

# ECE4730J

## Advanced Embedded System

### LAB 4: WRITE AND LOAD A KERNEL MODULE

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Name	Student ID
Yihua Liu	518021910998
Shuocheng Chen	517021911139
Yiming Ju	518370910059

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1. Bash script [5]:

```
1 mkdir modules
2 cd modules
3 # Copy simple_module.c to modules by SFTP/SCP
4 # Write a Makefile
5 sudo apt install bison # dependency
6 sudo make -C /usr/src/linux-headers-5.11.0-1021-raspi M=$PWD
   ↪ modules
```

Makefile [4]:

```
1 obj-m := simple_module.o
```

Note that SUBDIR= is no longer supported since Ubuntu 20.04, use M= instead [2]. Detailed information is summarized in [3]. Output:

```
1 make: Entering directory
   ↪ '/usr/src/linux-headers-5.11.0-1021-raspi'
2 CC [M] /home/yihua/modules/simple_module.o
3 MODPOST /home/yihua/modules/Module.symvers
4 CC [M] /home/yihua/modules/simple_module.mod.o
5 LD [M] /home/yihua/modules/simple_module.ko
6 make: Leaving directory
   ↪ '/usr/src/linux-headers-5.11.0-1021-raspi'
```

It will generate:

- Module.symvers
- modules.order
- simple\_module.ko

- simple\_module.mod
- simple\_module.mod.c
- simple\_module.mod.o
- simple\_module.o
- .Module.symvers.cmd
- .modules.order.cmd
- .simple\_module.ko.cmd
- .simple\_module.mod.cmd
- .simple\_module.mod.o.cmd
- .simple\_module.o.cmd

```
yihua@ECE4730J-FA2021-Group3:~/modules$ sudo make -C /usr/src/linux-headers-5.11.0-1021-raspi M=$PWD modules
make: Entering directory '/usr/src/linux-headers-5.11.0-1021-raspi'
CC [M] /home/yihua/modules/simple_module.o
MODPOST /home/yihua/modules/Module.symvers
CC [M] /home/yihua/modules/simple_module.mod.o
LD [M] /home/yihua/modules/simple_module.ko
make: Leaving directory '/usr/src/linux-headers-5.11.0-1021-raspi'
```

Figure 1. The output after we compile the module.

2. Output of dmesg:

```
1 [11933.762154] simple_module: loading out-of-tree module taints
   ↪ kernel.
2 [11933.762612] simple_module initialized
```

```
yihua@ECE4730J-FA2021-Group3:~/modules$ sudo insmod simple_module.ko
yihua@ECE4730J-FA2021-Group3:~/modules$ dmesg
dmesg: read kernel buffer failed: Operation not permitted
yihua@ECE4730J-FA2021-Group3:~/modules$ sudo dmesg
[11933.762154] simple_module: loading out-of-tree module taints kernel.
[11933.762612] simple_module initialized
yihua@ECE4730J-FA2021-Group3:~/modules$
```

Figure 2. The message that appears in the system log.

3. Output of lsmod <sup>1</sup>:

1	Module	Size	Used by
2	simple_module	16384	0
3	rfcomm	94208	4

<sup>1</sup>Warning: do not use Lab4-\*.log for the file names of \ inputminted, otherwise they will be deleted by bibtex.

