

Lesson 5: Embedded Linux Device Driver – Kernel Mode (Assignment 5)

Command – lsmod

```
cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code $ lsmod
Module           Size  Used by
spidev          20480  0
spi_bcm2835     20480  0
i2c_bcm2835     16384  0
rfcomm          53248  0
cmac            16384  0
algif_hash      16384  0
aes_arm64       16384  0
aes_generic     36864  1 aes_arm64
algif_skcipher  16384  0
af_alg          28672  2 algif_hash,algif_skcipher
bnep            24576  0
hci_uart        53248  1
btbcm           24576  1 hci_uart
bluetooth       565248  7 hci_uart,btbcm,bnep,rfcomm
ecdh_generic    16384  1 bluetooth
ecc              36864  1 ecdh_generic
libaes          16384  3 aes_arm64,bluetooth,aes_generic
8021q           32768  0
garp             16384  1 8021q
stp              16384  1 garp
llc              16384  2 stp,garp
brcmfmac        331776  0
vc4              331776  14
brcmutil        24576  1 brcmfmac
snd_soc_hdmi_codec 20480  2
drm_display_helper 16384  1 vc4
cfg80211        925696  1 brcmfmac
cec              53248  1 vc4
rfkill           32768  5 bluetooth,cfg80211
drm_dma_helper   20480  1 vc4
raspberrypi_hwmon 16384  0
v3d              90112  8
drm_kms_helper   204800  4 drm_dma_helper,vc4
gpu_sched        49152  1 v3d
drm_shmem_helper  24576  1 v3d
snd_soc_core     274432  2 vc4,snd_soc_hdmi_codec
```

Command - modinfo backlight

```
cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code $ modinfo backlight
filename:   /lib/modules/6.1.21-v8+/kernel/drivers/video/backlight/backlight.ko.xz
description: Backlight Lowlevel Control Abstraction
author:     Jamey Hicks <jamey.hicks@hp.com>, Andrew Zabolotny <zap@homelink.ru>
license:    GPL
srcversion: 7FF72367413063866E2C9A8
depends:
intree:     Y
name:      backlight
vermagic:   6.1.21-v8+ SMP preempt mod_unload modversions aarch64
cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code $
```

Command - ls /lib/modules/\$(uname -r)

```
cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code $ ls /lib/modules
6.1.21-v8+
cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code $ ls /lib/modules/$(uname -r)
kernel      modules.builtin      modules.builtin.modinfo  modules.devname  modules.symbols
modules.alias  modules.builtin.alias.bin  modules.dep        modules.order    modules.symbols.bin
modules.alias.bin  modules.builtin.bin   modules.dep.bin   modules.softdep
cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code $
```

Command - sudo modprobe -r i2c_bcm2835

```
cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code $ sudo modprobe -r i2c_bcm2835
cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code $ lsmod
Module           Size Used by
spidev          20480  0
spi_bcm2835     20480  0
rfcomm          53248  0
cmac            16384  0
algif_hash      16384  0
aes_arm64       16384  0
aes_generic     36864  1 aes_arm64
algif_skcipher  16384  0
af_alg          28672  2 algif_hash,algif_skcipher
bnep            24576  0
hci_uart        53248  1
btbcm          24576  1 hci_uart
bluetooth      565248  7 hci_uart,btbcm,bnep,rfcomm
ecdh_generic    16384  1 ecdh_generic
ecc             36864  1 ecdh_generic
libaes          16384  3 aes_arm64,bluetooth,aes_generic
8021q          32768  0
garp            16384  1 8021q
stp             16384  1 garp
llc             16384  2 stp,garp
brcmfmac       331776  0
vc4             331776  14
brcmutil       24576  1 brcmfmac
snd_soc_hdmi_codec 20480  2
drm_display_helper 16384  1 vc4
cfg80211       925696  1 brcmfmac
cec             53248  1 vc4
rfkill          32768  5 bluetooth,cfg80211
drm_dma_helper  20480  1 vc4
raspberrypi_hwmon 16384  0
v3d             90112  8
drm_kms_helper  204800  4 drm_dma_helper,vc4
gpu_sched       49152  1 v3d
drm_shmem_helper 24576  1 v3d
snd_soc_core    274432  2 vc4,snd_soc_hdmi_codec
```

