

Operating Systems Homework 1 Report

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Discussion Questions

1. What is a kernel? What are the differences between *mainline*, *stable*, and *longterm*? What is a kernel panic

The **kernel** of the operating system refers to the program that is always running on the computer. The kernel might include software for CPU scheduling, file system management, etc... which are integral to the normal operation of the system. There are different ways to release an operating system kernel.

The **mainline** kernel is the kernel that is currently being worked on and developed. Since there is constant development work occurring on the mainline kernel, there are constant releases of this kernel.

Once the mainline kernel has been released and iterated on, it moves to be a **stable** kernel. The stable kernel receives less updates than the mainline kernel, those usually being more significant bug fixes.

The final step is becoming a **longterm** kernel. This kernel will be mostly be used for bugfixes for older versions of the operating system.

A big purpose of these releases and constant updates is to minimize the occurrence of **kernel panics**. These are errors which might have serious consequences on the operation of the kernel. The causes for a kernel panic might involve unrecoverable errors in memory, drivers, or other kernel component.

2. What are the differences between *building*, *debugging*, and *profiling*?

Building the kernel refers to compiling the source operating system source code. In the second step of the homework, we download the kernel using the `wget` command. Then we further download additional required dependencies and compile the kernel source code using the `sudo make -j$(nproc)` command. This turns all the code in the corresponding Linux version to a bootable format.

Once we have built the kernel, we have to **debug** it. Like in any program, the operating system is bound to have some flaws or unintended behavior, or *bugs*. However, since we are compiling a pretty

basic layer of software on which all our other programs run, it is quite different. To debug a kernel, we require one machine to make our changes and then we send our changes to another machine.

While we first debug our program and then build it, we still have to measure its performance, which we call **profiling**. This process involves tracing the performance or measuring the number of system calls to identify potential performance bottlenecks. Programs such as Valgrind can trace the amount of system memory used, and other such programs can help us measure how well our programs perform.

3 What are GCC, GDB, and KGDB, and what are they used for?

GCC refers to the **GNU Compiler Collection**, a collection of frontends for various languages. However, if in bash we just type `gcc` we will get the C compiler to run. We use this specific compiler to compile the kernel, since much of the source code is written in C.

GDB refers to the GNU project's debugger. Essentially, we can run the program using certain precautions. For example, GDB can start our program and place breakpoints within it. We can also check the values of variables at that point, along with performing small changes to debug. For this project, we perform some debugging on the kernel using GDB and then send the changes to the other virtual machine. In this way, we go around the issue of debugging the operating system we need to debug the operating system.

KGDB is a debugging tool used to debug the kernel. For example, in the assignment, we set the `CONFIG_FRAME_POINTER` setting inserts code directly in the executable. This code then can save the state of the registers during execution. We can then use this code with GDB during the debugging process.

4. What are the `/usr/`, `/boot/`, `/home/`, `/boot/grub` folders for?

These folders are all directories under the Linux filesystem. They all have different purposes. For example the `/usr/` directory contains user utilities that are shared among all users of a system. The `ls` program which lists the files in a directory is located in `/usr/bin`, for example.

The `/boot/` and `/boot/grub` folders concern the programs and procedures needed at boot time. The regular `/boot/` folder contains code for UEFI (depending on the system) or BIOS, the code for `initramfs` which decompresses the kernel during the boot process, as well as the actual Linux image file. During the boot process, we use the bootloader to load the initial filesystem in main memory, which is in charge of loading the main kernel.

Inside the `/boot/` directory there also resides the code for `GRUB`, which stands for the **GR**and **U**nified **B**ootloader. The bootloader is a program responsible for loading the main operating system kernel. GRUB can detect the operating system(s) present on a machine and provides a way to select which operating system to load. It also allows a restricted command line, whose commands are also defined under `/boot/grub`.

The `/home` directory is where most of the individual user's files are kept. When we spawn a new terminal, it will place us in the user's home folder, whose contents are only available to the currently signed in user.

5. What are the general steps to debug a Linux kernel?

Firstly, we need two instances of Linux to debug the kernel. We have to use one instance to run actually debug the kernel and then we send the changes to the other Linux instance. We use GDB to remotely debug the kernel.

The Target machine is where all our kernel source code is stored. We build the kernel and copy the image file from the Target machine to the Host machine using `scp`. Then upon restarting the Target machine we are brought to the kdb prompt before we log in to the system. At this point, from the Host machine, we can run `gdb ./vmlinuz` to start debugging the kernel image. Then, we set the target of the debug to be the Target machine using the target machine's IP address. We test this by using the `continue` command on the gdb prompt and waiting for our Target machine to boot into the Ubuntu menu.

The overall debug process follows these general steps:



Figure 1: Debug Process

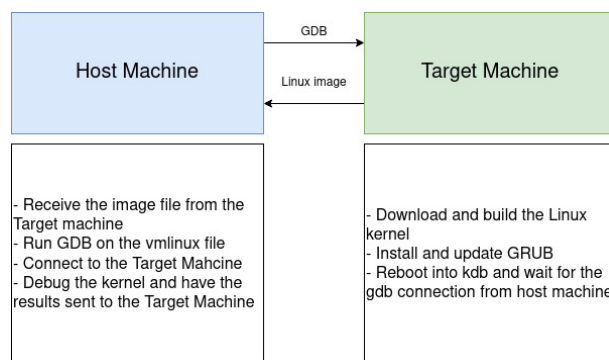


Figure 2: Some functions of the Host and Target machines, respectively.