4	cmac	16384	2	
5	algif_hash	20480	1	
6	aes_arm64	16384	2	
7	algif_skcipher	20480	1	
8	af_alg	32768	6	algif_hash,algif_skcipher
9	hci_uart	151552	1	
10	btqca	24576	1	hci_uart
11	btrtl	24576	1	hci_uart
12	btbcm	24576	1	hci_uart
13	btintel	32768	1	hci_uart
14	bnep	32768	2	
15	snd_soc_hdmi_codec	24576	2	
16	vc4	290816	16	
17	drm_kms_helper	282624	3	vc4
18	cec	73728	2	drm_kms_helper,vc4
19	snd_soc_core	278528	2	vc4,snd_soc_hdmi_codec
20	snd_bcm2835	32768	1	
21	btsdio	20480	0	
22	snd_compress	32768	1	snd_soc_core
23	ac97_bus	16384	1	snd_soc_core
24	snd_pcm_dmaengine	20480	1	snd_soc_core
25	bluetooth	696320	35	
	↪ btrtl,btqca,btsdio,btintel,hci_uart,btbcm,bnep,rftcomm			
26	snd_pcm_oss	61440	0	
27	snd_mixer_oss	32768	1	snd_pcm_oss
28	ecdh_generic	16384	1	bluetooth
29	input_leds	16384	0	
30	joydev	28672	0	
31	ecc	32768	1	ecdh_generic
32	snd_pcm	139264	6	snd_bcm2835,snd_soc_hdmi_codec,
	↪ ,snd_compress,snd_pcm_oss,snd_soc_core,snd_pcm_dmaengine			
33	snd_seq_dummy	16384	0	
34	snd_seq_oss	53248	0	
35	snd_seq_midi	20480	0	
36	snd_seq_midi_event	16384	2	snd_seq_midi,snd_seq_oss
37	bcm2835_isp	32768	0	
38	bcm2835_codec	49152	0	
39	bcm2835_v4l2	45056	0	
40	brcmfmac	393216	0	
41	snd_rawmidi	49152	1	snd_seq_midi
42	v4l2_mem2mem	40960	1	bcm2835_codec
43	bcm2835_mmal_vchiq	40960	3	
	↪ bcm2835_codec,bcm2835_v4l2,bcm2835_isp			
44	videobuf2_vmalloc	20480	1	bcm2835_v4l2
45	videobuf2_dma_contig	24576	2	bcm2835_codec,bcm2835_isp
46	brcmutil	28672	1	brcmfmac
47	snd_seq	90112	6	
	↪ snd_seq_midi,snd_seq_oss,snd_seq_midi_event,snd_seq_dummy			
48	videobuf2_memops	20480	2	
	↪ videobuf2_vmalloc,videobuf2_dma_contig			

```

49 videobuf2_v4l2          32768  4
   ↳ bcm2835_codec,bcm2835_v4l2,v4l2_mem2mem,bcm2835_isp
50 videobuf2_common       65536  5 bcm2835_codec,videobuf2_v4l2,b
   ↳ cm2835_v4l2,v4l2_mem2mem,bcm2835_isp
51 cfg80211               921600  1 brcmfmac
52 snd_seq_device         20480  4
   ↳ snd_seq,snd_seq_midi,snd_seq_oss,snd_rawmidi
53 snd_timer              45056  2 snd_seq,snd_pcm
54 videodev               290816  6 bcm2835_codec,videobuf2_v4l2,b
   ↳ cm2835_v4l2,videobuf2_common,v4l2_mem2mem,bcm2835_isp
55 crct10dif_ce           20480  1
56 v3d                    81920  4
57 mc                     73728  6 videodev,bcm2835_codec,videobu
   ↳ f2_v4l2,videobuf2_common,v4l2_mem2mem,bcm2835_isp
58 raspberrypi_hwmon      16384  0
59 gpu_sched              49152  1 v3d
60 vc_sm_cma              40960  2 bcm2835_mmal_vchiq,bcm2835_isp
61 snd                    110592  16
   ↳ snd_seq,snd_seq_device,snd_seq_oss,snd_bcm2835,snd_soc_hdm
   ↳ i_codec,snd_timer,snd_compress,snd_pcm_oss,snd_soc_core,sn
   ↳ d_pcm,snd_rawmidi,snd_mixer_oss
62 fb_sys_fops            20480  1 drm_kms_helper
63 syscopyarea            16384  1 drm_kms_helper
64 sysfillrect            16384  1 drm_kms_helper
65 sysimgblt              16384  1 drm_kms_helper
66 bcm2835_gpiomem        16384  0
67 rpivid_mem             16384  0
68 nvmem_rmem             16384  0
69 uio_pdrv_genirq        20480  0
70 uio                     24576  1 uio_pdrv_genirq
71 sch_fq_codel           20480  7
72 ppdev                  24576  0
73 lp                     24576  0
74 parport                45056  2 lp,ppdev
75 drm                    606208  13
   ↳ gpu_sched,drm_kms_helper,v3d,vc4
76 ip_tables              40960  0
77 x_tables               49152  1 ip_tables
78 autofs4                53248  2
79 btrfs                  1478656  0
80 blake2b_generic        24576  0
81 xor                    20480  1 btrfs
82 xor_neon               16384  1 xor
83 hid_generic            16384  0
84 usbhid                 69632  0
85 raid6_pq               110592  1 btrfs
86 libcrc32c              16384  1 btrfs
87 dwc2                   258048  0
88 roles                  16384  1 dwc2

