Device driver programming:

Can we load module statically?
Yes, It needs a bit of hacking to move into kernel source tree. Tweak the Makefile or Kconfig so that the code is built in. and then rebuild kernel image. For ex: you move code to drivers/ directory and update Makefile of drivers.

How to configure and install kernel:
1) Download the kernel source code.
2) Extract the Source Code: `tar xvf linux-5.9.6.tar.xz`
3) Configure Kernel:
   - Navigate to the code directory using the `cd` command (`cd linux-5.9.6`)
   - Copy the existing configuration file using the `cp` command (`cp -v /boot/config-$(uname -r) .config`)
   - To make changes to the configuration file, run the `make` command (`make menuconfig`)
4) Build the Kernel (make -j 4)
5) Install the required modules with this command (`sudo make modules_install`)
6) `Install the kernel (sudo make install)`
7) `Update initramfs`
8) `Update grub.`
   `Check installed kernel version: uname -r`
   `check installed kernel date: uname -v`
   `Kernel is installed in path: /lib/modules/$(uname-r)`

lsmod – List Modules that Loaded Already

lsmod command will list modules that are already loaded in the kernel as shown beblow.

```
# lsmod
Module                  Size  Used by
ppp_deflate            12806  0
zlib_deflate           26445  1 ppp_deflate
bsd_comp               12785  0
..
```

2. insmod – Insert Module into Kernel

insmod command will insert a new module into the kernel as shown below.

```
# insmod /lib/modules/3.5.0-19-generic/kernel/fs/squashfs/squashfs.ko

# lsmod | grep "squash"
squashfs               35834  0
```

3. modinfo – Display Module Info

modinfo command will display information about a kernel module as shown below.

```
# modinfo /lib/modules/3.5.0-19-generic/kernel/fs/squashfs/squashfs.ko

filename:       /lib/modules/3.5.0-19-generic/kernel/fs/squashfs/squashfs.ko
license:        GPL
author:         Phillip Lougher
description:    squashfs 4.0, a compressed read-only filesystem
srcversion:     89B46A0667BD5F2494C4C72
depends:
intree:         Y
```

```
vermagic:       3.5.0-19-generic SMP mod_unload modversions 686
```

4. rmmod – Remove Module from Kernel

rmmod command will remove a module from the kernel. You cannot remove a module which is already used by any program.

```
# rmmod squashfs.ko
```

5. modprobe – Add or Remove modules from the kernel

modprobe is an intelligent command which will load/unload modules based on the dependency between modules. Refer to modprobe commands for more detailed examples.

II. Write a Simple Hello World Kernel Module

1. Installing the linux headers

You need to install the linux-headers-.. first as shown below. Depending on your distro, use apt-get or yum.

```
# apt-get install build-essential linux-headers-$(uname -r)
```

2. Hello World Module Source Code

Next, create the following hello.c module in C programming language.

```
#include <linux/module.h>    // included for all kernel modules
#include <linux/kernel.h>    // included for KERN_INFO
#include <linux/init.h>      // included for __init and __exit macros

MODULE_LICENSE("GPL");
MODULE_AUTHOR("Ankit");
MODULE_DESCRIPTION("A Simple Hello World module");

static int __init hello_init(void)
{
    printk(KERN_INFO "Hello world!\n"); //printing to kernel buffer.
    return 0;    // Non-zero return means that the module couldn't be loaded.
}

static void __exit hello_cleanup(void)
{
    printk(KERN_INFO "Cleaning up module.\n"); //printing to kernel buffer.
}

module_init(hello_init);
module_exit(hello_cleanup);
```

Warning: All kernel modules will operate on kernel space, a highly privileged mode. So be careful with what you write in a kernel module.

3. Create Makefile to Compile Kernel Module

The following makefile can be used to compile the above basic hello world kernel module.

```
obj-m += hello.o
```

```
all:
    make -C /lib/modules/$(shell uname -r)/build M=$(PWD) modules

clean:
    make -C /lib/modules/$(shell uname -r)/build M=$(PWD) clean
```

Use the make command to compile hello world kernel module as shown below.

```
# make

make -C /lib/modules/3.5.0-19-generic/build M=/home/lakshmanan/a modules
make[1]: Entering directory `/usr/src/linux-headers-3.5.0-19-generic'
  CC [M]  /home/lakshmanan/a/hello.o
  Building modules, stage 2.
  MODPOST 1 modules
  CC      /home/lakshmanan/a/hello.mod.o
  LD [M]  /home/lakshmanan/a/hello.ko
make[1]: Leaving directory `/usr/src/linux-headers-3.5.0-19-generic'
```

The above will create hello.ko file, which is our sample Kernel module.