6. For this project, why do we need two virtual machines?

As explained in question 1, the **kernel** is the program that is always running on the system. All the programs we run on our machine interface in some way with the kernel to utilize system resources. This includes the debugger. We can't run the debugger on the kernel that is currently executing.

To remedy this, we have another instance of the kernel running and we have the one machine remotely debug the kernel running on the other machine. This means that we can debug some previously impossible commands from the host machine by specifying the actions on our GDB command line and having the action go to the remote target which is the target machine.

7. In section 3.3, what are the differences between `make`, `make modules_install`, and `make install`?

In general, the `make` program determines which files in a program need to be recompiled and will carry out the compilation. In section 3.3, we have to use `make` to compile different parts of our operating system. When we just use the `make` command, we are going to compile the main kernel, which is the longest step of the entire assignment, due to the kernel's size. The result is the image file `vmlinuz`.

After we compile the kernel, we have to compile the system **modules**, or system programs that are not part of the main kernel but can be loaded by the kernel. We compile these modules with the `make modules` command. Once we have the compiled modules, we run the `make modules_install` command to install the kernel modules into the `vmlinuz` image file.

The `make install` command will then will take the binaries created in the previous steps and place them in some appropriate binaries, along with other rules.

8. In section 3.4, what are the commands `kgdbwait` and `kgdboc=ttyS1,115200` for?

The `kgdbwait` kernel parameter will force the kernel to wait for a connection for the remote debugger when starting. Then the next time we start the kernel we will get a gdb command prompt rather than directly booting into our system.

Now that we are set to wait for a remote connection from a debugger, we next tell kgdb where this serial connection will be. We specify the `ttys1` file which we had previously confirmed to be the point of connection between our two systems. The next part, 112500 is the name of the port on which we will be receiving messages.

9. What is grub? What is grub.cfg?

GRUB is a bootloading program. When the computer first boots, we load an initial bootloader such as BIOS or, more recently, UEFI. This initial bootloader is located in a fixed location, so we call it **firmware**. The job of this bootloader is to call another bootloader which is stored on a certain block in the disk. This second bootloader is GRUB. In the grub settings we have an entry for all the operating systems present on the system and their location. When executed, GRUB will allow us to choose which operating system to load.

As is custom with many Linux programs, files ending with `.cfg` are *configuration* files, meaning they store the settings the program will use. GRUB is no different, and in this file we have entries for all the operating systems we can boot. There is also the image file to use when loading the OS.

10. List at least 10 commands you can use with GDB.

By running the command

```
1 man gdb
```

we can see some of the commands. They include: ¹

Command	Description
break	Set a breakpoint in function.
run	Start the program.
bt (backtrace)	Show the program stack (currently executing).
c	Continue running.
next	Execute next program line skipping function calls.
edit	Look at the program line.
list	Type the text of program closeby.
step	Execute next program line including function calls.
help	Display help messages.
quit	Exit the program.

¹These are the lines listed as command in the manual.

Screenshots and Explanation

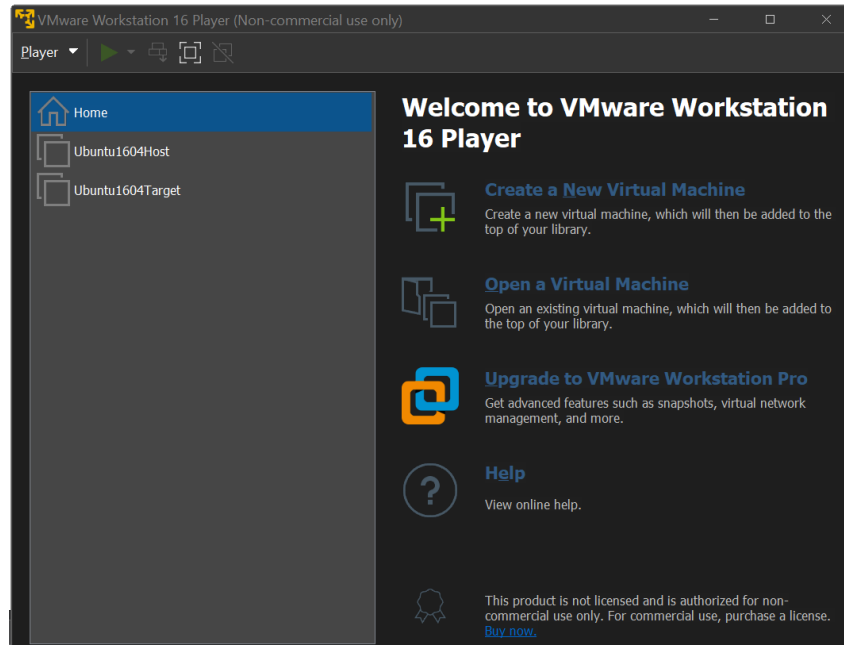
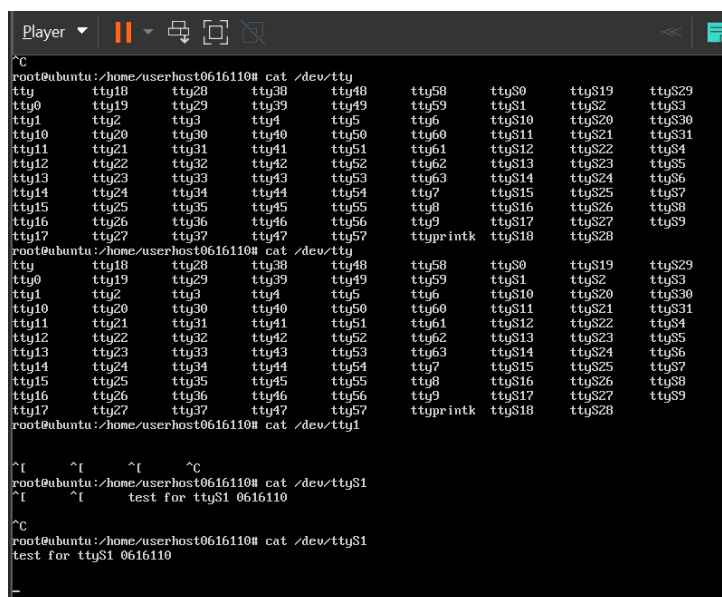