Command - sudo modprobe i2c_bcm2835

```
|cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code $ sudo modprobe i2c_bcm2835
|cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code $ lsmod
Module           Size Used by
i2c_bcm2835      16384  0
spi-dev          20480  0
spi_bcm2835      20480  0
rfcomm            53248  0
cmac              16384  0
algif_hash        16384  0
aes_arm64         16384  0
aes_generic       36864  1 aes_arm64
algif_skcipher   16384  0
af_alg             28672  2 algif_hash,algif_skcipher
bnep              24576  0
hci_uart          53248  1
btbcm              24576  1 hci_uart
bluetooth         565248 7 hci_uart,btbcm,bnep,rfcomm
ecdh_generic      16384  1 ecdh_generic
ecc                36864  1 ecdh_generic
libaes             16384  3 aes_arm64,bluetooth,aes_generic
8021q              32768  0
garp               16384  1 8021q
stp                16384  1 garp
llc                16384  2 stp,garp
brcmfmac          331776  0
vc4                331776  14
brcmutil           24576  1 brcmfmac
snd_soc_hdmi_codec 20480  2
drm_display_helper 16384  1 vc4
cfg80211          925696  1 brcmfmac
cec                53248  1 vc4
rfkill              32768  5 bluetooth,cfg80211
drm_dma_helper     20480  1 vc4
raspberrypi_hwmon 16384  0
v3d                90112  8
drm_kms_helper     204800  4 drm_dma_helper,vc4
gpu_sched           49152  1 v3d
drm_shmem_helper    24576  1 v3d
```

Steps for Building Kernel Module

Command - sudo apt update

```
cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code $ sudo apt update
Get:1 http://security.debian.org/debian-security bullseye-security InRelease [48.4 kB]
Hit:2 http://deb.debian.org/debian bullseye InRelease
Get:3 http://deb.debian.org/debian bullseye-updates InRelease [44.1 kB]
Hit:4 http://archive.raspberrypi.org/debian bullseye InRelease
Fetched 92.4 kB in 2s (53.3 kB/s)
Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
All packages are up to date.
cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code $
```

Command - sudo apt upgrade

```
cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code $ sudo apt upgrade
Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
Calculating upgrade... Done
The following packages were automatically installed and are no longer required:
  libfuse2 raspinfo
Use 'sudo apt autoremove' to remove them.
0 upgraded, 0 newly installed, 0 to remove and 0 not upgraded.
cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code $
```

Command - sudo apt-cache search linux-headers

```
cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code $ sudo apt-cache search linux-headers
linux-libc-dev-amd64-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-arm64-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-armel-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-armhf-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-i386-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-ppc64el-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-s390x-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-mips-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-mips64-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-mips64el-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-mips64r6-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-mips64r6el-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-mipsel-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-mipsn32-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-mipsn32el-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-mipsn32r6-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-mipsn32r6el-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-mipsr6-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-mipsr6el-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-alpha-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-hppa-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-m68k-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-powerpc-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-ppc64-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-riscv64-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-sh4-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-sparc64-cross - Linux Kernel Headers for development (for cross-compiling)
linux-libc-dev-x32-cross - Linux Kernel Headers for development (for cross-compiling)
linux-headers-5.10.0-22-arm64 - Header files for Linux 5.10.0-22-arm64
linux-headers-5.10.0-22-armmp - Header files for Linux 5.10.0-22-armmp
linux-headers-5.10.0-22-armmp-lpae - Header files for Linux 5.10.0-22-armmp-lpae
linux-headers-5.10.0-22-cloud-arm64 - Header files for Linux 5.10.0-22-cloud-arm64
linux-headers-5.10.0-22-common - Common header files for Linux 5.10.0-22
linux-headers-5.10.0-22-common-rt - Common header files for Linux 5.10.0-22-rt
linux-headers-5.10.0-22-rt-arm64 - Header files for Linux 5.10.0-22-rt-arm64
linux-headers-5.10.0-22-rt-armmp - Header files for Linux 5.10.0-22-rt-armmp
linux-headers-5.10.0-26-arm64 - Header files for Linux 5.10.0-26-arm64
```

