for Versatil Express target being used for Qemu emulation
- Or collect any well tested configuration file as base config

```
make ARCH=arm mrproper
make ARCH=arm vexpress_defconfig
(or)
# copy custom config file as .config under KSRC
```

- Please note that mrproper will remove built files, including the configuration. So run this only for any new build.

Further Customization

- Run menuconfig for further customization
- Resolve any host dependencies at this stage, e.g. libncurses5-dev, flex, bison etc.

```
make ARCH=arm menuconfig
```

- Let’s do these minimal changes for now
  - General Setup -> Local Version -> "-custom“
  - Device Drivers -> Block Devices ->
    - Enable RAM Block device support
    - Increase default RAM disk size to suitable limit, say 65536
  - Enable the block layer
    - Support for large (2TB+)

Build the kernel

- Run menuconfig for further customization
- Build kernel image

```
make ARCH=arm CROSS_COMPILE=arm-linux-gnueabi- zImage -j <n>
```

- Build Device Tree Binaries

```
make ARCH=arm CROSS_COMPILE=arm-linux-gnueabi- dtbs firmware
```

- Build dynamic modules (can skip for now)

```
make ARCH=arm CROSS_COMPILE=arm-linux-gnueabi- modules
make ARCH=arm CROSS_COMPILE=arm-linux-gnueabi- modules_install \
       INSTALL_MOD_PATH=<tempdir> # or mount point of target rootfs
```

Test the Built outcome

- Collect built outcome to a temporary location

```
# switch to KSRC
cp $KSRC/arch/arm/boot/zImage       <path-of-temp-boot-dir>
cp $KSRC/arch/arm/boot/dts/*.dtb    <path-of-temp-boot-dir>
```

- Ensure rootfs.img is also in same location
- Emulate using Qemu

```
qemu-system-arm -M vexpress-a9 -m 1024 -serial stdio \
        -kernel zImage -dtb vexpress-v2p-ca9.dtb \
        -sd rootfs.img -append "console=ttyAMA0 root=/dev/mmcblk0 rw"
```

Post Boot Checks

```
# In Target
uname -r
uname -v
ls /boot                  # observe new entry
ls /lib/modules           # observe new entry


# In Host
ls -lh $KSRC/arch/arm/boot/zImage
ls -lh $KSRC/vmlinux
```

Cross Referencers – Browse Source code

- Cscope

```
make cscope
```

- Online LXR Tools
  - elixir.bootlin.com
  - lxr.linux.no

Building Custom Kernel (Native)

Download Kernel Source

- Let's consider the steps for Ubuntu 20.04, you can adapt suitable names, versions for other Ubuntu versions / Linux distributions
- Download custom source for Linux kernel from ubuntu package manager (compatible and similar one from which running kernel is built)

```
sudo apt install linux-source
# switch to suitable dir under workspace
tar –jxvf /usr/src/linux-source-5.4.0.tar.bz2
# consider extracted source as KSRC
```

- Alternatives:-
  - Download kernel source from kernel.org or any other reputed sites
  - Checkout kernel source from git.kernel.org or any other reputed repo

Configuration File

- Configuration file provided in /boot dir, i.e config-5.x.y-default
- Default configuration files under KSRC
- obtain configuration of running kernel

```
cp /proc/config.gz .
gunzip config.gz
mv config config_running
```

- Any other well tested configuration file, say config-custom

```
make mrproper
make x86_64_defconfig  # defconfig
# (or) copy identified config as .config
# make oldconfig   # can skip for now
```

Further Customization

- Run menuconfig

```
make menuconfig
# change local version, i.e. General Setup --> Local version --> "xxxxx"
```

Build the Kernel Image & Modules

```
sudo apt-get builddep linux
sudo apt-get install libncurses-dev flex bison openssl libssl-dev \
      dkms libelf-dev libudev-dev libpci-dev libiberty-dev autoconf

make –j 4 bzImage    # or 8, depending on no.of CPUs
make modules
make firmware
```

Ref:- https://wiki.ubuntu.com/Kernel/BuildYourOwnKernel

Deployment

```
make modules_install    # deploys dynamic modules to /lib/modules

make install            # Deploys compresses kernel image to /boot
                        # and updates GRUB configuration with an
                        # additional entry to boot new kernel
```

TODO:- signing new kernel image, modules in case SecureBoot is eanbled

Post Boot Checks

```
uname -r
uname -v
ls /boot                # observe new entry
ls /lib/modules         # observe new entry

ls -lh /boot/vmlinuz-5.x.y-custom
ls -lh $KSRC/arch/arm/boot/zImage
ls -lh $KSRC/vmlinux
```