Figure 3: The Two Virtual Machines in VMWare

For the first screenshot of the assignment, we can observe the target and the host virtual machines in VMWare. Using the Ubuntu image file downloaded from the official website, we create two identical virtual machines: each gets one CPU core, 100GB of storage (allocated as needed), and 2GB of RAM initially. I installed the server version of Ubuntu to save on space, so although there is no GUI, the commands still worked as intended.



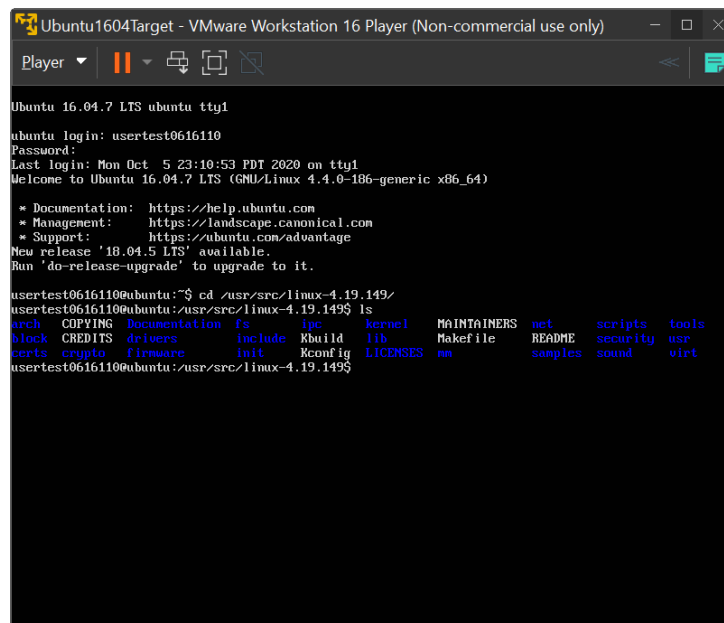
```

^C
root@ubuntu:/home/userhost0616110# cat /dev/tty
tty0 tty18 tty28 tty38 tty48 tty58 ttyS0 ttyS19 ttyS29
tty1 tty19 tty29 tty39 tty49 tty59 ttyS1 ttyS2 ttyS3
tty10 tty20 tty30 tty40 tty50 tty60 ttyS10 ttyS20 ttyS30
tty11 tty21 tty31 tty41 tty51 tty61 ttyS11 ttyS21 ttyS31
tty12 tty22 tty32 tty42 tty52 tty62 ttyS12 ttyS22 ttyS4
tty13 tty23 tty33 tty43 tty53 tty63 ttyS13 ttyS23 ttyS5
tty14 tty24 tty34 tty44 tty54 tty64 ttyS14 ttyS24 ttyS6
tty15 tty25 tty35 tty45 tty55 tty65 ttyS15 ttyS25 ttyS7
tty16 tty26 tty36 tty46 tty56 tty66 ttyS16 ttyS26 ttyS8
tty17 tty27 tty37 tty47 tty57 tty67 ttyS17 ttyS27 ttyS9
root@ubuntu:/home/userhost0616110# cat /dev/tty
tty0 tty18 tty28 tty38 tty48 tty58 ttyS0 ttyS19 ttyS29
tty1 tty19 tty29 tty39 tty49 tty59 ttyS1 ttyS2 ttyS3
tty10 tty20 tty30 tty40 tty50 tty60 ttyS10 ttyS21 ttyS31
tty11 tty21 tty31 tty41 tty51 tty61 ttyS11 ttyS22 ttyS4
tty12 tty22 tty32 tty42 tty52 tty62 ttyS12 ttyS23 ttyS5
tty13 tty23 tty33 tty43 tty53 tty63 ttyS13 ttyS24 ttyS6
tty14 tty24 tty34 tty44 tty54 tty64 ttyS14 ttyS25 ttyS7
tty15 tty25 tty35 tty45 tty55 tty65 ttyS15 ttyS26 ttyS8
tty16 tty26 tty36 tty46 tty56 tty66 ttyS16 ttyS27 ttyS9
tty17 tty27 tty37 tty47 tty57 tty67 ttyS17 ttyS28
root@ubuntu:/home/userhost0616110# cat /dev/tty1
^C
^C
^C
^C
root@ubuntu:/home/userhost0616110# cat /dev/ttyS1
^C
^C
test for ttyS1 0616110
^C
root@ubuntu:/home/userhost0616110# cat /dev/ttyS1
test for ttyS1 0616110