Command - sudo apt install raspberrypi-kernel-headers

```
linux-headers-arm64 - Header files for Linux arm64 configuration (meta-package)
linux-headers-cloud-arm64 - Header files for Linux cloud-arm64 configuration (meta-package)
linux-headers-rt-arm64 - Header files for Linux rt-arm64 configuration (meta-package)
linux-headers-5.10.0-25-arm64 - Header files for Linux 5.10.0-25-arm64
linux-headers-5.10.0-25-armmp - Header files for Linux 5.10.0-25-armmp
linux-headers-5.10.0-25-armmp-lpae - Header files for Linux 5.10.0-25-armmp-lpae
linux-headers-5.10.0-25-cloud-arm64 - Header files for Linux 5.10.0-25-cloud-arm64
linux-headers-5.10.0-25-common - Common header files for Linux 5.10.0-25
linux-headers-5.10.0-25-common-rt - Common header files for Linux 5.10.0-25-rt
linux-headers-5.10.0-25-rt-arm64 - Header files for Linux 5.10.0-25-rt-arm64
linux-headers-5.10.0-25-rt-armmp - Header files for Linux 5.10.0-25-rt-armmp
raspberrypi-kernel-headers - Header files for the Raspberry Pi Linux kernel
cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code $ dpkg -L raspberrypi-kernel-headers
dpkg-query: package 'raspberrypi-kernel-headers' is not installed
Use dpkg --contents (= dpkg-deb --contents) to list archive files contents.
cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code $ sudo apt install raspberrypi-kernel-headers
Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
The following packages were automatically installed and are no longer required:
  libfuse2 raspinfo
Use 'sudo apt autoremove' to remove them.
The following NEW packages will be installed:
  raspberrypi-kernel-headers
0 upgraded, 1 newly installed, 0 to remove and 0 not upgraded.
Need to get 10.2 MB of archives.
After this operation, 64.8 MB of additional disk space will be used.
Get:1 http://archive.raspberrypi.org/debian bullseye/main arm64 raspberrypi-kernel-headers arm64 1:1.20230405-1 [10.2 MB]
Fetched 10.2 MB in 3s (3,273 kB/s)
Selecting previously unselected package raspberrypi-kernel-headers.
(Reading database ... 93146 files and directories currently installed.)
Preparing to unpack .../raspberrypi-kernel-headers_1%3a1.20230405-1_arm64.deb ...
Unpacking raspberrypi-kernel-headers (1:1.20230405-1) ...
Setting up raspberrypi-kernel-headers (1:1.20230405-1) ...
cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code $
```

Command - dpkg -L raspberrypi-kernel-headers

```
cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code $ dpkg -L raspberrypi-kernel-headers
/.
/lib
/lib/modules
/lib/modules/6.1.21-v8+
/usr
/usr/share
/usr/share/doc
/usr/share/doc/raspberrypi-kernel-headers
/usr/share/doc/raspberrypi-kernel-headers/changelog.Debian.gz
/usr/share/doc/raspberrypi-kernel-headers/copyright
/usr/src
/usr/src/linux-headers-6.1.21-v8+
/usr/src/linux-headers-6.1.21-v8+/.config
/usr/src/linux-headers-6.1.21-v8+/Documentation
/usr/src/linux-headers-6.1.21-v8+/Documentation/Kconfig
/usr/src/linux-headers-6.1.21-v8+/Documentation/Makefile
/usr/src/linux-headers-6.1.21-v8+/Documentation/admin-guide
/usr/src/linux-headers-6.1.21-v8+/Documentation/admin-guide/cifs
/usr/src/linux-headers-6.1.21-v8+/Documentation/admin-guide/cifs/winucase_convert.pl
/usr/src/linux-headers-6.1.21-v8+/Documentation/devicetree
/usr/src/linux-headers-6.1.21-v8+/Documentation/devicetree/bindings
/usr/src/linux-headers-6.1.21-v8+/Documentation/devicetree/bindings/Makefile
/usr/src/linux-headers-6.1.21-v8+/Documentation/kbuild
/usr/src/linux-headers-6.1.21-v8+/Documentation/kbuild/Kconfig.recursion-issue-01
/usr/src/linux-headers-6.1.21-v8+/Documentation/kbuild/Kconfig.recursion-issue-02
/usr/src/linux-headers-6.1.21-v8+/Documentation/kbuild/Kconfig.select-break
/usr/src/linux-headers-6.1.21-v8+/Documentation/sphinx
/usr/src/linux-headers-6.1.21-v8+/Documentation/sphinx/parse-headers.pl
/usr/src/linux-headers-6.1.21-v8+/Documentation/tools
/usr/src/linux-headers-6.1.21-v8+/Documentation/tools/rtla
/usr/src/linux-headers-6.1.21-v8+/Documentation/tools/rtla/Makefile
/usr/src/linux-headers-6.1.21-v8+/Documentation/trace
/usr/src/linux-headers-6.1.21-v8+/Documentation/trace/postprocess
/usr/src/linux-headers-6.1.21-v8+/Documentation/trace/postprocess/trace-pagealloc-postprocess.pl
/usr/src/linux-headers-6.1.21-v8+/Documentation/trace/postprocess/trace-vmscan-postprocess.pl
/usr/src/linux-headers-6.1.21-v8+/Documentation/userspace-api
/usr/src/linux-headers-6.1.21-v8+/Documentation/userspace-api/media
```