Kernel Modules

Simple Hello Module

```c
//hello.c
#include <linux/init.h>
#include <linux/module.h>
#include <linux/kernel.h>
int __init init_module(void)
{
  printk("Hello World..welcome\n");
  return 0;
}
void __exit cleanup_module(void)
{
  printk("Bye,Leaving the world\n");
}

MODULE_LICENSE("GPL");
MODULE_AUTHOR("Your name");
MODULE_DESCRIPTION("A Simple Module");
```

```
# Makefile:-
obj-m += hello.o
```

```
# compile the module
make –C ${KSRC}  M=${PWD}  modules

# use ARCH=arm,
# CROSS_COMPILE=arm-linux-gnueabi-
# if cross compiling for Qemu
```

Use /lib/modules/`uname –r`/build as KSRC , if compiling for Host with available kernel headers.

Testing on Target (Qemu)

```
# copy the ko file to target rootfs
# if cross compiled for Qemu, skip this if
# compiled natively for ubuntu

sudo mount -o loop,rw,sync rootfs.img /mnt/rootfs
sudo cp hello.ko /mnt/rootfs/home/root
sudo umount /mnt/rootfs
```

```
# Testing module on target

dmesg -c
insmod hello.ko  # sudo
lsmod
cat /proc/modules
dmesg
rmmod hello      # sudo
dmesg
```

Testing on Host (Ubuntu)

```
# copy the ko file to target rootfs
# if cross compiled for Qemu, skip this if
# compiled natively for ubuntu

sudo mount -o loop,rw,sync rootfs.img /mnt/rootfs
sudo cp hello.ko /mnt/rootfs/home/root
sudo umount /mnt/rootfs
```

```
# Testing module on target

dmesg -c
insmod hello.ko  # sudo
lsmod
cat /proc/modules
dmesg
rmmod hello      # sudo
dmesg
```

Simple Hello Module

```
#include <linux/init.h>
#include <linux/module.h>
#include <linux/kernel.h>
static int __init hello_init(void) {
  printk("Hello World..welcome\n");
  return 0;
}
static void __exit hello_exit(void) {
  printk("Bye,Leaving the world\n");
}
module_init(hello_init);
module_exit(hello_exit);
MODULE_LICENSE("GPL");
MODULE_AUTHOR("Your name");
MODULE_DESCRIPTION("A Simple
Module");
```

```
//Makefile:-
obj-m += hello.o
KSRC = /lib/modules/$(shell uname -r)/build

all:
        make -C ${KSRC}  M=${PWD}  modules
clean:
        make -C ${KSRC}  M=${PWD}  clean

# use ARCH=arm,
# CROSS_COMPILE=arm-linux-gnueabi-
# if cross compiling for Qemu,
# and choose suitable KSRC depending on
# compiling for Qemu or Host
```

Significance of __init, __exit ??

Module Parameters

```
#include <linux/init.h>
#include <linux/module.h>
#include <linux/kernel.h>
int ndevices=1
module_param(ndevice,int,S_IRUGO);
static int __init pdemo_init(void) {
  printk("Hello World..welcome\n");
  return 0;
}
static void __exit pdemo_exit(void) {
  printk("Bye,Leaving the world\n");
}
module_init(pdemo_init);
module_exit(pdemo_exit);
MODULE_LICENSE("GPL");
MODULE_AUTHOR("Your name");
MODULE_DESCRIPTION("Parameter demo Module");
```

```
insmod hello.ko ndevices=5
```

modinfo paramdemo.ko

Module Dependency - simple

```
#include <linux/init.h>
#include <linux/module.h>
#include <linux/kernel.h>
int xvar=100;
void sayHello(void) {  }
static int __init simple_init(void) {
  printk("Hello World..welcome\n");
  return 0;
}
static void __exit simple _exit(void) {
  printk("Bye,Leaving the world\n");
}
module_init(simple_init);
module_exit(simple_exit);
EXPORT_SYMBOL_GPL(xvar);
EXPORT_SYMBOL_GPL(sayHello);
MODULE_LICENSE("GPL");
MODULE_AUTHOR("Your name");
MODULE_DESCRIPTION("A Hello, World Module");
```

```
//Makefile:-
obj-m += simple.o
```

Significance of MODULE_LICENSE, EXPORT_SYMBOL_GPL!!