```

Figure 4: Testing the connection by printing the contents of `ttyS1`

At this point, we had set the pipe name in our VMWare settings. Although it might seem weird to read a connection through a file, it is consistent with the UNIX design, where famously “everything is a file”. The message at the bottom of the command output refers to the text received from our test machine. Due to the connection being a serial port, we have to use the `ttyS1` with the `S` rather than just the `tty1`, etc... In the end, whenever we receive a message on this serial connection, we can `cat` the file.



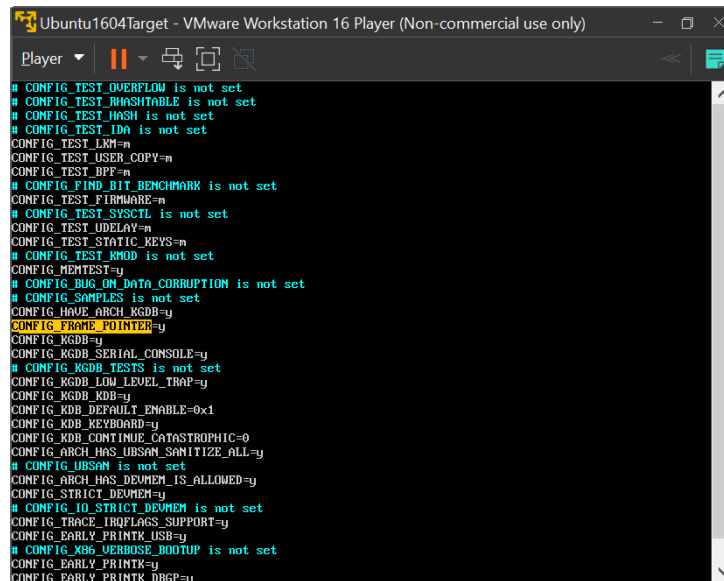
```
Ubuntu1604Target - VMware Workstation 16 Player (Non-commercial use only)
Player
Ubuntu 16.04.7 LTS ubuntu tty1
ubuntu login: usertest0616110
Password:
Last login: Mon Oct 5 23:10:53 PDT 2020 on tty1
Welcome to Ubuntu 16.04.7 LTS (GNU/Linux 4.4.0-186-generic x86_64)

 * Documentation:  https://help.ubuntu.com
 * Management:    https://landscape.canonical.com
 * Support:       https://ubuntu.com/advantage
New release '18.04.5 LTS' available.
Run 'do-release-upgrade' to upgrade to it.

usertest0616110@ubuntu:~$ cd /usr/src/linux-4.19.149/
usertest0616110@ubuntu:~$ ls
arch  COPYING  Documentation  fs  ipc  kernel  MAINTAINERS  net  scripts  tools
block CREDITS  drivers        include  Kbuild  lib  Makefile  README  security  usr
certs  crypto  firmware      init     Kconfig  LICENSES  mm  samples  sound  virt
usertest0616110@ubuntu:~$ cd /usr/src/linux-4.19.149$
```

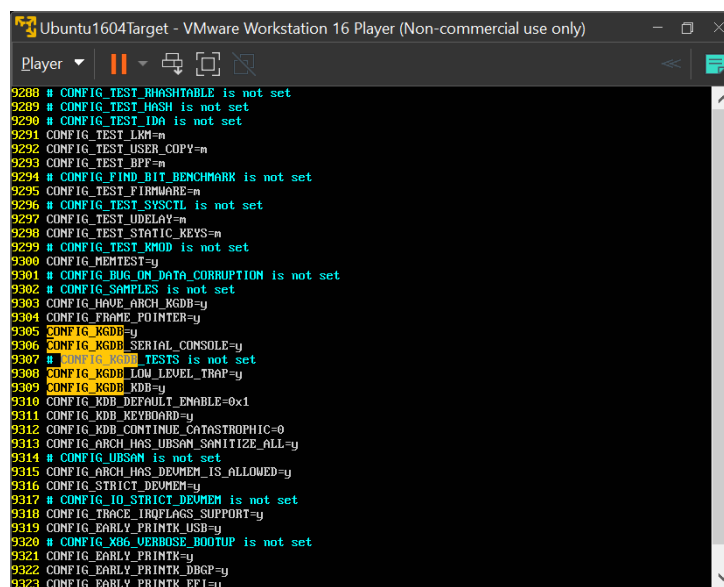
Figure 5: Downloading the Linux kernel on the target machine