```

89	udc_core	69632	1	dwc2
90	i2c_brcmstb	20480	0	
91	spidev	24576	0	
92	xhci_pci	24576	0	
93	xhci_pci_renesas	24576	1	xhci_pci
94	phy_generic	20480	1	

```

yihua@ECE4730/FA2021-Group3:~/modules$ lsmod
Module                  Size  Used by
single_module           16384  0
rfcomm                  94208  4
cmac                    16384  2
algif_hash              20480  1
aes_arm64               16384  2
algif_skcipher          20480  1
af_alg                  32768  6 algif_hash,algif_skcipher
hci_uart               151552  1
btqca                   24576  1 hci_uart
btrtl                   24576  1 hci_uart
btbcm                   24576  1 hci_uart
btintel                 32768  1 hci_uart
bnep                    32768  2
snd_soc_hdmi_codec      24576  2
vc4                     290816  16
drm_kms_helper          282624  3 vc4
cec                     73728  2 drm_kms_helper,vc4
snd_soc_core            278528  2 vc4,snd_soc_hdmi_codec
bcm2835                 32768  1
btusb                   20480  0
snd_compress            32768  1 snd_soc_core
ac97_bus                16384  1 snd_soc_core
snd_pcm_dmaengine       20480  1 snd_soc_core
bluetooth               694320  35 btrtl,btqca,btusb,btintel,hci_uart,btcm,bnep,rfcomm
snd_pcm_oss              61440  0
snd_mixer_oss           32768  1 snd_pcm_oss
ecch_generic            16384  1 bluetooth
ltpm_leds               16384  0
joydev                  28672  0
ecc                     32768  1 ecch_generic
snd_pcm                 139264  6 snd_bcm2835,snd_soc_hdmi_codec,snd_compress,snd_pcm_oss,snd_soc_core,snd_pcm_dmaengine
snd_seq_dummy           16384  0
snd_seq_oss             53248  0
snd_seq_midi            20480  0
snd_seq_midi_event      16384  2 snd_seq_midi,snd_seq_oss
bcm2835_isp             32768  0
bcm2835_codec           49152  0
bcm2835_v4l2            45856  0
brcmfnac                393216  0
snd_rawmidi             49152  1 snd_seq_midi
v4l2_mem2mem            40960  1 bcm2835_codec
bcm2835_mmal_vchiq      40960  3 bcm2835_codec,bcm2835_v4l2,bcm2835_isp
videobuf2_vmalloc       20480  1 bcm2835_v4l2
videobuf2_dma_contig    24576  2 bcm2835_codec,bcm2835_isp
brcmutil                28672  1 brcmfnac
snd_seq                 98112  6 snd_seq_midi,snd_seq_oss,snd_seq_midi_event,snd_seq_dummy
videobuf2_memops        20480  2 videobuf2_vmalloc,videobuf2_dma_contig
videobuf2_v4l2          32768  4 bcm2835_codec,bcm2835_v4l2,v4l2_mem2mem,bcm2835_isp
videobuf2_common        65376  5 bcm2835_codec,videobuf2_v4l2,bcm2835_v4l2,v4l2_mem2mem,bcm2835_isp
cfg80211                921600  1 brcmfnac
snd_seq_device          20480  4 snd_seq,snd_seq_midi,snd_seq_oss,snd_rawmidi
snd_timer               45856  2 snd_seq,snd_pcm
videodec                290816  0 bcm2835_codec,videobuf2_v4l2,bcm2835_v4l2,videobuf2_common,v4l2_mem2mem,bcm2835_isp
v4l2_dvcodec            20480  1

```

Figure 3. The output that was produced by lsmod.

