

Stage3 作业提交文档

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完成情况：完成所有题目

这次是重新提交，因为最终完成了第四题

情况简述：

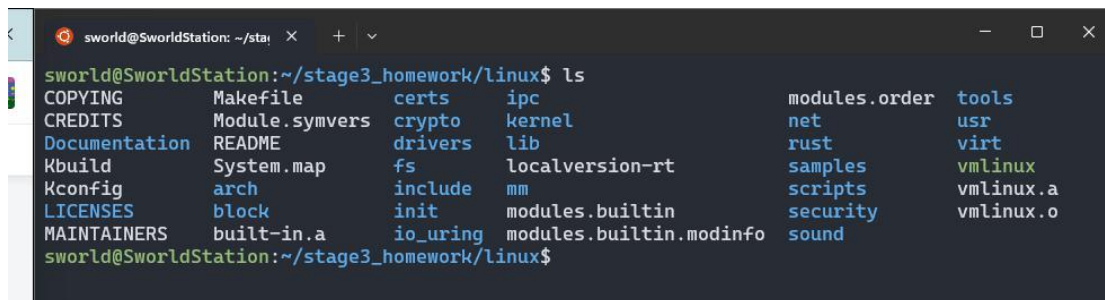
第三阶段的前几题都比我想象中要顺利，在遇到问题后进行搜索也都比较快地解决了问题，然而到最后一题，先是 Rust-Analyzer 的配置让我卡了很久（原因也是我没认真看 README 里的链接），在打上 Patch 后终于解决了，在阅读了[带注释的 C 版本源代码](#)后，终于完成了。

在这个过程中，真是深感自己知识不足，因为只是相关专业(信息管理与信息系统)，对计算机底层的一些知识都是靠自学得来的，有的部分掌握尚有欠缺，这段时间也比较忙，没能及时补上，不过此次训练营还是给我带来了挺多收获的，也参与了大家的讨论，我觉得是挺不错的。

作业详情

Exercise 1

环境仍然使用 Stage2 的环境，使用仓库 https://www.github.com/zxgsn/stage3_homework 准备好的代码仓库，按照步骤进行构建，成功生成了所需文件，也可以看到 vmlinux 文件



```
sworld@SworldStation: ~/stage3_homework/linux$ ls
COPYING      Makefile      certs         ipc           modules.order  tools
CREDITS      Module.symvers  crypto        kernel        net            usr
Documentation README         drivers       lib           rust          virt
Kbuild       System.map     fs            localversion-rt samples       vmlinux
Kconfig      arch           include       mm            scripts        vmlinux.a
LICENSES     block          init          modules.builtin  security       vmlinux.o
MAINTAINERS  built-in.a     io_uring      modules.builtin.modinfo  sound
```

Exercise 2

使用脚本启动，发现启动失败

```
sworld@SworldStation:~/stage3_homework/src_e1000$ chmod 777 ./build_image.sh
sworld@SworldStation:~/stage3_homework/src_e1000$ ./build_image.sh
make -C ../linux M=$PWD
make[1]: Entering directory '/home/sworld/stage3_homework/linux'
  RUSTC [M] /home/sworld/stage3_homework/src_e1000/r4l_e1000_demo.o
  MODPOST /home/sworld/stage3_homework/src_e1000/Module.symvers
  CC [M] /home/sworld/stage3_homework/src_e1000/r4l_e1000_demo.mod.o
  LD [M] /home/sworld/stage3_homework/src_e1000/r4l_e1000_demo.ko
make[1]: Leaving directory '/home/sworld/stage3_homework/linux'

5313 blocks
qemu-system-x86_64: -netdev user,id=eth0: network backend 'user' is not compiled into this binary
sworld@SworldStation:~/stage3_homework/src_e1000$
```