SourceCode - km-1-hello_c

```
GNU nano 5.4                                     km-1-hello.c
#include <linux/init.h>
#include <linux/module.h>
#include <linux/kernel.h>

MODULE_LICENSE("GPL");
MODULE_AUTHOR("Normal McEntire<norman.mcintire@gmail.com>");
MODULE_DESCRIPTION("Hello World Kernel Module");
MODULE_VERSION("0.1");

static int __init hello_init(void) // static hides as it is accessed only in this file and can't be accessed outside
{
    printk(KERN_INFO "Hello kernel Module"); // no comma
    return 0;                                // since it goes into kernel ring buffer we can see this message using dmesg
}

static void __exit hello_exit(void)
{
    printk(KERN_INFO "Goodbye kernel module\n"); // no comma
}

module_init(hello_init); // called when module is loaded
module_exit(hello_exit); // called when module is unloaded
```

[Read 22 lines]

^G Help **^O** Write Out **^W** Where Is **^K** Cut **^T** Execute **^C** Location **M-U** Undo **M-A** Set Mark
^X Exit **^R** Read File **^** Replace **^U** Paste **^J** Justify **^** Go To Line **M-E** Redo **M-6** Copy

SourceCode – Makefile

```
GNU nano 5.4                                     Makefile
# Makefile for building kernel module
obj-m := km-1-hello.o

KERNEL_SRC ?= /lib/modules/$(shell uname -r)/build

all default: modules
install: modules_install

modules modules_install help clean:
    $(MAKE) -C $(KERNEL_SRC) M=$(shell pwd) $@
```

[Read 10 lines]

^G Help ^O Write Out ^W Where Is ^K Cut ^T Execute ^C Location M-U Undo M-A Set Mark
^X Exit ^R Read File ^\ Replace ^U Paste ^J Justify ^L Go To Line M-E Redo M-6 Copy

Output - make (km-1-hello)

```
cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello $ make
make -C /lib/modules/6.1.21-v8+/build M=/home/cxr1020/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello m
odules
make[1]: Entering directory '/usr/src/linux-headers-6.1.21-v8+'
  CC [M]  /home/cxr1020/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello/km-1-hello.o
  MODPOST /home/cxr1020/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello/Module.symvers
  CC [M]  /home/cxr1020/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello/km-1-hello.mod.o
  LD [M]  /home/cxr1020/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello/km-1-hello.ko
make[1]: Leaving directory '/usr/src/linux-headers-6.1.21-v8+'
cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello $ ls
km-1-hello.c  km-1-hello.mod  km-1-hello.mod.o  Makefile  Module.symvers
km-1-hello.ko  km-1-hello.mod.c  km-1-hello.o  modules.order
cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello $ modinfo km-1-hello.ko
filename:      /home/cxr1020/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello/km-1-hello.ko
version:       0.1
description:   Hello World Kernel Module
author:        Normal McEntire<norman.mcintire@gmail.com>
license:       GPL
srcversion:    BB6B7E2EF1D01753818F603
depends:
name:          km_1_hello
vermagic:      6.1.21-v8+ SMP preempt mod_unload modversions aarch64
cxr1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello $
```