#### 4. Output of lsmod:

1	Module	Size	Used by
2	rfcomm	94208	4
3	cmac	16384	2
4	algif_hash	20480	1
5	aes_arm64	16384	2
6	algif_skcipher	20480	1
7	af_alg	32768	6 algif_hash,algif_skcipher
8	hci_uart	151552	1
9	btqca	24576	1 hci_uart
10	btrtl	24576	1 hci_uart
11	btbcm	24576	1 hci_uart
12	btintel	32768	1 hci_uart
13	bnep	32768	2
14	snd_soc_hdmi_codec	24576	2
15	vc4	290816	16
16	drm_kms_helper	282624	3 vc4
17	cec	73728	2 drm_kms_helper,vc4
18	snd_soc_core	278528	2 vc4,snd_soc_hdmi_codec

```

19 snd_bcm2835          32768 1
20 btsdio              20480 0
21 snd_compress        32768 1 snd_soc_core
22 ac97_bus            16384 1 snd_soc_core
23 snd_pcm_dmaengine    20480 1 snd_soc_core
24 bluetooth           696320 35
    ↳ btrtl,btqca,btsdio,btintel,hci_uart,bluetooth,bnep,rftcomm
25 snd_pcm_oss         61440 0
26 snd_mixer_oss       32768 1 snd_pcm_oss
27 ecdh_generic        16384 1 bluetooth
28 input_leds          16384 0
29 joydev              28672 0
30 ecc                 32768 1 ecdh_generic
31 snd_pcm             139264 6 snd_bcm2835,snd_soc_hdmi_codec,
    ↳ ,snd_compress,snd_pcm_oss,snd_soc_core,snd_pcm_dmaengine
32 snd_seq_dummy       16384 0
33 snd_seq_oss         53248 0
34 snd_seq_midi        20480 0
35 snd_seq_midi_event  16384 2 snd_seq_midi,snd_seq_oss
36 bcm2835_isp         32768 0
37 bcm2835_codec       49152 0
38 bcm2835_v4l2        45056 0
39 brcmfmac            393216 0
40 snd_rawmidi         49152 1 snd_seq_midi
41 v4l2_mem2mem        40960 1 bcm2835_codec
42 bcm2835_mmal_vchiq  40960 3
    ↳ bcm2835_codec,bcm2835_v4l2,bcm2835_isp
43 videobuf2_vmalloc   20480 1 bcm2835_v4l2
44 videobuf2_dma_contig 24576 2 bcm2835_codec,bcm2835_isp
45 brcmutil            28672 1 brcmfmac
46 snd_seq             90112 6
    ↳ snd_seq_midi,snd_seq_oss,snd_seq_midi_event,snd_seq_dummy
47 videobuf2_memops    20480 2
    ↳ videobuf2_vmalloc,videobuf2_dma_contig
48 videobuf2_v4l2      32768 4
    ↳ bcm2835_codec,bcm2835_v4l2,v4l2_mem2mem,bcm2835_isp
49 videobuf2_common    65536 5 bcm2835_codec,videobuf2_v4l2,b
    ↳ cm2835_v4l2,v4l2_mem2mem,bcm2835_isp
50 cfg80211            921600 1 brcmfmac
51 snd_seq_device      20480 4
    ↳ snd_seq,snd_seq_midi,snd_seq_oss,snd_rawmidi
52 snd_timer           45056 2 snd_seq,snd_pcm
53 videodev            290816 6 bcm2835_codec,videobuf2_v4l2,b
    ↳ cm2835_v4l2,videobuf2_common,v4l2_mem2mem,bcm2835_isp
54 crct10dif_ce        20480 1
55 v3d                 81920 4
56 mc                  73728 6 videodev,bcm2835_codec,videobu
    ↳ f2_v4l2,videobuf2_common,v4l2_mem2mem,bcm2835_isp
57 raspberrypi_hwmon   16384 0