Now begins the part where we build and configure the kernel. We use the `wget` command to download the content directly from the `kernel.org` site for the kernel version we need. This downloads a compressed file in the `tar.xz` format, so we need to decompress it. We then download some of the required packages for compilation using the `sudo apt install ...` command, along with the names of the programs we wish to install. We also used the `cp` command to copy the config file from the `boot/` folder according to our kernel version. By this point, we should have all the source files we need to compile the kernel, which are shown in the screenshot.



```
Ubuntu1604Target - VMware Workstation 16 Player (Non-commercial use only)
Player
# CONFIG_TEST_OVERFLOW is not set
# CONFIG_TEST_RHASHTABLE is not set
# CONFIG_TEST_HASH is not set
# CONFIG_TEST_IDA is not set
CONFIG_TEST_LKM=m
CONFIG_TEST_USER_COPY=m
CONFIG_TEST_BPF=m
# CONFIG_FIND_BIT_BENCHMARK is not set
CONFIG_TEST_FIRMWARE=m
# CONFIG_TEST_SYSCALL is not set
CONFIG_TEST_UDELAY=m
CONFIG_TEST_STATIC_KEYS=m
# CONFIG_TEST_KMOD is not set
CONFIG_MEMTEST=y
# CONFIG_BUG_ON_DATA_CORRUPTION is not set
# CONFIG_SAMPLES is not set
CONFIG_HAVE_ARCH_KGDB=y
CONFIG_FRAME_POINTER=y
CONFIG_KGDB=y
CONFIG_KGDB_SERIAL_CONSOLE=y
# CONFIG_KGDB_TESTS is not set
CONFIG_KGDB_LOW_LEVEL_TRAP=y
CONFIG_KGDB_KDB=y
CONFIG_KDB_DEFAULT_ENABLE=0x1
CONFIG_KDB_KEYBOARD=y
CONFIG_KDB_CONTINUE_CATASTROPHIC=0
CONFIG_ARCH_HAS_UBSAN_SANITIZE_ALL=y
# CONFIG_UBSAN is not set
CONFIG_ARCH_HAS_DEVMEM_IS_ALLOWED=y
CONFIG_STRICT_DEVMEM=y
# CONFIG_IQ_STRICT_DEVMEM is not set
CONFIG_TRACE_IRQFLAGS_SUPPORT=y
CONFIG_EARLY_PRINTK_USB=y
# CONFIG_X86_VERBOSE_BOOTUP is not set
CONFIG_EARLY_PRINTK=y
CONFIG_EARLY_PRINTKDBG=y
```

Figure 6: KGDB settings part 1



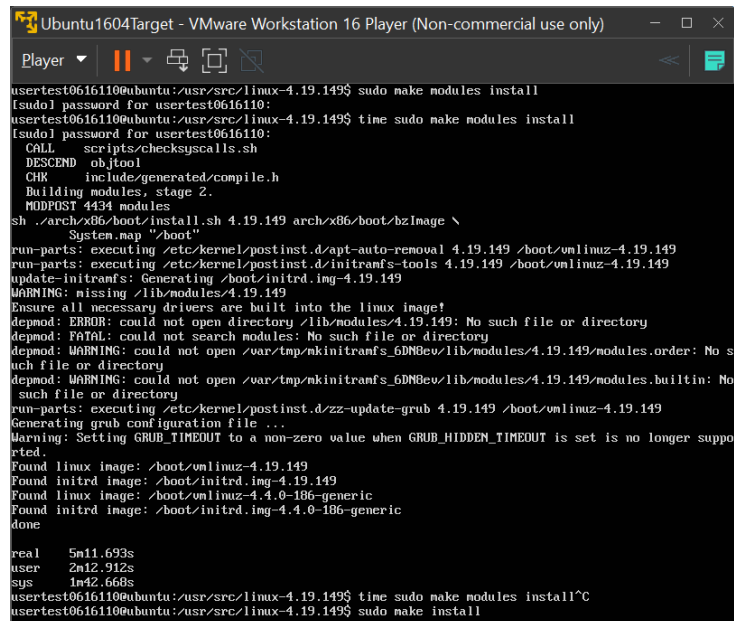
```
Ubuntu1604Target - VMware Workstation 16 Player (Non-commercial use only)
Player
9288 # CONFIG_TEST_RHASHTABLE is not set
9289 # CONFIG_TEST_HASH is not set
9290 # CONFIG_TEST_IDA is not set
9291 CONFIG_TEST_LKM=m
9292 CONFIG_TEST_USER_COPY=m
9293 CONFIG_TEST_BPF=m
9294 # CONFIG_FIND_BIT_BENCHMARK is not set
9295 CONFIG_TEST_FIRMWARE=m
9296 # CONFIG_TEST_SYSCALL is not set
9297 CONFIG_TEST_UDELAY=m
9298 CONFIG_TEST_STATIC_KEYS=m
9299 # CONFIG_TEST_KMOD is not set
9300 CONFIG_MEMTEST=y
9301 # CONFIG_BUG_ON_DATA_CORRUPTION is not set
9302 # CONFIG_SAMPLES is not set
9303 CONFIG_HAVE_ARCH_KGDB=y
9304 CONFIG_FRAME_POINTER=y
9305 CONFIG_KGDB=y
9306 CONFIG_KGDB_SERIAL_CONSOLE=y
9307 # CONFIG_KGDB_TESTS is not set
9308 CONFIG_KGDB_LOW_LEVEL_TRAP=y
9309 CONFIG_KGDB_KDB=y
9310 CONFIG_KDB_DEFAULT_ENABLE=0x1
9311 CONFIG_KDB_KEYBOARD=y
9312 CONFIG_KDB_CONTINUE_CATASTROPHIC=0
9313 CONFIG_ARCH_HAS_UBSAN_SANITIZE_ALL=y
9314 # CONFIG_UBSAN is not set
9315 CONFIG_ARCH_HAS_DEVMEM_IS_ALLOWED=y
9316 CONFIG_STRICT_DEVMEM=y
9317 # CONFIG_IQ_STRICT_DEVMEM is not set
9318 CONFIG_TRACE_IRQFLAGS_SUPPORT=y
9319 CONFIG_EARLY_PRINTK_USB=y
9320 # CONFIG_X86_VERBOSE_BOOTUP is not set
9321 CONFIG_EARLY_PRINTK=y
9322 CONFIG_EARLY_PRINTKDBG=y
9323 CONFIG_EARLY_PRINTK_EFI=y
```