4. Insert or Remove the Sample Kernel Module

Now that we have our hello.ko file, we can insert this module to the kernel by using insmod command as shown below.

```
# insmod hello.ko

# dmesg | tail -1
[ 8394.731865] Hello world!

# rmmod hello.ko

# dmesg | tail -1
[ 8707.989819] Cleaning up module.
```

When a module is inserted into the kernel, the **module_init** macro will be invoked, which will call the function hello_init. Similarly, when the module is removed with rmmod, **module_exit** macro will be invoked, which will call the hello_exit. Using dmesg command, we can see the output from the sample Kernel module.

Output file generated when we compile our module:

modules.order

```
--------------------------------------------------
This file records the order in which modules appear in Makefiles. This
is used by modprobe to deterministically resolve aliases that match
multiple modules.

----------------------------------------------------------------------


If the files are present the source file is compiled to a "modulname.o", and
"modulename.mod.c" is created which is compiled to "modulename.mod.o".
The modulename.mod.c is a file that basically contains the information about the
module (Version information etc).
```

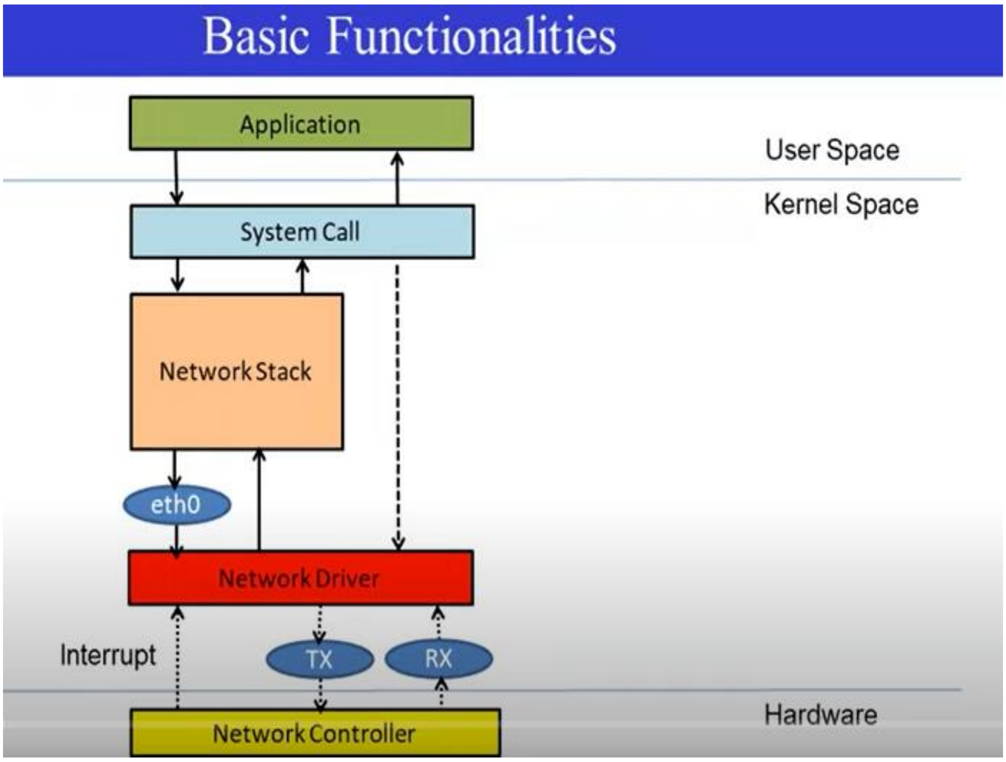
The modulename.o and the modulename.mod.o are linked together by modpost in the next stage to create the "modulename.ko" .