发现是 Qemu 问题，由于我使用的是 Stage2 留下来的自己编译的 Qemu，因此去除了该环境变量，使用 apt-get 重新下载 Qemu，运行成功

```
sworld@SworldStation: ~/stag  X  sworld@SworldStation: ~/sta  X  +  v  -  □  X
[ 0.835458] hid: raw HID events driver (C) Jiri Kosina
[ 0.836870] usbcore: registered new interface driver usbhid
[ 0.836879] usbhid: USB HID core driver
[ 0.840831] Initializing XFRM netlink socket
[ 0.841299] NET: Registered PF_INET6 protocol family
[ 0.844772] Segment Routing with IPv6
[ 0.844866] In-situ OAM (IOAM) with IPv6
[ 0.845317] sit: IPv6, IPv4 and MPLS over IPv4 tunneling driver
[ 0.847299] NET: Registered PF_PACKET protocol family
[ 0.847860] 9pnet: Installing 9P2000 support
[ 0.848505] Key type dns_resolver registered
[ 0.849640] IPI shorthand broadcast: enabled
[ 0.849934] sched_clock: Marking stable (825150267, 24520537)->(849927589, -256785)
[ 0.851136] registered taskstats version 1
[ 0.851149] Loading compiled-in X.509 certificates
[ 0.854294] cryptomgr_test (45) used greatest stack depth: 15576 bytes left
[ 0.857633] PM: Magic number: 3:222:84
[ 0.858335] printk: console [netcon0] enabled
[ 0.858342] netconsole: network logging started
[ 0.860405] printk: console [netcon0] printing thread started
[ 0.975971] ata2: found unknown device (class 0)
[ 0.978759] ata2.00: ATAPI: QEMU DVD-ROM, 2.5+, max UDMA/100
[ 0.983881] scsi 1:0:0:0: CD-ROM QEMU QEMU DVD-ROM 2.5+ PQ: 0 ANSI: 5
[ 1.014659] sr 1:0:0:0: [sr0] scsi3-mmc drive: 4x/4x cd/rw xa/form2 tray
[ 1.014831] cdrom: Uniform CD-ROM driver Revision: 3.20
[ 1.031001] sr 1:0:0:0: Attached scsi generic sg0 type 5
[ 1.457106] input: ImExPS/2 Generic Explorer Mouse as /devices/platform/i8042/serio1/inpu3
[ 1.704322] tsc: Refined TSC clocksource calibration: 3799.972 MHz
[ 1.704424] clocksource: tsc: mask: 0xffffffffffffffff max_cycles: 0x6d8c7c24e93, max_idle
[ 1.704520] clocksource: Switched to clocksource tsc
[ 13.736308] cfg80211: Loading compiled-in X.509 certificates for regulatory database
[ 13.765003] modprobe (69) used greatest stack depth: 14216 bytes left
[ 13.771330] cfg80211: Loaded X.509 cert 'sforshee: 00b28ddf47aef9cea7'
[ 13.772083] platform regulatory.0: Direct firmware load for regulatory.db failed with err2
[ 13.772204] cfg80211: failed to load regulatory.db
[ 13.773743] ALSA device list:
[ 13.773898] No soundcards found.
[ 13.806438] Freeing unused kernel image (initmem) memory: 1288K
[ 13.808086] Write protecting the kernel read-only data: 22528K
[ 13.810093] Freeing unused kernel image (text/rodata gap) memory: 2032K
[ 13.811173] Freeing unused kernel image (rodata/data gap) memory: 1616K
[ 13.933197] x86/mm: Checked W+X mappings: passed, no W+X pages found.
[ 13.933832] Run sbinit as init process
[ 13.954591] mount (74) used greatest stack depth: 13872 bytes left
[ 14.008552] mdev (76) used greatest stack depth: 13840 bytes left

Please press Enter to activate this console.
~ #
```