Figure 7: KGDB settings part 2

These two screenshots show the settings that we edited. They all are setting the kernel debugger compilation. The `CONFIG_FRAME_POINTER` setting will leave code blocks behind that can be picked up by our debugger. The other settings mostly make sure we are compiling with KGDB set to true so that when we boot the system we can go directly to the debugger command line.

Figure 8: Compiling the Linux kernel

Figure 9: Compiling kernel modules



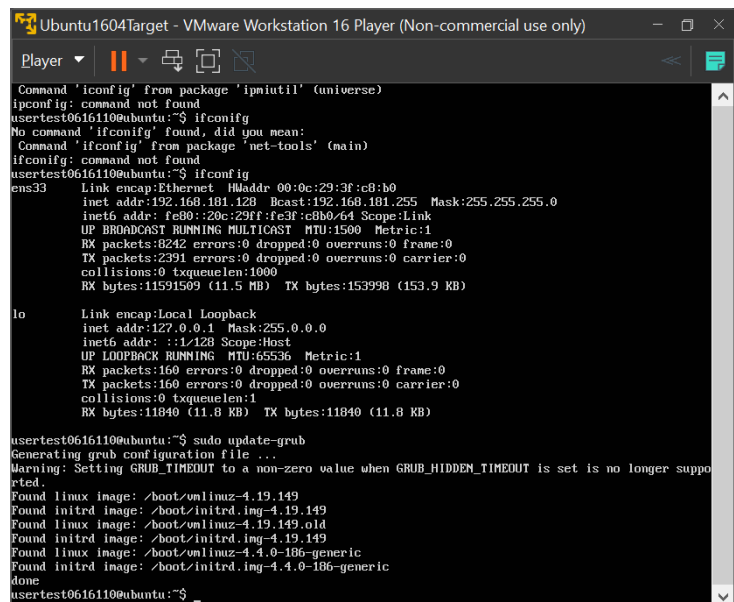
```

Ubuntu1604Target - VMware Workstation 16 Player (Non-commercial use only)
Player
usertest0616110@ubuntu:/usr/src/linux-4.19.149$ sudo make modules install
[sudo] password for usertest0616110:
usertest0616110@ubuntu:/usr/src/linux-4.19.149$ time sudo make modules install
[sudo] password for usertest0616110:
CALL scripts/checksyscalls.sh
DESCEND objtool
CHK include/generated/compile.h
Building modules, stage 2.
MODPOST 4434 modules
sh ./arch/x86/boot/install.sh 4.19.149 arch/x86/boot/bzImage \
System.map "/boot"
run-parts: executing /etc/kernel/postinst.d/apt-auto-removal 4.19.149 /boot/vmlinuz-4.19.149
run-parts: executing /etc/kernel/postinst.d/initramfs-tools 4.19.149 /boot/vmlinuz-4.19.149
update-initramfs: Generating /boot/initrd.img-4.19.149
WARNING: missing /lib/modules/4.19.149
Ensure all necessary drivers are built into the linux image!
depmod: ERROR: could not open directory /lib/modules/4.19.149: No such file or directory
depmod: FATAL: could not search modules: No such file or directory
depmod: WARNING: could not open /var/tmp/mkinitramfs_6DN0ev/lib/modules/4.19.149/modules.order: No such file or directory
depmod: WARNING: could not open /var/tmp/mkinitramfs_6DN0ev/lib/modules/4.19.149/modules.builtin: No such file or directory
run-parts: executing /etc/kernel/postinst.d/zz-update-grub 4.19.149 /boot/vmlinuz-4.19.149
Generating grub configuration file ...
Warning: Setting GRUB_TIMEOUT to a non-zero value when GRUB_HIDDEN_TIMEOUT is set is no longer supported.
Found linux image: /boot/vmlinuz-4.19.149
Found initrd image: /boot/initrd.img-4.19.149
Found linux image: /boot/vmlinuz-4.4.0-186-generic
Found initrd image: /boot/initrd.img-4.4.0-186-generic
done
real    5m11.693s
user    2m12.912s
sys     1m42.668s
usertest0616110@ubuntu:/usr/src/linux-4.19.149$ time sudo make modules install^C
usertest0616110@ubuntu:/usr/src/linux-4.19.149$ sudo make install