Network Device driver stack:

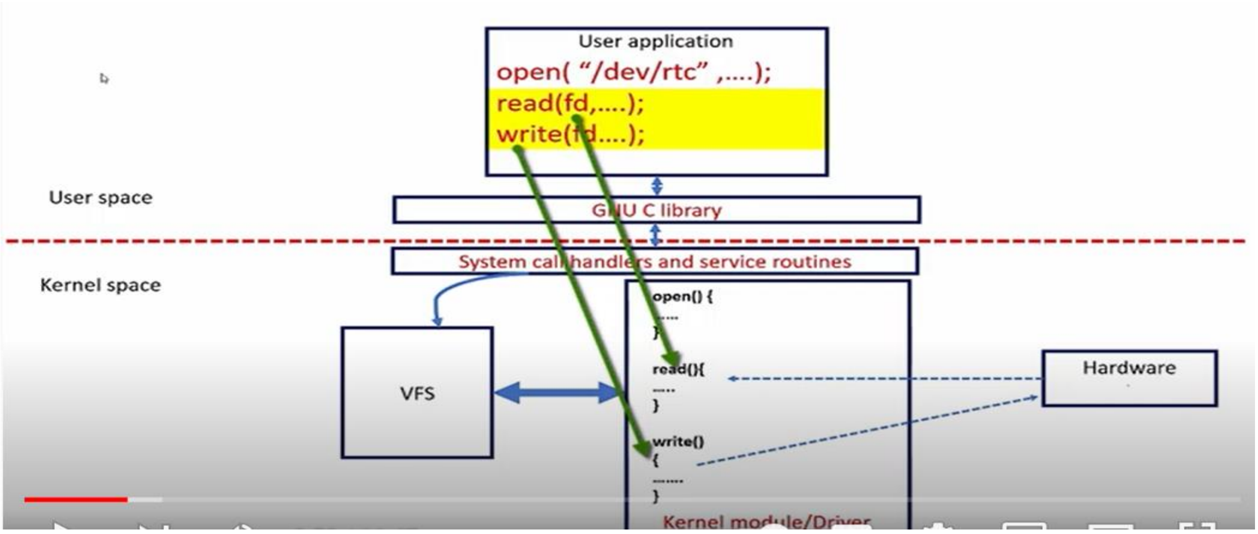
Struct net_dvice is used for network device.

Device Allocation: alloc_netdev()

Device Registration: register_netdevice()



Character device driver:



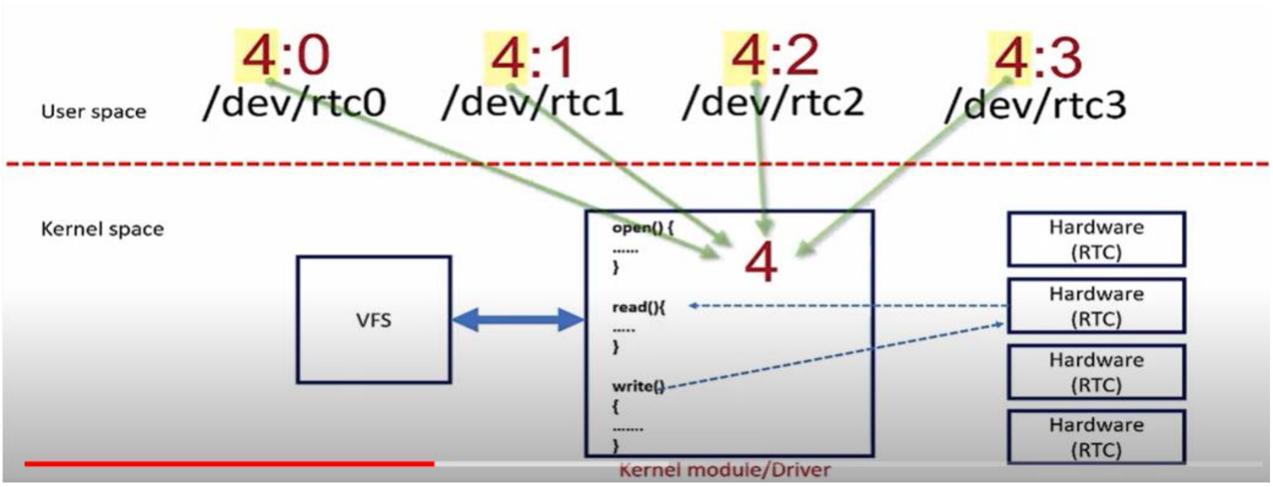
When we want to communicate(open/read/write) to device. Application calls system call (open/read/write)

User space system call is connected to driver system call implementation is taken care by VFS. Our device driver has to get registered with vfs.