Module Dependency - sample

```
#include <linux/init.h>
#include <linux/module.h>
#include <linux/kernel.h>
extern int xvar;
extern void sayHello(void);
static int __init sample_init(void) {
  printk("Hello World..xvar=%d\n“,xvar);
  sayHello();
  return 0;
}
static void __exit sample _exit(void) {
  printk("Bye,Leaving the world\n");
}
module_init(sample_init);
module_exit(sample_exit);
MODULE_LICENSE("GPL");
MODULE_AUTHOR("Your name");
MODULE_DESCRIPTION("A Hello, World Module");
```

```
//Makefile:-
obj-m += hello.o
```

- ❑ Can you load sample module before simple?
- ❑ Can you unload simple module before sample module?
- ❑ Idle sequence of loading & unloading modules
- ❑ Check modinfo on these

Symbol Table

```
cat /proc/kallsyms | grep xxx
# System.map generated in KSRC
# System.map-($ uname –r) in /boot, in case of native
# difference between kallsyms and System.map ??
```

```
arm-linux-gnueabi-nm vmlinux | less
arm-linux-gnueabi-objdump -t vmlinux | less
arm-linux-gnueabi-objdump -d vmlinux | less
```

In-Tree Module : Dynamic

```
#Create a sub dir in KSRC
mkdir drivers/char/dtest
# place hello.c in dtest

# create a Makefile in dtest
obj-m += hello.o

# add following entry to drivers/char/Makefile
# be cautious about this step, as editing
# existing file
obj-m += dtest/

# Re-build the kernel & redeploy
```

```
# Reboot with updated kernel image
# updated rootfs in case of Qemu

find /lib/modules -name hello.ko

dmesg -c
modprobe hello
```

TODO:- Try dynamic modules which are dependent each other

```
make ARCH=arm CROSS_COMPILE=arm-linux-gnueabi- zImage modules
sudo mount -o loop,rw.sync rootfs.img /mnt/rootfs
make ARCH=arm CROSS_COMPILE=arm-linux-gnueabi- modules_install INSTALL_MOD_PATH=/mnt/rootfs
sudo umount /mnt/rootfs
```

Static Module (In-Tree)

```
#Create a sub dir in KSRC
mkdir drivers/char/stest
# place sdemo.c in dtest

# create a Makefile in dtest
obj-y += sdemo.o

# add following entry to drivers/char/Makefile
obj-y += stest/
# be cautious , as editing existing file

# Re-build the kernel & redeploy
# reboot with new kernel
# No need to rebuild modules (or) modules_install
```

```
arm-linux-gnueabi-nm vmlinux | grep sdemo_init
arm-linux-gnueabi-objdump -t vmlinux | grep sdemo_init
# normal nm, objdump in case of native
```

```
#check /proc/kallsyms
cat /proc/kallsyms | grep sdemo_init
cat /proc/kallsyms | grep svar
cat /proc/kallsyms | grep sayHello
dmesg | grep sdemo

# check sdemo_init under generated
# System.map also
```

- ❑ Do sdemo_exit visible under kernel symbol table?
- ❑ Check symbol table with or without __init
- ❑ Do sdemo is listed under lsmod or available under /lib/modules?

Static Module (In-Tree)

```
//sdemo.c – ref code for static module

int svar=100;
void sayHello(void);

static int __init sdemo_init(void) {
  int i;
  for(i=1;i<=4;i++)
    printk("sdemo, i=%d\n",xvar);
  return 0;
}

static void __exit sdemi _exit(void) {
  printk("Bye,Leaving the world\n");
}

EXPORT_SYMBOL_GPL(svar);
EXPORT_SYMBOL_GPL(sayHello);
```

Kconfig entries

```
# Create a dir driver/char/mtest under KSRC
# Place simple.c, sample.c in mtest
```

```
# driver/char/mtest/Kconfig

config SIMPLE
  tristate "Simple module"     #bool
  default n
  help  A simple module

config SAMPLE
  tristate "Sample module"     #bool
  depends on SIMPLE
  default n
  help  A sample module
```

```
# drivers/char/mtest/Makefile
obj-$(CONFIG_SIMPLE) += simple.o
obj-$(CONFIG_SAMPLE) += sample.o
```

```
# drivers/char/Makefile
obj-y += mtest/
```

```
# drivers/char/Kconfig
source "drivers/char/mtest/Kconfig"
```

Kconfig entries

```
# driver/char/mtest/Kconfig – v2

menu "My Custom Modules“

config SIMPLE
  tristate "Simple module"     #bool
  default n
  help  A simple module

config SAMPLE
  tristate "Sample module"     #bool
  depends on SIMPLE
  default n
  help  A sample module

endmenu
```