```

Figure 10: Installing the compiled kernel modules to the compiled kernel image

These screenshots show the different steps in the compilation and installation process. In the first one, we compile the main Linux kernel. This creates the image file, which we will use to boot. We still have to include the kernel modules into the `vmlinuz` image file. Finally, we install the compiled kernel on our system.



```

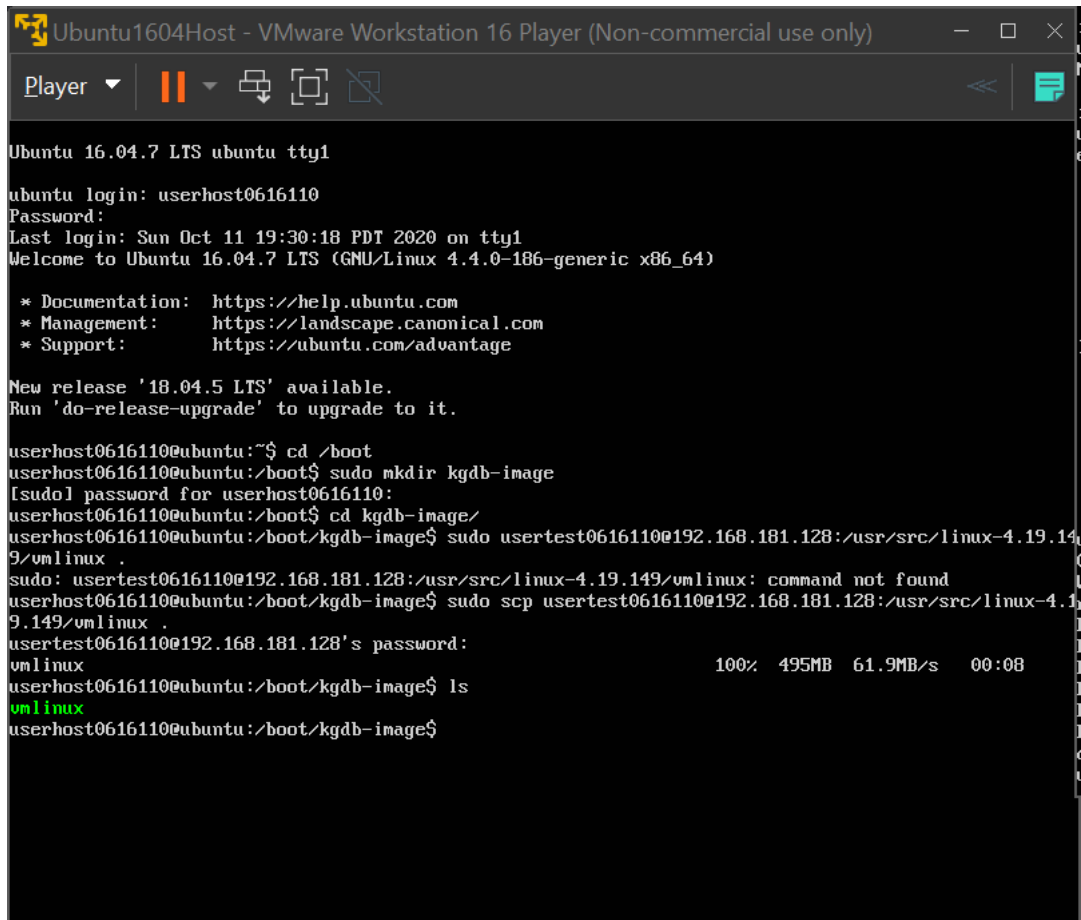
Ubuntu1604Target - VMware Workstation 16 Player (Non-commercial use only)
Player
Command 'ifconfig' from package 'ipmitool' (universe)
ifconfig: command not found
usertest0616110@ubuntu:~$ ifconfig
No command 'ifconfig' found, did you mean:
Command 'ifconfig' from package 'net-tools' (main)
ifconfig: command not found
usertest0616110@ubuntu:~$ ifconfig
ens33    Link encap:Ethernet HWaddr 00:0c:29:3f:c8:b0
          inet addr:192.168.101.128 Bcast:192.168.101.255 Mask:255.255.255.0
          inet6 addr: fe80::20c:29ff:fe3f:c8b0/64 Scope:Link
          UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
          RX packets:8242 errors:0 dropped:0 overruns:0 frame:0
          TX packets:2391 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:11591509 (11.5 MB)  TX bytes:153998 (153.9 KB)

lo       Link encap:Local Loopback
          inet addr:127.0.0.1 Mask:255.0.0.0
          inet6 addr: ::1/128 Scope:Host
          UP LOOPBACK RUNNING  MTU:65536  Metric:1
          RX packets:160 errors:0 dropped:0 overruns:0 frame:0
          TX packets:160 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1
          RX bytes:11840 (11.8 KB)  TX bytes:11840 (11.8 KB)

usertest0616110@ubuntu:~$ sudo update-grub
Generating grub configuration file ...
Warning: Setting GRUB_TIMEOUT to a non-zero value when GRUB_HIDDEN_TIMEOUT is set is no longer supported.
Found linux image: /boot/vmlinuz-4.19.149
Found initrd image: /boot/initrd.img-4.19.149
Found linux image: /boot/vmlinuz-4.19.149.old
Found initrd image: /boot/initrd.img-4.19.149
Found linux image: /boot/vmlinuz-4.4.0-186-generic
Found initrd image: /boot/initrd.img-4.4.0-186-generic
done
usertest0616110@ubuntu:~$ _