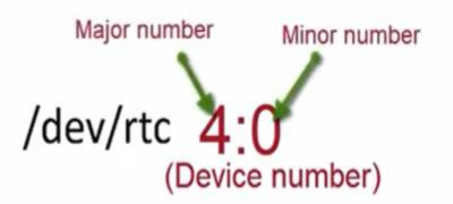
When you use open system call on device file, how does the kernel connect to open system call to intended driver's open call?

Kernel uses device no. Assign no. to driver

Below there are 4 instances of rtc type devices but driver will be same for all devices. There are 4 files created by driver. Communication with device will be done using device files.



Device number is combination of major number and minor number.



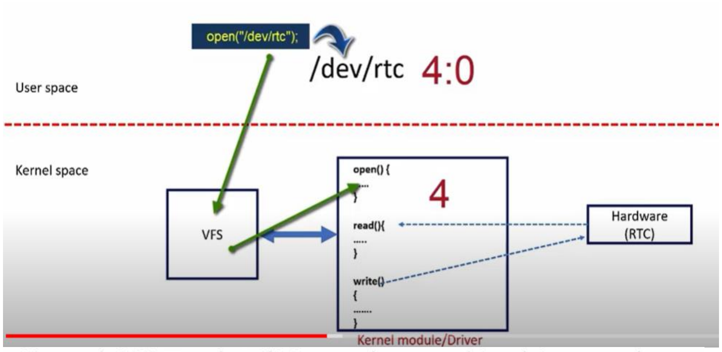
Major no. and minor no. can be checked in system by cd to dev and check ls-l command:

Connection establishment b/w device file access and driver:

Driver creates the device no., device file, makes char device registration with VFS using CDEV_ADD and

Implements the driver's file operation methods for open. Read, write etc.

When user program uses open system call on device file(dev/rtc), system call is handled by VFS first. VFS gets the device no. and compares it with driver registration list, that means this driver to get registered with VFS using device no. that we call character device add, CDEV_ADD (). When VFS gets open call from application, it opens a file by creating new file object and linking it to corresponding inode object.



Kernel APIs and utilities to be used in driver code

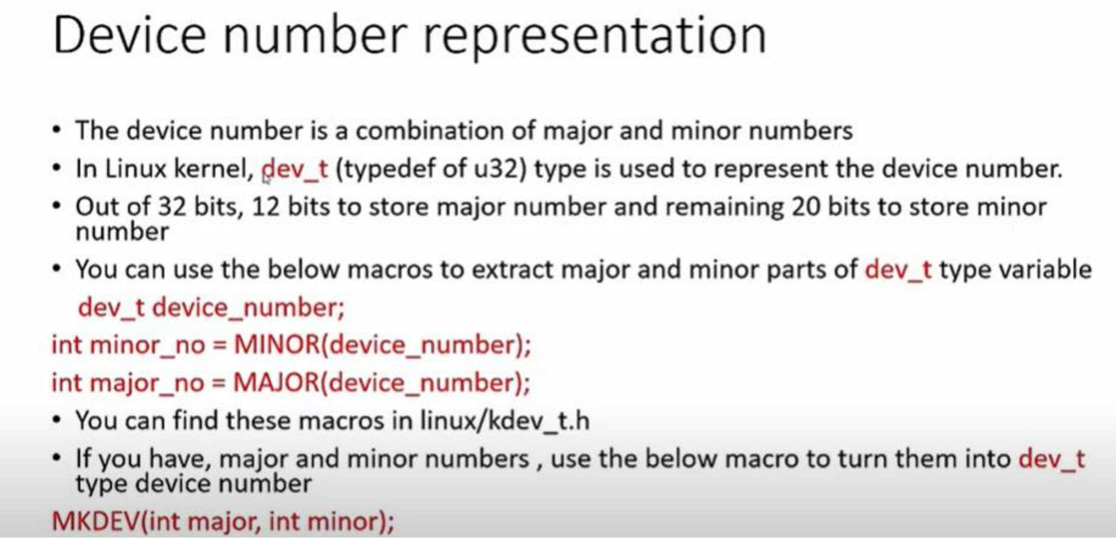
alloc_chrdev_region();	1.Create device number
cdev_init(); cdev_add();	2. Make a char device registration with the VFS
class_create(); device_create();	3. Create device files

Below creation calls are written in Init function of driver and deletion calls in Exit function of driver.

