

作业1：编译Linux内核

作业说明：

进入Linux文件夹，使用如下命令编译：

```
make x86_64_defconfig  
make LLVM=1 menuconfig  
#set the following config to yes  
General setup  
    ---> [*] Rust support  
make LLVM=1 -j$(nproc)
```

编译成功后会在Linux文件夹下得到一个vmlinux文件，如下图所示：

The terminal output shows the build process for a x86_64_defconfig kernel. It includes various assembly (AS), C/C++ (CC), and linker (LD) commands for generating compressed files like head_64.o, vmlinux.bin, and vmlinux.gz. It also shows the creation of the vmlinux executable. The final command listed is 'Kernel: arch/x86/boot/bzImage'.

```
CPUSTR arch/x86/boot/cpustr.h  
CC arch/x86/boot/cpu.o  
AS arch/x86/boot/compressed/head_64.o  
VOFFSET arch/x86/boot/compressed/../voffset.h  
CC arch/x86/boot/compressed/string.o  
CC arch/x86/boot/compressed/cmdline.o  
CC arch/x86/boot/compressed/error.o  
OBJCOPY arch/x86/boot/compressed/vmlinux.bin  
RELOCS arch/x86/boot/compressed/vmlinux.relocs  
HOSTCC arch/x86/boot/compressed/mkpiggy  
CC arch/x86/boot/compressed/cpuflags.o  
CC arch/x86/boot/compressed/early_serial_console.o  
CC arch/x86/boot/compressed/kaslr.o  
CC arch/x86/boot/compressed/ident_map_64.o  
CC arch/x86/boot/compressed/idt_64.o  
AS arch/x86/boot/compressed/idt_handlers_64.o  
AS arch/x86/boot/compressed/mem_encrypt.o  
CC arch/x86/boot/compressed/pgtable_64.o  
CC arch/x86/boot/compressed/acpi.o  
AS arch/x86/boot/compressed/efi_thunk_64.o  
CC arch/x86/boot/compressed/efi.o  
CC arch/x86/boot/compressed/misc.o  
GZIP arch/x86/boot/compressed/vmlinux.bin.gz  
MKPIGGY arch/x86/boot/compressed/piggy.S  
AS arch/x86/boot/compressed/piggy.o  
LD arch/x86/boot/compressed/vmlinux  
ZOFFSET arch/x86/boot/zoffset.h  
OBJCOPY arch/x86/boot/vmlinux.bin  
AS arch/x86/boot/header.o  
LD arch/x86/boot/setup.elf  
OBJCOPY arch/x86/boot/setup.bin  
BUILD arch/x86/boot/bzImage  
Kernel: arch/x86/boot/bzImage is ready (#1)  
ljh@ljh-vm:~/linux/rust/cicv-r4l-3-LJHua-MyMan/linux$ ls  
arch      crypto      io_uring      LICENSES      modules.order  samples      usr  
block     Documentation ipc      MAINTAINERS  Module.symvers scripts      virt  
built-in.a drivers      Kbuild      Makefile    net          security  vmlinux  
certs      fs          Kconfig      mm          README      sound      vmlinux.a  
COPYING   include      kernel      modules.builtin  README.md  System.map vmlinux.o  
CREDITS   init       lib      modules.builtin.modinfo  rust      tools  
ljh@ljh-vm:~/linux/rust/cicv-r4l-3-LJHua-MyMan/linux$
```

作业2：对Linux内核进行一些配置

Q: 在该文件夹中调用make LLVM=1，该文件夹内的代码将编译成一个内核模块。请结合你学到的知识，回答以下两个问题：

1、编译成内核模块，是在哪个文件中以哪条语句定义的？

答：Linux内核使用的是`Kconfig/Kbuild`来配置和编译内核，以`obj-m += 模块名.o`语句定义。

2、该模块位于独立的文件夹内，却能编译成Linux内核模块，这叫做out-of-tree module，请分析它是如何与内核代码产生联系的？

答：在编译时，使用了内核源码树中的`Kbuild`系统。`Makefile`中会引用内核源码路径，使用如下命令进行编译：

```

# SPDX-License-Identifier: GPL-2.0

KDIR ?= ./linux

default:
    $(MAKE) -C $(KDIR) M=$$PWD