然后启用 Rust 编写的网卡驱动模块

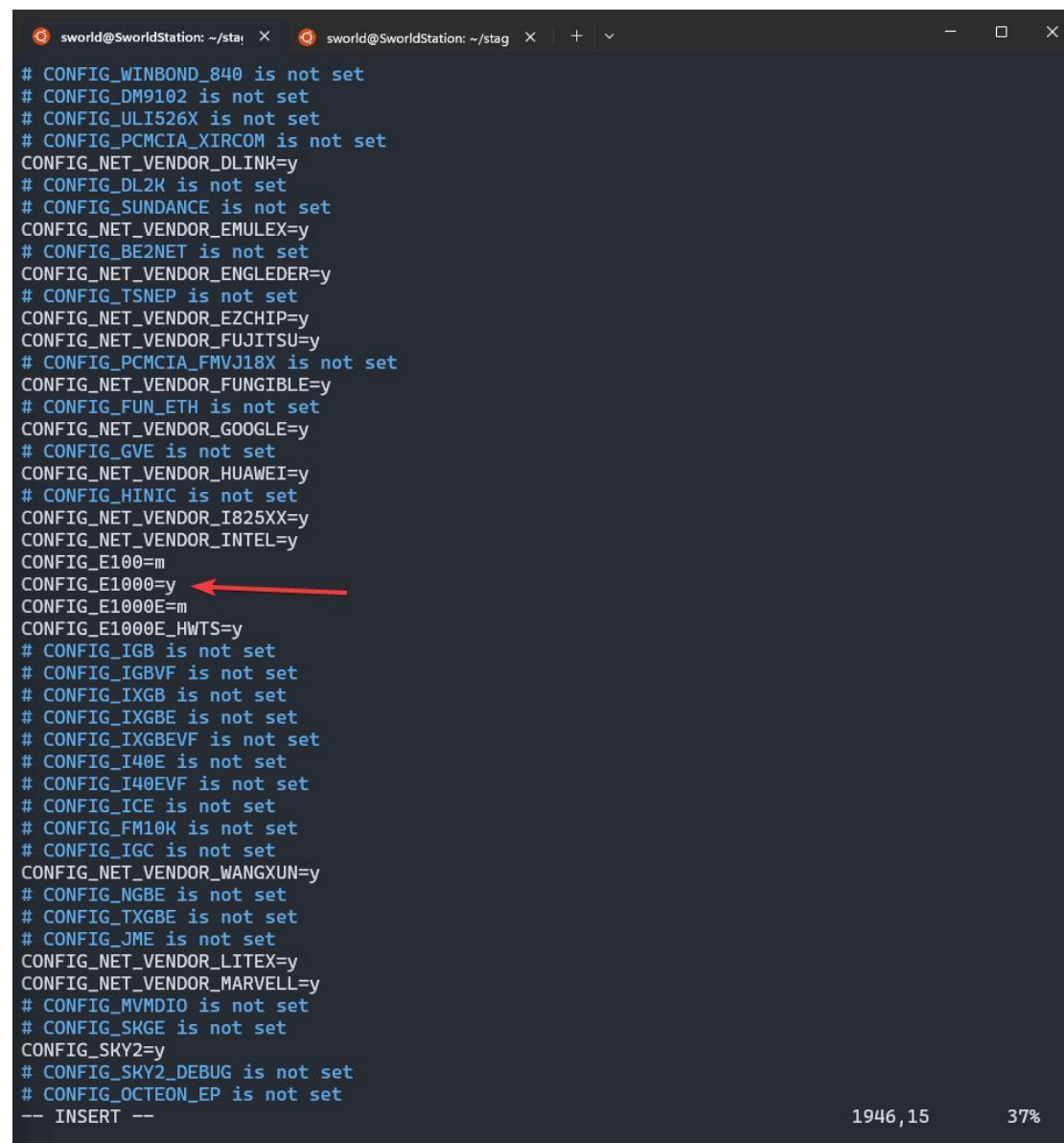
```
sworld@SworldStation: ~/stag x sworld@SworldStation: ~/sta! x + v
~ # ls
bin          linuxrc      root         usr
dev          proc         sbin
etc          r4l_e1000_demo.ko sys
~ # insmod r4l_e1000_demo.ko
[ 174.535210] r4l_e1000_demo: loading out-of-tree module taints kernel.
[ 174.538813] r4l_e1000_demo: Rust for linux e1000 driver demo (init)
[ 174.539065] r4l_e1000_demo: Rust for linux e1000 driver demo (probe): None
[ 174.646523] ACPI: \_SB_.LNKC: Enabled at IRQ 11
[ 174.667205] r4l_e1000_demo: Rust for linux e1000 driver demo (net device get_stats64)
~ # [ 174.668628] insmod (87) used greatest stack depth: 10968 bytes left
█
```