Creation	Deletion
alloc_chrdev_region();	unregister_chrdev_region();
cdev_init(); cdev_add();	cdev_del();
class_create(); device_create();	class_destroy(); device_destroy();

Kernel Header file details

Kernel functions and data structures	Kernel header file
alloc_chrdev_region() unregister_chrdev_region()	include/linux/fs.h
cdev_init() cdev_add() cdev_del()	include/linux/cdev.h
device_create() class_create() device_destroy() class_destroy()	include/linux/device.h
copy_to_user() copy_from_user()	include/linux/uaccess.h
VFS structure definitions	inclue/linux/fs.h



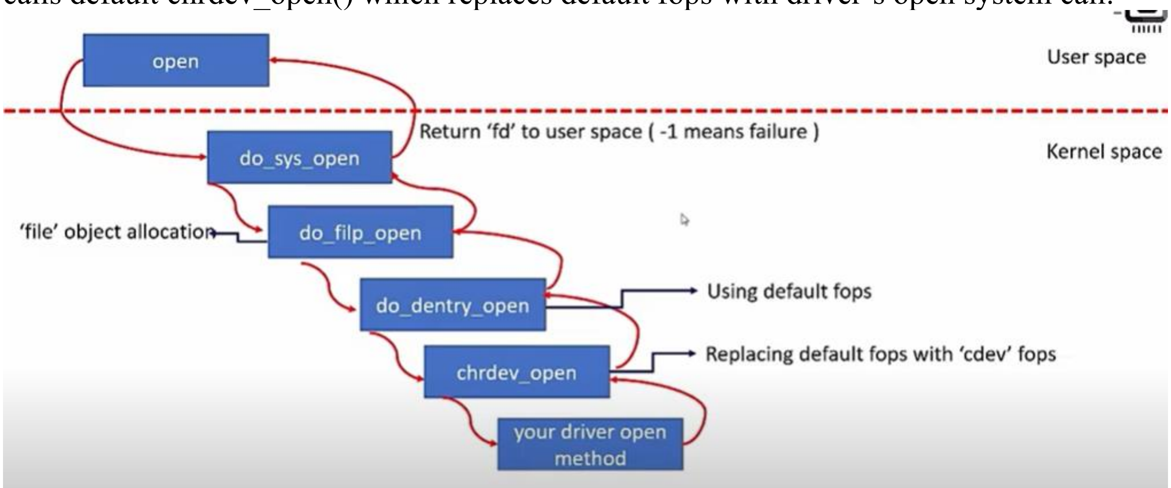
Device Files: The device file allows transparent communication b/w user-space application and hardware.

Device file creation:

1) **Manually:** We can create device file manually by mknod:
   mknod -m <permissions> <name> <device type> <major> <minor>
   sudo mknod -m 666 /dev/etx_device c 246 0

2) **Automatically:** The automatic creation of device files can be handled with udev. Udev is the device manager for the Linux kernel that creates/removes device nodes in the /dev directory dynamically.

   When device file is created -> vfs calls special_init_inode() function and this function checks type of device. inode object created in memory ->
   special_init_inode() does: in memory inode object's **device no** is initialized with device number of newly created device file. and inode object's file ops is initialized with dummy default file operation methods.
   When we call open method ()->
   file object is created and now it calls do_dentry_open(). do_dentry_open() uses default ops. It calls default chrdev_open() which replaces default fops with driver's open system call.



When device file gets created

1) create device file using udev
2) inode object gets created in memory and inode's i_rdev field is initialized with device number
3) inode object's i_fop field is set to dummy default file operations (def_chr_fops)

When user process executes open system call

1) user invokes open system call on the device file
2) file object gets created
3) inode's i_fop gets copied to file object's f_op (dummy default file operations of char device file)
4) open function of dummy default file operations gets called (chrdev_open)
5) inode object's i_cdev field is initialized with cdev which you added during cdev_add (lookup happens using inode-> i_rdev field)
6) inode->cdev->fops (this is a real file operations of your driver) gets copied to file->f_op
7) file->f_op->open method gets called (read open method of your driver)