```

Figure 11: Updating the GRUB configuration file



```
Ubuntu1604Host - VMware Workstation 16 Player (Non-commercial use only)
Player
Ubuntu 16.04.7 LTS ubuntu tty1
ubuntu login: userhost0616110
Password:
Last login: Sun Oct 11 19:30:18 PDT 2020 on tty1
Welcome to Ubuntu 16.04.7 LTS (GNU/Linux 4.4.0-186-generic x86_64)

 * Documentation:  https://help.ubuntu.com
 * Management:    https://landscape.canonical.com
 * Support:       https://ubuntu.com/advantage

New release '18.04.5 LTS' available.
Run 'do-release-upgrade' to upgrade to it.

userhost0616110@ubuntu:~$ cd /boot
userhost0616110@ubuntu:/boot$ sudo mkdir kgdb-image
[sudo] password for userhost0616110:
userhost0616110@ubuntu:/boot$ cd kgdb-image/
userhost0616110@ubuntu:/boot/kgdb-image$ sudo usertest0616110@192.168.181.128:/usr/src/linux-4.19.149/vmlinuz .
sudo: usertest0616110@192.168.181.128:/usr/src/linux-4.19.149/vmlinuz: command not found
userhost0616110@ubuntu:/boot/kgdb-image$ sudo scp usertest0616110@192.168.181.128:/usr/src/linux-4.19.149/vmlinuz .
usertest0616110@192.168.181.128's password:
vmlinuz                                     100% 495MB 61.9MB/s 00:08
userhost0616110@ubuntu:/boot/kgdb-image$ ls
vmlinuz
userhost0616110@ubuntu:/boot/kgdb-image$
```

Figure 12: Checking the vmlinuz file

As previously mentioned, GRUB is a program that loads an operating system available on the system. When we update the configuration file, we are adding entries for all our operating systems. Then when we see the GRUB boot menu on powering the virtual machine on again we will be allowed to choose from those operating systems. The second screenshot shows the host machine copying the image file with the debug options from the target machine. This is done so that we can run GDB on the image file from the host machine.

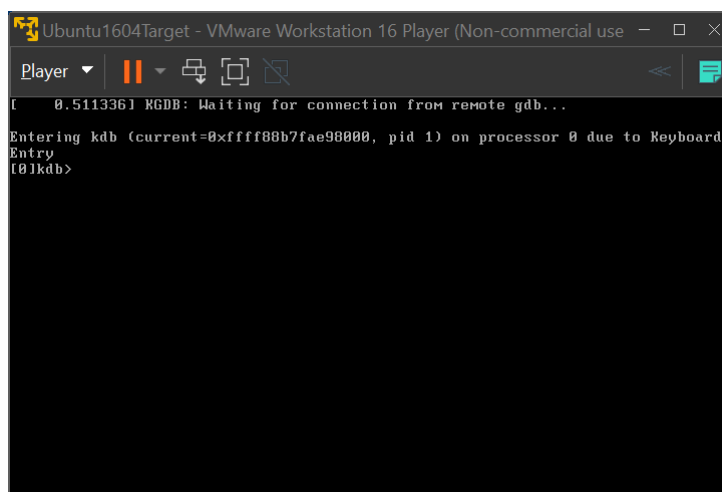


Figure 13: Target machine waiting for remote connection from GDB for kernel debugging.

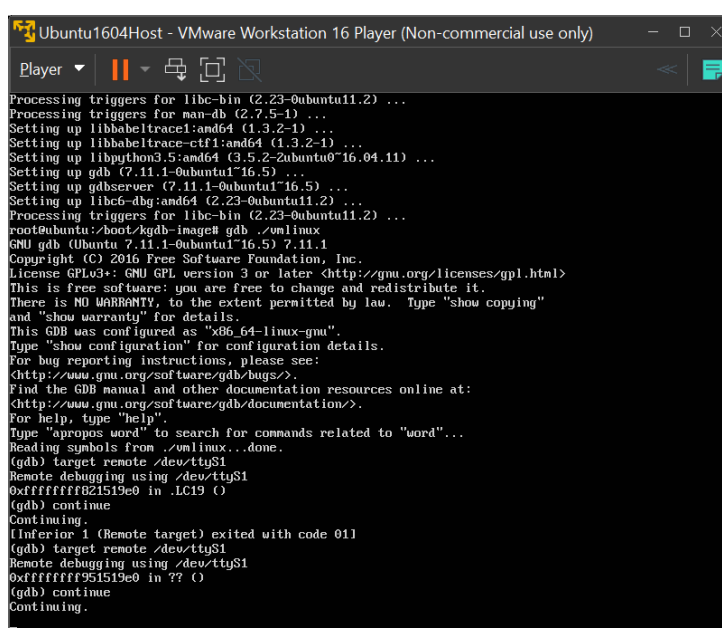


Figure 14: Remotely debugging the kernel through the host machine. Here we make the target machine continue the kernel execution on the Target machine.

For the final set of screenshots, we restarted the target virtual machine. Since we compiled the kernel with debug options, when we boot, we go straight to the debug command line. Since we also compiled with the kgdb set to wait from the `ttys1` serial port, we get the message that it's waiting for a remote gdb connection. This is also why we can connect the host gdb instance, which we run on the linux image that we copied in the previous section. The second screenshot shows the host ma-

chine command line having the target machine kernel execution continue. On the target machine, this means the computer was caused to load. Now we are debugging the kernel on one machine and have it execute on another machine.