执行后续指令，可以使用 ping 命令

```
sworld@SworldStation: ~/stag x sworld@SworldStation: ~/sta! x + v
[ 625.469815] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 625.469824] r4l_e1000_demo: pending_irqs: 131
[ 625.469939] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
[ 625.470879] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=1
[ 625.470914] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 625.470918] r4l_e1000_demo: pending_irqs: 131
[ 625.472527] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
64 bytes from 10.0.2.2: seq=0 ttl=255 time=7.242 ms
[ 626.475465] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=2
[ 626.475561] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 626.475578] r4l_e1000_demo: pending_irqs: 131
[ 626.475608] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
64 bytes from 10.0.2.2: seq=1 ttl=255 time=0.484 ms
64 bytes from 10.0.2.2: seq=2 ttl=255 time=0.381 ms
[ 627.476287] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=3
[ 627.476379] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 627.476385] r4l_e1000_demo: pending_irqs: 131
[ 627.476408] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
64 bytes from 10.0.2.2: seq=3 ttl=255 time=0.412 ms
[ 628.477285] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=4
[ 628.477382] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 628.477389] r4l_e1000_demo: pending_irqs: 131
[ 628.477417] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
64 bytes from 10.0.2.2: seq=4 ttl=255 time=0.395 ms
[ 629.478043] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=5
[ 629.478137] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 629.478143] r4l_e1000_demo: pending_irqs: 131
[ 629.478165] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
64 bytes from 10.0.2.2: seq=5 ttl=255 time=0.433 ms
[ 630.479167] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=6
[ 630.479288] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 630.479294] r4l_e1000_demo: pending_irqs: 131
[ 630.479322] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
[ 631.479823] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=7
[ 631.479952] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 631.479958] r4l_e1000_demo: pending_irqs: 131
[ 631.479978] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
64 bytes from 10.0.2.2: seq=6 ttl=255 time=1.044 ms
64 bytes from 10.0.2.2: seq=7 ttl=255 time=0.391 ms[ 632.481463] r4l_e1000_demo: Rust for 10
[ 632.481569] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 632.481575] r4l_e1000_demo: pending_irqs: 131
[ 632.481598] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)

^C
--- 10.0.2.2 ping statistics ---
8 packets transmitted, 8 packets received, 0% packet loss
round-trip min/avg/max = 0.381/1.347/7.242 ms
~ # █
```


修改 .config 文件，启用原版驱动，并且重新编译



```
sword@SwordStation: ~/sta | sword@SwordStation: ~/stag
# CONFIG_WINBOND_840 is not set
# CONFIG_DM9102 is not set
# CONFIG_ULI526X is not set
# CONFIG_PCMCIA_XIRCOM is not set
CONFIG_NET_VENDOR_DLINK=y
# CONFIG_DL2K is not set
# CONFIG_SUNDANCE is not set
CONFIG_NET_VENDOR_EMULEX=y
# CONFIG_BE2NET is not set
CONFIG_NET_VENDOR_ENGLEDER=y
# CONFIG_TSNEP is not set
CONFIG_NET_VENDOR_EZCHIP=y
CONFIG_NET_VENDOR_FUJITSU=y
# CONFIG_PCMCIA_FMVJ18X is not set
CONFIG_NET_VENDOR_FUNGIBLE=y
# CONFIG_FUN_ETH is not set
CONFIG_NET_VENDOR_GOOGLE=y
# CONFIG_GVE is not set
CONFIG_NET_VENDOR_HUAWEI=y
# CONFIG_HINIC is not set
CONFIG_NET_VENDOR_I825XX=y
CONFIG_NET_VENDOR_INTEL=y
CONFIG_E100=m
CONFIG_E100=y
CONFIG_E100E=m
CONFIG_E100E_HWTS=y
# CONFIG_IGB is not set
# CONFIG_IGBVF is not set
# CONFIG_IXGB is not set
# CONFIG_IXGBE is not set
# CONFIG_IXGBEVF is not set
# CONFIG_I40E is not set
# CONFIG_I40EVF is not set
# CONFIG_ICE is not set
# CONFIG_FM10K is not set
# CONFIG_IGC is not set
CONFIG_NET_VENDOR_WANGXUN=y
# CONFIG_NGBE is not set
# CONFIG_TXGBE is not set
# CONFIG_JME is not set
CONFIG_NET_VENDOR_LITEX=y
CONFIG_NET_VENDOR_MARVELL=y
# CONFIG_MVMIO is not set
# CONFIG_SKGE is not set
CONFIG_SKY2=y
# CONFIG_SKY2_DEBUG is not set
# CONFIG_OCTEON_EP is not set
-- INSERT --
```