```

```

58 gpu_sched                49152  1 v3d
59 vc_sm_cma                40960  2 bcm2835_mmal_vchiq,bcm2835_isp
60 snd                      110592 16
    ↳ snd_seq,snd_seq_device,snd_seq_oss,snd_bcm2835,snd_soc_hdm
    ↳ i_codec,snd_timer,snd_compress,snd_pcm_oss,snd_soc_core,sn
    ↳ d_pcm,snd_rawmidi,snd_mixer_oss
61 fb_sys_fops              20480  1 drm_kms_helper
62 syscopyarea              16384  1 drm_kms_helper
63 sysfillrect              16384  1 drm_kms_helper
64 sysimgblt                16384  1 drm_kms_helper
65 bcm2835_gpiomem          16384  0
66 rpivid_mem               16384  0
67 nvmem_rmem               16384  0
68 uio_pdrv_genirq          20480  0
69 uio                      24576  1 uio_pdrv_genirq
70 sch_fq_codel             20480  7
71 ppdev                    24576  0
72 lp                       24576  0
73 parport                  45056  2 lp,ppdev
74 drm                      606208 13
    ↳ gpu_sched,drm_kms_helper,v3d,vc4
75 ip_tables                40960  0
76 x_tables                 49152  1 ip_tables
77 autofs4                  53248  2
78 btrfs                    1478656 0
79 blake2b_generic          24576  0
80 xor                      20480  1 btrfs
81 xor_neon                 16384  1 xor
82 hid_generic              16384  0
83 usbhid                   69632  0
84 raid6_pq                 110592 1 btrfs
85 libcrc32c                16384  1 btrfs
86 dwc2                     258048 0
87 roles                    16384  1 dwc2
88 udc_core                 69632  1 dwc2
89 i2c_brcmstb              20480  0
90 spidev                   24576  0
91 xhci_pci                 24576  0
92 xhci_pci_renesas         24576  1 xhci_pci
93 phy_generic              20480  1

```

```

yhyu@ECE4730U-FA2021-Group5 ~ -modules
$ lsmod
Module                  Size  Used by
rfcomm                  94200  4
btusb                   16384  1
algif_hash              20480  1
algif_skcipher          16384  1
algif_skcipher         20480  1
af_alg                  32768  0 algif_hash,algif_skcipher
hcl_uart                161552  1
btqca                   24576  1 hcl_uart
btintel                 24576  1 hcl_uart
btbcbn                  24576  1 hcl_uart
btintel                 32768  2
btusb                   32768  2
snd_soc_hdmi_codec      24576  2
v4l2                    266816  16
drm_kms_helper          282624  1 v4l2
32768  2 drm_kms_helper,v4l2
snd_soc_core            278528  2 v4l2,snd_soc_hdmi_codec
snd_bcm2835             32768  1
btusb                   20480  1
snd_compress           32768  1 snd_soc_core
btusb                   16384  1 snd_soc_core
snd_pcm_dmaengine       20480  1 snd_soc_core
690320 35 btintel,btqca,btusb,hcl_uart,btcbn,bmap,rfcomm
snd_pcm_oss             61440  0
snd_mixer_oss           32768  1 snd_pcm_oss
ecdh_generic            16384  1 bluetooth
input_leds              16384  0
joydev                  26624  0
ncc                     32768  0
snd_pcm                157248  6 snd_bcm2835,snd_soc_hdmi_codec,snd_compress,snd_pcm_oss,snd_soc_core,snd_pcm_dmaengine
snd_seq_dummy           16384  0
snd_seq_oss             53248  0
snd_seq_midi            20480  0
snd_seq_midi_event      16384  2 snd_seq_midi,snd_seq_oss
bcm2835_otp              32768  0
bcm2835_codec           49152  0
bcm2835_v4l2            40960  0
bcmrfmac                393216  0
snd_rawmidi             49152  1 snd_seq_midi
v4l2_mem2mem            40960  1 bcm2835_codec
bcm2835_analog_v4l2     49960  1 bcm2835_codec,bcm2835_v4l2,bcm2835_otp
bcm2835_v4l2            20480  1 bcm2835_v4l2
v4l2_m2m_bcm2835        24576  2 bcm2835_codec,bcm2835_otp
videobuf2_dma_contig    28672  1 bcmrfmac
videobuf2_v4l2          96112  6 snd_seq_midi,snd_seq_oss,snd_seq_midi_event,snd_seq_dummy
videobuf2_memops        20480  1 videobuf2_v4l2,v4l2_m2m_bcm2835
videobuf2_v4l2          32768  4 bcm2835_codec,bcm2835_v4l2,v4l2_mem2mem,bcm2835_otp
videobuf2_common        65536  4 bcm2835_codec,videobuf2_v4l2,bcm2835_v4l2,v4l2_mem2mem,bcm2835_otp
v4l2_core                92160  1 bcmrfmac
snd_seq_device          20480  4 snd_seq,snd_seq_midi,snd_seq_oss,snd_rawmidi
snd_timer               40864  2 snd_seq,snd_pcm
v4l2_device             296816  4 bcm2835_codec,videobuf2_v4l2,bcm2835_v4l2,videobuf2_common,v4l2_mem2mem,bcm2835_otp
crctidif_ce             20480  1