Output - insmod km-1-hello_ko

```
|cxd1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello $ sudo modprobe km-1-hello.ko
modprobe: FATAL: Module km-1-hello.ko not found in directory /lib/modules/6.1.21-v8+
|cxd1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello $ sudo insmod km-1-hello.ko
|cxd1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello $ lsmod | head -4
Module           Size Used by
km_1_hello       16384  0
i2c_bcm2835     16384  0
spidev          20480  0
|cxd1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello $ dmesg | tail -4
[90273.131342] vc4-drm gpu: [drm] User-defined mode not supported: "3840x2160": 30 297000 3840 4016 4104 4400 2160 2168 2178 2250
0x68 0x5
[94810.023841] OF: overlay: WARNING: memory leak will occur if overlay removed, property: /soc/i2c@7e804000/status
[117894.022361] OF: overlay: WARNING: memory leak will occur if overlay removed, property: /soc/spi@7e204000/status
[122927.492007] km_1_hello: loading out-of-tree module taints kernel.
|cxd1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello $
```

Output - rmmod km-1-hello_ko

```
|cxd1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello $ sudo modprobe km-1-hello.ko
modprobe: FATAL: Module km-1-hello.ko not found in directory /lib/modules/6.1.21-v8+
|cxd1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello $ sudo insmod km-1-hello.ko
|cxd1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello $ lsmod | head -4
Module           Size Used by
km_1_hello       16384  0
i2c_bcm2835     16384  0
spidev          20480  0
|cxd1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello $ dmesg | tail -4
[90273.131342] vc4-drm gpu: [drm] User-defined mode not supported: "3840x2160": 30 297000 3840 4016 4104 4400 2160 2168 2178 2250
0x68 0x5
[94810.023841] OF: overlay: WARNING: memory leak will occur if overlay removed, property: /soc/i2c@7e804000/status
[117894.022361] OF: overlay: WARNING: memory leak will occur if overlay removed, property: /soc/spi@7e204000/status
[122927.492007] km_1_hello: loading out-of-tree module taints kernel.
|cxd1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello $ sudo rmmod km-1-hello.ko
|cxd1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello $ lsmod | head -4
Module           Size Used by
i2c_bcm2835     16384  0
spidev          20480  0
spi_bcm2835     20480  0
|cxd1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello $ dmesg | tail -4
[117894.022361] OF: overlay: WARNING: memory leak will occur if overlay removed, property: /soc/spi@7e204000/status
[122927.493720] Hello kernel Module
[123112.736035] Goodbye kernel module
|cxd1020@raspberrypi:~/Documents/EmbeddedLinuxRepo/CSR-EmbeddedLinux/Assignment05-Code/km-1-hello $
```

Resulting Linux directory

```
pi@raspberrypi:~/Desktop/raspberrypi/linux $ ls
arch      CREDITS      include  Kconfig      Makefile      Module.symvers  samples  tools      vmlinux.o
block     crypto       init     kernel      mm           net        scripts  usr
built-in.a Documentation io_uring lib       modules.builtin README    security  virt
certs     drivers      ipc      LICENSES   modules.builtin.modinfo README.md    sound    vmlinux
COPYING   fs          Kbuild   MAINTAINERS modules.order   rust      System.map vmlinux.a
pi@raspberrypi:~/Desktop/raspberrypi/linux $
```

Building The kernel

```
pi@raspberrypi:~/Desktop/raspberrypi/linux $ ls
arch      CREDITS      include  Kconfig      Makefile      Module.symvers  samples  tools      vmlinux.o
block     crypto       init     kernel      mm           net        scripts  usr
built-in.a Documentation io_uring lib       modules.builtin README    security  virt
certs     drivers      ipc      LICENSES   modules.builtin.modinfo README.md    sound    vmlinux
COPYING   fs          Kbuild   MAINTAINERS modules.order   rust      System.map vmlinux.a
pi@raspberrypi:~/Desktop/raspberrypi/linux $ cd arch
pi@raspberrypi:~/Desktop/raspberrypi/linux/arch $ ls
alpha arm  csky  ia64  loongarch  microblaze  nios2  parisc  riscv  sh  um  xtensa
arc  arm64 hexagon Kconfig m68k   mips   openrisc  powerpc s390  sparc  x86
pi@raspberrypi:~/Desktop/raspberrypi/linux/arch $ cd arm/boot/
pi@raspberrypi:~/Desktop/raspberrypi/linux/arch/arm/boot $ ls
boot compressed deflate_xip_data.sh dts  Image  install.sh  Makefile  zImage
pi@raspberrypi:~/Desktop/raspberrypi/linux/arch/arm/boot $
```