1946,15 37%

重新运行指令，成功

```
sworld@SworldStation: ~/stag  x  sworld@SworldStation: ~/sta  x  +  v  -  □  x

[ 1.936689] modprobe (68) used greatest stack depth: 14216 bytes left
[ 1.942931] cfg80211: Loaded X.509 cert 'sforshee: 00b28ddf47aef9cea7'
[ 1.943684] platform regulatory.0: Direct firmware load for regulatory.db failed with err2
[ 1.943800] cfg80211: failed to load regulatory.db
[ 1.945011] ALSA device list:
[ 1.945138]   No soundcards found.
[ 1.977970] Freeing unused kernel image (initmem) memory: 1288K
[ 1.979563] Write protecting the kernel read-only data: 22528k
[ 1.981117] Freeing unused kernel image (text/rodata gap) memory: 2032K
[ 1.982144] Freeing unused kernel image (rodata/data gap) memory: 1596K
[ 2.103292] x86/mm: Checked W+X mappings: passed, no W+X pages found.
[ 2.104029] Run/sbin/init as init process
[ 2.124319] mount (73) used greatest stack depth: 14112 bytes left
[ 2.177934] mdev (75) used greatest stack depth: 13840 bytes left

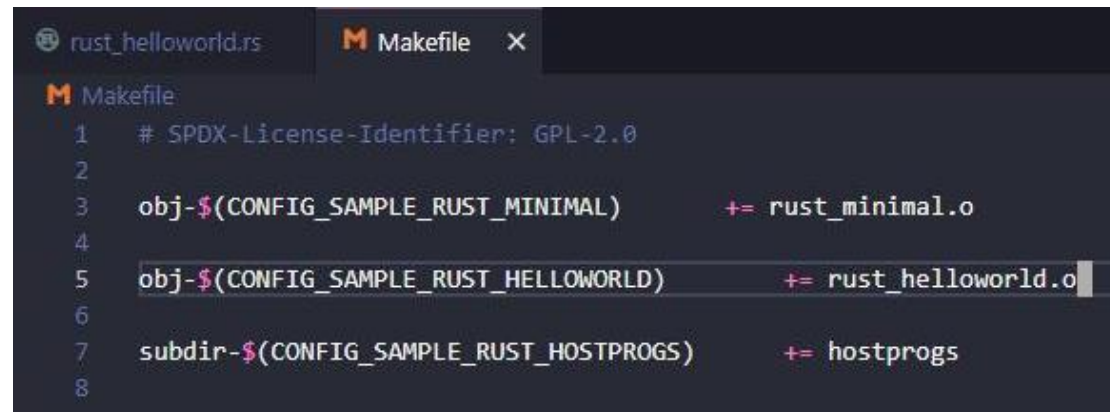
Please press Enter to activate this console.
~ # ifconfig
eth0      Link encap:Ethernet  HWaddr 52:54:00:12:34:56