```

这条命令告诉 make 在指定的内核源码目录下进行编译，并将当前目录作为模块源代码目录。这样，尽管模块位于独立文件夹，仍能利用内核的构建系统进行编译。

具体步骤及结果：

1. 重新编译Linux内核，并禁用默认的C版本 e1000 网卡驱动
2. 启动脚本，打开 qemu 并安装内核模块，在未安装e1000驱动前，使用 ifconfig 命令结果为空

```

[ 2.047008] NET: Registered PF_PACKET protocol family
[ 2.048802] 9pnet: Installing 9P2000 support
[ 2.049342] Key type dns_resolver registered
[ 2.051225] IPI shorthand broadcast: enabled
[ 2.051786] sched_clock: Marking stable (1991919733, 58866323)->(2271533005, -220746949)
[ 2.054811] registered taskstats version 1
[ 2.055123] Loading compiled-in X.509 certificates
[ 2.064709] cryptomgr_test (44) used greatest stack depth: 15584 bytes left
[ 2.082475] PM: Magic number: 0:38:208
[ 2.083278] vc vcsa: hash matches
[ 2.083945] printk: console [netcon0] enabled
[ 2.084148] netconsole: network logging started
[ 2.127760] ata2: found unknown device (class 0)
[ 2.134011] ata2.00: ATAPI: QEMU DVD-ROM, 2.5+, max UDMA/100
[ 2.146407] scsi 1:0:0:0: CD-ROM           QEMU   QEMU DVD-ROM      2.5+ PQ: 0 ANSI: 5
[ 2.184841] sr 1:0:0:0: [sr0] scsi3-mmc drive: 4x/4x cd/rw xa/form2 tray
[ 2.185842] cdrom: Uniform CD-ROM driver Revision: 3.20
[ 2.206618] sr 1:0:0:0: Attached scsi generic sg0 type 5
[ 2.526769] tsc: Refined TSC clocksource calibration: 2303.975 MHz
[ 2.527861] clocksource: tsc: mask: 0xfffffffffffff max_cycles: 0x2135e017487, max_idle_ns: 440795235214 ns
[ 2.529115] clocksource: Switched to clocksource tsc
[ 2.631588] input: ImExPS/2 Generic Explorer Mouse as /devices/platform/i8042/serio1/input/input3
[ 14.942836] cfg80211: Loading compiled-in X.509 certificates for regulatory database
[ 15.019316] modprobe (67) used greatest stack depth: 14272 bytes left
[ 15.042234] cfg80211: Loaded X.509 cert 'sforshee: 00b28ddf47ae9cea7'
[ 15.044293] platform regulatory.0: Direct firmware load for regulatory.db failed with error -2
[ 15.045166] cfg80211: failed to load regulatory.db
[ 15.046967] ALSA device list:
[ 15.047284]   No soundcards found.
[ 15.098428] Freeing unused kernel image (initmem) memory: 1324K
[ 15.100771] Write protecting the kernel read-only data: 24576k
[ 15.104453] Freeing unused kernel image (text/rodata gap) memory: 2032K
[ 15.105532] Freeing unused kernel image (rodata/data gap) memory: 840K
[ 15.286378] x86/mm: Checked W+X mappings: passed, no W+X pages found.
[ 15.287172] Run sbin/init as init process
[ 15.338442] mount (72) used greatest stack depth: 14160 bytes left
[ 15.520988] mdev (74) used greatest stack depth: 13960 bytes left

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