No changes required for

- drivers/char/Makefile
- drivers/char/Kconfig
- drivers/char/mtest/Makefile

- ❑ Observe changes in menuconfig
- ❑ Observe generated .config, and entries CONFIG_SIMPLE, CONFIG_SAMPLE
- ❑ Check the dependency between config entries

Kconfig entries

```
# driver/char/mtest/Kconfig – v3
menuconfig CUSTOM
tristate "My Custom Modules"
select SIMPLE
help  "My Custom modules"
if CUSTOM
config SIMPLE
  tristate "Simple module"     #bool
  default n
  help  A simple module

config SAMPLE
  tristate "Sample module"     #bool
  depends on SIMPLE
  default n
  help  A sample module
endif
```

```
# drivers/char/Makefile
obj-$(CONFIG_CUSTOM) += mtest/
```

No changes required for

- drivers/char/Kconfig
- drivers/char/mtest/Makefile

TODO:-
Add Kconfig entries to sdemo (static module)

Adding System Calls

Adding system call in kernel space (ARM)

```
//include/linux/syscalls.h
asmlinkage long sys_mytestcall(void);
```

```
//arch/arm/tools/syscall.tbl
398   common  mytestcall mysys_testcall
```

```
//kernel/sys.c (or)
//add in kernel/mysys.c and
//adjust kernel/Makefile with
//       obj-y +=mysys.o

SYSCALL_DEFINE0(testcall)
{
  printk("This is my test call\n");
  return 0;
}
```

TODO:-

- ❑ Receiving simple arguments
- ❑ Receiving strings
- ❑ Receiving structure variables
- ❑ Returning results via structures

Checking system call presence

On host:-
arm-linux-gnueabi-nm vmlinux | grep mytestcall

On target:-
cat /proc/kallsyms | grep mytestcall

Invoking System Call from Userspace

```
//Method-1 : generic wrapper syscall
#include<unistd.h>
#include<stdio.h>

#define __NR_testcall 398

int main() {
  int ret;
  ret=syscall(__NR_testcall);
  if(ret<0)
     perror("testcall");
  return 0;
}
```

TODO:-

Invoking System calls

- ❑ Passing simple arguments
- ❑ Passing strings
- ❑ Passing structure variables
- ❑ Retrieving results via structures

Invoking System Call from Userspace

```
//Method-2A : Simple Assembly
Code
mov r7,#398
SVC 0
mov r7,#1
mov r0,#0
SVC 0
```

```
//Method-2B : Inline Assembly
asm("MOV r7, #398;"
    "SVC #0;"
    "MOV %[result], r0" : [result] "=r" (ret)
);
```

```
arm-linux-gnueabi-as test.s –o test.o
arm-linux-gnueabi-ld test.o –o test.out
```

```
arm-linux-gnueabi-gcc test.c –o t.out
```

```
arm-linux-gnueabi-objdump –d test.o
```

Coding Time – Own System Calls

- Write your own system call which takes simple parameters
- Write your own system call which returns length of passed string
- Write your own system call which returns reversed string (or) echo back
- Write your own system call which logs pid, ppid of calling process
- Write your own system call which returns pid of calling process
- Write your own system call which logs various attributes of calling process
- Write your own system call which returns various attributes of calling process (by passing an empty structure variable), Hints:- sched.h, struct task_struct, current macro
  - pid, ppid, command name
  - uid, gid of process owner
  - state, priority
- Write your own system call which traverses entire process list and logs pid, ppid, command name of each process , Hint:- next_task, init_task

Userspace test code to invoke each system call
you may use syscall macro for simplicity

Appendix – Signing Modules

Secure Boot : Signing Modules (Ubuntu Native)

```
mokutil --sb-state                          # check if secure boot is enabled or not

# Choose a secure dir, say /root/mysignatures
openssl req -new -x509 -newkey rsa:2048 -keyout MOK.priv -outform DER -out MOK.der \
                                          -nodes -days 36500 -subj "/CN=YOUR_NAME/“

mokutil --import /root/mysignatures/MOK.der  # register password when prompted
# reboot the system, feed specific characters of registered passwod
/usr/src/linux-headers-5.4.0-52-generic/scripts/sign-file sha256      \
              /root/mysignatures/MOK.priv /root/mysignatures/MOK.der hello.ko
```

```
# Create script sign-my-module in /usr/local/sbin
/usr/src/linux-headers-5.4.0-52-generic/scripts/sign-file sha256      \
              /root/mysignatures/MOK.priv /root/mysignatures/MOK.der $1

# To sign any module
sign-my-module
```

Thank You !

L&T Technology Services