          inet addr:10.0.2.15  Bcast:10.0.2.255  Mask:255.255.255.0
          inet6 addr: fe80::5054:ff:fe12:3456/64 Scope:Site
          UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
          RX packets:1 errors:0 dropped:0 overruns:0 frame:0
          TX packets:7 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:110 (110.0 B)  TX bytes:602 (602.0 B)

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:0 errors:0 dropped:0 overruns:0 frame:0
          TX packets:0 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:0 (0.0 B)  TX bytes:0 (0.0 B)

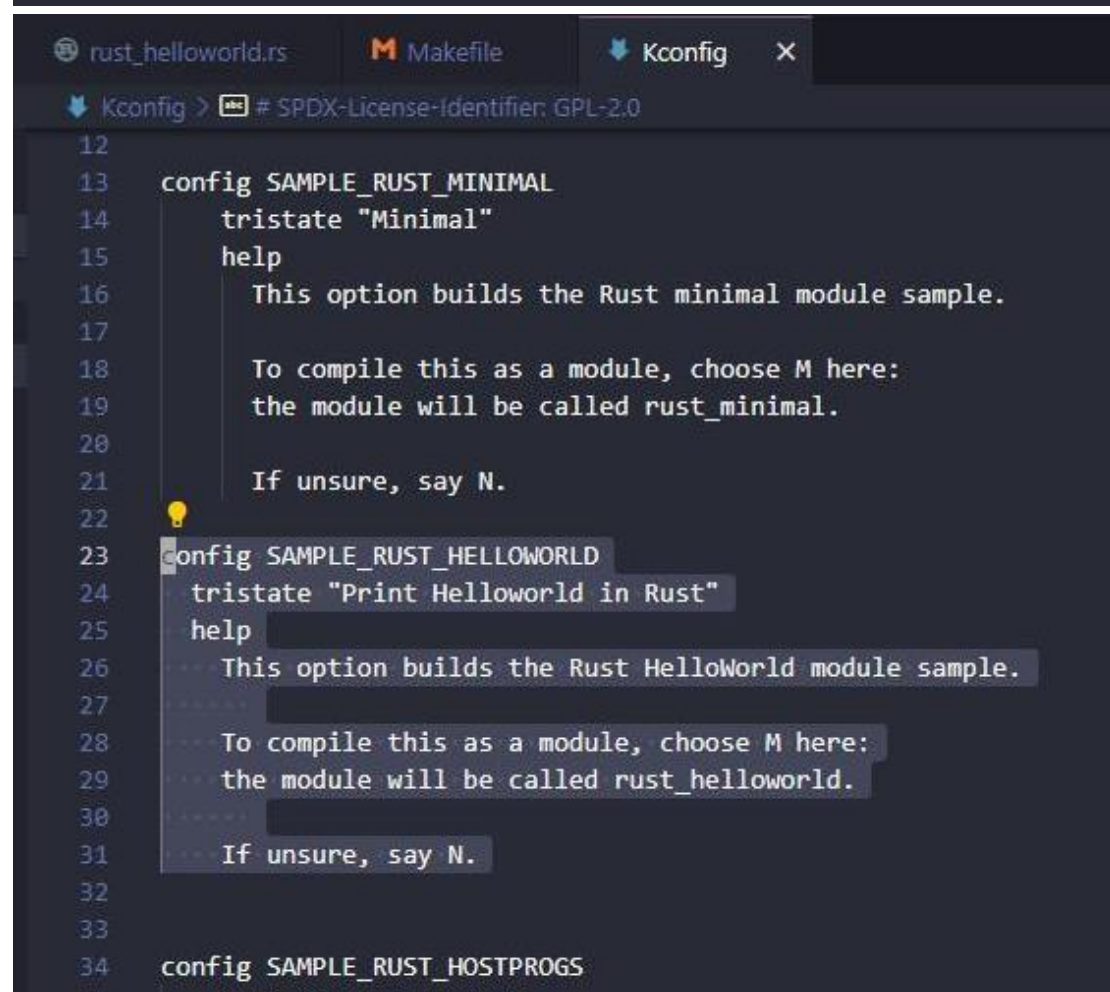
~ # ping 10.0.2.2
PING 10.0.2.2 (10.0.2.2): 56 data bytes
64 bytes from 10.0.2.2: seq=0 ttl=255 time=4.750 ms
64 bytes from 10.0.2.2: seq=1 ttl=255 time=0.392 ms
64 bytes from 10.0.2.2: seq=2 ttl=255 time=0.334 ms
64 bytes from 10.0.2.2: seq=3 ttl=255 time=0.349 ms
64 bytes from 10.0.2.2: seq=4 ttl=255 time=0.293 ms
^C
--- 10.0.2.2 ping statistics ---
5 packets transmitted, 5 packets received, 0% packet loss
round-trip min/avg/max = 0.293/1.223/4.750 ms
~ #
```