```

3. 安装 e1000 驱动模块，并执行 ip link set eth0 up 连接对应网卡

```

[ 15.338442] mount (72) used greatest stack depth: 14160 bytes left
[ 15.520988] mdev (74) used greatest stack depth: 13960 bytes left

Please press Enter to activate this console.

~ # ifconfig
~ # insmod r4l_e1000_demo.ko
[ 69.717211] r4l_e1000_demo: loading out-of-tree module taints kernel.
[ 69.733831] r4l_e1000_demo: Rust for linux e1000 driver demo (init)
[ 69.734565] r4l_e1000_demo: Rust for linux e1000 driver demo (probe): None
[ 69.942554] ACPI: \_SB_.LNKC: Enabled at IRQ 11
[ 69.966541] r4l_e1000_demo: Rust for linux e1000 driver demo (net device get_stats64)
[ 69.969401] insmod (81) used greatest stack depth: 11192 bytes left
~ # ip link set eth0 up
[ 81.540231] r4l_e1000_demo: Rust for linux e1000 driver demo (net device open)
[ 81.544011] r4l_e1000_demo: Rust for linux e1000 driver demo (net device get_stats64)
[ 81.545650] IPv6: ADDRCONF(NETDEV_CHANGE): eth0: link becomes ready
~ # [ 81.551122] r4l_e1000_demo: Rust for linux e1000 driver demo (net device get_stats64)
[ 81.558378] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=0, tdh=0, rdt=7, rdh=0
[ 81.559567] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 81.559929] r4l_e1000_demo: pending_irqs: 3
[ 81.560961] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
[ 81.565209] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=1, tdh=1, rdt=7, rdh=0
[ 81.565757] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 81.566264] r4l_e1000_demo: pending_irqs: 3
[ 81.566863] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
[ 81.910881] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=2, tdh=2, rdt=7, rdh=0
[ 81.911245] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 81.911769] r4l_e1000_demo: pending_irqs: 3
[ 81.912198] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
[ 82.591781] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=3, tdh=3, rdt=7, rdh=0
[ 82.592427] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 82.592978] r4l_e1000_demo: pending_irqs: 3
[ 82.593508] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
[ 82.594867] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=4, tdh=4, rdt=7, rdh=0
[ 82.595553] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 82.596048] r4l_e1000_demo: pending_irqs: 3
[ 82.596472] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
[ 83.487328] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=5, tdh=5, rdt=7, rdh=0
[ 83.487747] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 83.488092] r4l_e1000_demo: pending_irqs: 3
[ 83.488253] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)

```

4. 执行 `ip addr add 10.0.2.15/255.255.255.0 brd + dev eth0` 为网卡配置 ip 地址和广播地址；为网卡添加一条新的路由 `ip route add default via 10.0.2.1`，之后 `ping 10.0.2.2` 结果如下：

```

[ 139.424709] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)

~ # ip addr add 10.0.2.15/255.255.255.0 brd + dev eth0
[ 154.183427] r4l_e1000_demo: Rust for linux e1000 driver demo (net device get_stats64)
[ 154.185365] r4l_e1000_demo: Rust for linux e1000 driver demo (net device get_stats64)
~ # ip route add default via 10.0.2.1
~ # ping 10.0.2.2
PING 10.0.2.2 (10.0.2.2): 56 data bytes
[ 171.546070] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=2, tdh=2, rdt=7, rdh=0
[ 171.546882] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 171.547153] r4l_e1000_demo: pending_irqs: 131
[ 171.547652] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
[ 171.549511] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=3, tdh=3, rdt=0, rdh=1
[ 171.549961] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 171.550200] r4l_e1000_demo: pending_irqs: 131
[ 171.551157] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
64 bytes from 10.0.2.2: seq=0 ttl=255 time=12.575 ms
[ 172.555781] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=4, tdh=4, rdt=1, rdh=2
[ 172.556745] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 172.557438] r4l_e1000_demo: pending_irqs: 131
[ 172.558231] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
64 bytes from 10.0.2.2: seq=1 ttl=255 time=3.575 ms
[ 173.559990] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=5, tdh=5, rdt=2, rdh=3
[ 173.560446] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 173.560817] r4l_e1000_demo: pending_irqs: 131
[ 173.560954] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
64 bytes from 10.0.2.2: seq=2 ttl=255 time=1.523 ms
[ 174.563084] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=6, tdh=6, rdt=3, rdh=4
[ 174.563584] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 174.564270] r4l_e1000_demo: pending_irqs: 131
[ 174.565022] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
64 bytes from 10.0.2.2: seq=3 ttl=255 time=2.740 ms
[ 175.567111] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=7, tdh=7, rdt=4, rdh=5
[ 175.567761] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 175.568177] r4l_e1000_demo: pending_irqs: 131
[ 175.568372] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
64 bytes from 10.0.2.2: seq=4 ttl=255 time=2.096 ms

[ 176.570887] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=0, tdh=0, rdt=5, rdh=6
[ 176.571399] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 176.571849] r4l_e1000_demo: pending_irqs: 131