```

Figure 4. The output of `lsmod`.

Output of dmesg:

```

1      [11933.762154] simple_module: loading out-of-tree module taints
      ↪ kernel.
2      [11933.762612] simple_module initialized
3      [12616.534349] simple_module is being unloaded

```

[illegible]

Figure 5. The line of the system log, which show that the module was unloaded.

### 5. Bash script:



```

1  sudo make -C /usr/src/linux-headers-5.11.0-1021-raspi M=$PWD
   ↳ modules
2  sudo dmesg --clear
3  sudo insmod jiffies.ko
4  sudo dmesg
5  sudo rmmod jiffies.ko
6  sudo dmesg

```

Makefile:

```

1  obj-m := jiffies.o

```

```

yihua@ECE4730J-FA2021-Group3:~/modules$ sudo dmesg --clear
yihua@ECE4730J-FA2021-Group3:~/modules$ sudo insmod jiffies.ko
yihua@ECE4730J-FA2021-Group3:~/modules$ sudo dmesg
[17070.266678] simple module initialized
[17070.266704] jiffies = 4299159837
yihua@ECE4730J-FA2021-Group3:~/modules$ sudo rmmod jiffies.ko
yihua@ECE4730J-FA2021-Group3:~/modules$ sudo dmesg
[17070.266678] simple module initialized
[17070.266704] jiffies = 4299159837
[17075.748447] jiffies = 4299161208
[17075.748466] simple module is being unloaded
yihua@ECE4730J-FA2021-Group3:~/modules$

```

Figure 6. The system log message that shows the values of the jiffies variable when the module was loaded and unloaded.

Source code [1]:

```

1  /* simple_module.c - a simple template for a loadable kernel
   ↳ module in Linux,
2  based on the hello world kernel module example on pages
   ↳ 338-339 of Robert
3  Love's "Linux Kernel Development, Third Edition."
4  */
5
6  #include <linux/init.h>
7  #include <linux/module.h>
8  #include <linux/kernel.h>
9  #include <linux/jiffies.h>
10
11 /* init function - logs that initialization happened, returns
   ↳ success */
12 static int
13 simple_init(void)
14 {
15     printk(KERN_ALERT "simple module initialized\n");
16     printk(KERN_INFO "jiffies = %lu\n", jiffies);
17     return 0;

```

```

18 }
19
20 /* exit function - logs that the module is being removed */
21 static void
22 simple_exit(void)
23 {
24     printk(KERN_INFO "jiffies = %lu\n", jiffies);
25     printk(KERN_ALERT "simple module is being unloaded\n");
26 }
27
28 module_init(simple_init);
29 module_exit(simple_exit);
30
31 MODULE_LICENSE ("GPL");
32 MODULE_AUTHOR ("Yihua Liu");
33 MODULE_DESCRIPTION ("The Kernel Module to Get Jiffies for
↪ ECE4730J Lab4");

```

## References

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