Exercise 3

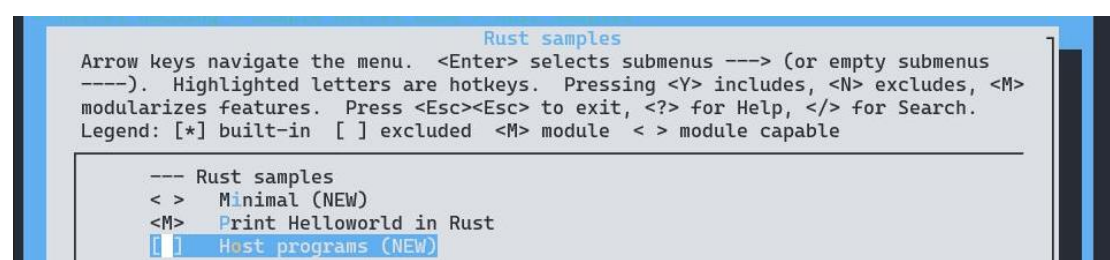
尝试构建 in-tree 模块，首先修改 Makefile 和 Kconfig，并且使用 menuconfig 进行配置



```
rust_helloworld.rs  Makefile  X
M Makefile
1 # SPDX-License-Identifier: GPL-2.0
2
3 obj-$(CONFIG_SAMPLE_RUST_MINIMAL) += rust_minimal.o
4
5 obj-$(CONFIG_SAMPLE_RUST_HELLOWORLD) += rust_helloworld.o
6
7 subdir-$(CONFIG_SAMPLE_RUST_HOSTPROGS) += hostprogs
8
```



```
rust_helloworld.rs  Makefile  Kconfig  X
Kconfig > # SPDX-License-Identifier: GPL-2.0
12
13 config SAMPLE_RUST_MINIMAL
14     tristate "Minimal"
15     help
16         This option builds the Rust minimal module sample.
17
18         To compile this as a module, choose M here:
19         the module will be called rust_minimal.
20
21         If unsure, say N.
22
23 config SAMPLE_RUST_HELLOWORLD
24     tristate "Print Helloworld in Rust"
25     help
26         This option builds the Rust HelloWorld module sample.
27
28         To compile this as a module, choose M here:
29         the module will be called rust_helloworld.
30
31         If unsure, say N.
32
33
34 config SAMPLE_RUST_HOSTPROGS
```



```
Rust samples
Arrow keys navigate the menu. <Enter> selects submenus ---- (or empty submenus
----). Highlighted letters are hotkeys. Pressing <Y> includes, <N> excludes, <M>
modularizes features. Press <Esc><Esc> to exit, <?> for Help, </> for Search.
Legend: [*] built-in [ ] excluded <M> module <> module capable

--- Rust samples
< > Minimal (NEW)
<M> Print Helloworld in Rust
[*] Host programs (NEW)
```

编译，获得 ko 文件，将其复制到对应目录

```
rpmsg/ rust/  
sworld@SworldStation:~/stage3_homework/linux$ ls samples/rust/  
Kconfig      hostprogs      rust_helloworld.mod  rust_helloworld.o  
Makefile     modules.order  rust_helloworld.mod.c rust_helloworld.rs  
built-in.a   rust_helloworld.ko  rust_helloworld.mod.o rust_minimal.rs
```

使用 insmod 加载，可以看到正确的输出

```
~ # ls  
bin          proc          rust_minimal.ko  
dev          r4l_e1000_demo.ko  sbin  
etc          root          sys  
linuxrc      rust_helloworld.ko  usr  
~ # insmod rust_minimal.ko  
[ 119.723075] rust_minimal: Rust minimal sample (init)  
[ 119.723103] rust_minimal: Am I built-in? false  
~ # rmmod rust_minimal.ko  
[ 124.683753] rust_minimal: My numbers are [72, 108, 200]  
[ 124.683836] rust_minimal: Rust minimal sample (exit)  
~ #  
~ #  
~ # insmod rust_helloworld.ko  
~ # rmmod rust_helloworld.ko  
~ # [ 130.172696] rust_helloworld: Hello World from Rust module  
[ 332.850941] kworker/dying (29) used greatest stack depth: 13664 bytes left
```