```

5. 执行 `ifconfig` 验证

```
[ 174.563584] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 174.564270] r4l_e1000_demo: pending_irqs: 131
[ 174.565022] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
64 bytes from 10.0.2.2: seq=3 ttl=255 time=2.740 ms
[ 175.567111] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=7, tdh=7, rdt=4, rdh=5
[ 175.567761] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 175.568177] r4l_e1000_demo: pending_irqs: 131
[ 175.568372] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
64 bytes from 10.0.2.2: seq=4 ttl=255 time=2.096 ms

[ 176.570887] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=0, tdh=0, rdt=5, rdh=6
[ 176.571399] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 176.571849] r4l_e1000_demo: pending_irqs: 131
[ 176.572350] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
64 bytes from 10.0.2.2: seq=5 ttl=255 time=2.384 ms
[ 177.574077] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=1, tdh=1, rdt=6, rdh=7
[ 177.574712] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 177.575011] r4l_e1000_demo: pending_irqs: 131
[ 177.575258] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)
64 bytes from 10.0.2.2: seq=6 ttl=255 time=2.014 ms
^C
--- 10.0.2.2 ping statistics ---
7 packets transmitted, 7 packets received, 0% packet loss
round-trip min/avg/max = 1.523/3.843/12.575 ms
~ # [ 197.790467] r4l_e1000_demo: Rust for linux e1000 driver demo (net device start_xmit) tdt=2, tdh=2, rdt=7, rdh=0
[ 197.791478] r4l_e1000_demo: Rust for linux e1000 driver demo (handle_irq)
[ 197.791884] r4l_e1000_demo: pending_irqs: 3
[ 197.792084] r4l_e1000_demo: Rust for linux e1000 driver demo (napi poll)

~ # ifconfig
[ 226.748924] r4l_e1000_demo: Rust for linux e1000 driver demo (net device get_stats64)
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:Link
              UP BROADCAST RUNNING MULTICAST MTU:1500 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)
```

作业 3：使用 rust 编写一个简单的内核模块并运行

1. 进入Linux目录下的samples/rust文件夹，添加一个 `rust_helloworld.rs` 文件，并添加以下内容

```
// SPDX-License-Identifier: GPL-2.0
/// Rust minimal sample.

use kernel::prelude::*;

module! {
    type: RustHelloWorld,
    name: "rust_helloworld",
    author: "whocare",
    description: "hello world module in rust",
    license: "GPL",
}

struct RustHelloWorld {}

impl kernel::Module for RustHelloWorld {
    fn init(_name: &'static CStr, _module: &'static ThisModule) -> Result<Self> {
        pr_info!("Hello World from Rust module\n");
        Ok(RustHelloWorld {})
    }
}

"rust_helloworld.rs" 22L, 491B
```

2. 在 `linux/sample/rust/kconfig` 添加配置

```
help
This option builds the Rust netfilter module sample.

To compile this as a module, choose M here:
the module will be called rust_netfilter.

If unsure, say N.

config SAMPLE_RUST_ECHO_SERVER
    tristate "Echo server module"
    help
        This option builds the Rust echo server module sample.

To compile this as a module, choose M here:
the module will be called rust_echo_server.

If unsure, say N.

config SAMPLE_RUST_HOSTPROGS
    bool "Host programs"
    help
        This option builds the Rust host program samples.

If unsure, say N.

config SAMPLE_RUST_SELFTESTS
    tristate "Self tests"
    help
        This option builds the self test cases for Rust.

If unsure, say N.

config SAMPLE_RUST_HELLOWORLD
    tristate "HelloWorld"
    help
        This option builds the Rust HelloWorld module sample.

If unsure, say N.

endif # SAMPLES_RUST
-- INSERT --
```

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3. 在 `linux/sample/rust/Makefile` 添加配置

```
# SPDX-License-Identifier: GPL-2.0

obj-$(CONFIG_SAMPLE_RUST_MINIMAL)
obj-$(CONFIG_SAMPLE_RUST_PRINT)
obj-$(CONFIG_SAMPLE_RUST_MODULE_PARAMETERS)
obj-$(CONFIG_SAMPLE_RUST_SYNC)
obj-$(CONFIG_SAMPLE_RUST_CHRDEV)
obj-$(CONFIG_SAMPLE_RUST_MISCDEV)
obj-$(CONFIG_SAMPLE_RUST_STACK_PROBING)
obj-$(CONFIG_SAMPLE_RUST_SEMAPHORE)
obj-$(CONFIG_SAMPLE_RUST_SEMAPHORE_C)
obj-$(CONFIG_SAMPLE_RUST_RANDOM)
obj-$(CONFIG_SAMPLE_RUST_PLATFORM)
obj-$(CONFIG_SAMPLE_RUST_NETFILTER)
obj-$(CONFIG_SAMPLE_RUST_ECHO_SERVER)
obj-$(CONFIG_SAMPLE_RUST_FS)
obj-$(CONFIG_SAMPLE_RUST_SELFTESTS)
obj-$(CONFIG_SAMPLE_RUST_HELLOWORLD)

subdir-$(CONFIG_SAMPLE_RUST_HOSTPROGS)
```