Exercise 4

首先清理环境

```
sworld@SworldStation:~/stage3_homework/linux$ make mrproper
CLEAN arch/x86/boot/compressed
CLEAN arch/x86/boot
CLEAN arch/x86/entry/vdso
CLEAN arch/x86/kernel/cpu
CLEAN arch/x86/kernel
CLEAN arch/x86/realmode/rm
CLEAN arch/x86/tools
CLEAN arch/x86/lib
CLEAN certs
CLEAN drivers/firmware/efi/libstub
CLEAN drivers/scsi
CLEAN drivers/tty/vt
CLEAN init
CLEAN lib
CLEAN net/wireless
CLEAN rust
CLEAN security/selinux
CLEAN usr
CLEAN .
CLEAN modules.builtin modules.builtin.modinfo .vmlinux.export.c
CLEAN scripts/basic
CLEAN scripts/kconfig
CLEAN scripts/mod
CLEAN scripts/selinux/genheaders
CLEAN scripts/selinux/mdp
CLEAN scripts
CLEAN include/config include/generated arch/x86/include/generated .config .version Module
.symvers rust/target.json rust/libmacros.so
```

根据 [该链接](#) 修改对应的文件(Makefile, Script 等), 然后在 off-tree 网卡驱动目录执行指令, 生成 Rust-Analyzer 所需文件

```
sworld@SworldStation:~/stage3_homework/src_e1000$ make -C ../linux M=$PWD rust-analyzer
make: Entering directory '/home/sworld/stage3_homework/linux'
make: Leaving directory '/home/sworld/stage3_homework/linux'
```

修改 stop 函数, 重新构建

```
fn stop(_dev: &net::Device, _data: &NetDevicePrvData) -> Result {
    pr_info!("Rust for linux e1000 driver demo (net device stop)\n");

    _dev.netif_tx_disable();
    _dev.netif_carrier_off();
    _data.napi.disable();
    *_data.tx_ring.lock() = None;
    *_data.rx_ring.lock() = None;

    Ok(())
}
```

执行指令, 并且可以 ping

```
--- 10.0.2.2 ping statistics ---
3 packets transmitted, 3 packets received, 0% packet loss
round-trip min/avg/max = 0.444/323.426/968.579 ms
~ #
```

执行 ip link set eth0 down

```
ip link set eth0 down
[  97.918909] r4l_e1000_demo: Rust for linux e1000 driver demo (net device stop)
[  97.919176] r4l_e1000_demo: Rust for linux e1000 driver demo (net device get_stats64)
~ #
```

执行 ip link set eth0 up

```
~ # ip link set eth0 up
[ 116.966310] r4l_e1000_demo: Rust for linux e1000 driver demo (net device open)
[ 116.966840] r4l_e1000_demo: Rust for linux e1000 driver demo (net device get_stats64)
[ 116.967192] IPv6: ADDRCONF(NETDEV_CHANGE): eth0: link becomes ready
[ 116.967299] r4l_e1000_demo: Rust for linux e1000 driver demo (net device get_stats64)
```

执行 ping

```
sworld@SworldStation: ~/horr x sworld@SworldStation: ~/sta x + v
~ # ping 10.0.2.2
PING 10.0.2.2 (10.0.2.2): 56 data bytes
[ 156.756025] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=1, tdh=1, rdt=70
[ 156.756118] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 156.756124] r4l_e1000_demo: pending_irqs: 131
[ 156.756131] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 156.756133] r4l_e1000_demo: pending_irqs: 0
[ 156.756156] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
[ 156.756222] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=2, tdh=2, rdt=01
[ 156.756273] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 156.756278] r4l_e1000_demo: pending_irqs: 131
[ 156.756280] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 156.756282] r4l_e1000_demo: pending_irqs: 0
[ 156.756313] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
64 bytes from 10.0.2.2: seq=0 ttl=255 time=2.145 ms
64 bytes from 10.0.2.2: seq=1 ttl=255 time=0.392 ms
[ 157.758631] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=3, tdh=3, rdt=12
[ 157.758727] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 157.758733] r4l_e1000_demo: pending_irqs: 131
[ 157.758739] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 157.758741] r4l_e1000_demo: pending_irqs: 0
[ 157.758760] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
^C
--- 10.0.2.2 ping statistics ---
2 packets transmitted, 2 packets received, 0% packet loss
round-trip min/avg/max = 0.392/1.268/2.145 ms
~ #
```

可见，up-down-up 执行过程没有报错，在完成后 ping 指令也可以正确运行