19.1 All

4 重新编译内核

```

ljh@ljh-vm:~/linux/rust/cicv-r4l-3-LJHua-MyMan/linux$ make LLVM=1 -j8
SYNC    include/config/auto.conf.cmd
DESCEND objtool
CALL    scripts/checksyscalls.sh
AR     samples/vfio-mdev/built-in.a
AR     samples/rust/built-in.a
RUSTC [M] samples/rust/rust_helloworld.o
AR     samples/built-in.a
AR     built-in.a
AR     vmlinux.a
LD     vmlinux.o
OBJCOPY modules.builtin.modinfo
GEN     modules.builtin
MODPOST Module.symvers
CC [M] samples/rust/rust_helloworld.mod.o
UPD    include/generated/utsversion.h
CC     init/version-timestamp.o
LD     .tmp_vmlinux.kallsyms1
LD [M] samples/rust/rust_helloworld.ko
NM     .tmp_vmlinux.kallsyms1.syms
KSYMS  .tmp_vmlinux.kallsyms1.S
AS     .tmp_vmlinux.kallsyms1.S
LD     .tmp_vmlinux.kallsyms2
NM     .tmp_vmlinux.kallsyms2.syms
KSYMS  .tmp_vmlinux.kallsyms2.S
AS     .tmp_vmlinux.kallsyms2.S
LD     vmlinux
NM     System.map
SORTTAB vmlinux
CC     arch/x86/boot/version.o
VOFFSET arch/x86/boot/compressed/../woffset.h
OBJCOPY arch/x86/boot/compressed/vmlinux.bin
RELOCS  arch/x86/boot/compressed/vmlinux.relocs
CC     arch/x86/boot/compressed/kaslr.o
GZIP   arch/x86/boot/compressed/vmlinux.bin.gz
CC     arch/x86/boot/compressed/misc.o
MKPIGGY arch/x86/boot/compressed/piggy.S
AS     arch/x86/boot/compressed/piggy.o
LD     arch/x86/boot/compressed/vmlinux
ZOFFSET arch/x86/boot/zoffset.h
OBJCOPY arch/x86/boot/vmlinux.bin

```

5. 将在 `samples/rust` 下看到一份 `rust_helloworld.ko` 的文件，将该文件复制到仓库中

`src_e1000/rootfs` 目录下，然后重新跑 `build_image.sh`

```

[ 14.651116] Freeing unused kernel image (text/rodata gap) memory: 2032K
[ 14.652909] Freeing unused kernel image (rodata/data gap) memory: 840K
[ 14.845650] x86/mm: Checked W+X mappings: passed, no W+X pages found.
[ 14.846284] Run sbin/init as init process
[ 14.901597] mount (72) used greatest stack depth: 14160 bytes left
[ 15.087647] mdev (74) used greatest stack depth: 13960 bytes left

Please press Enter to activate this console.
~ # ls
bin          linuxrc      root        usr
dev          proc         sbin
etc          r4l_e1000_demo.ko sys
~ # QEMU: Terminated
ljh@ljh-vm:~/linux/rust/cicv-r4l-3-LJHua-MyMan/src_e1000$ cd ../linux/samples/rust/
ljh@ljh-vm:~/linux/rust/cicv-r4l-3-LJHua-MyMan/linux/samples/rust$ ls
built-in.a   rust_echo_server.rs   rust_helloworld.o   rust_platform.rs   rust_stack_probing.rs
hostprogs    rust_fs.rs          rust_helloworld.rs  rust_print.rs    rust_sync.rs
Kconfig      rust_helloworld.ko  rust_minimal.rs   rust_random.rs
Makefile     rust_helloworld.mod  rust_miscdev.rs   rust_selftests.rs
modules.order rust_helloworld.mod.c rust_module_parameters.rs  rust_semaphore.c.c
rust_chrdev.rs rust_helloworld.mod.o rust_netfilter.rs   rust_semaphore.rs
ljh@ljh-vm:~/linux/rust/cicv-r4l-3-LJHua-MyMan/linux/samples/rust$ cp rust_helloworld.ko ../../src_e1000/rootfs/
ljh@ljh-vm:~/linux/rust/cicv-r4l-3-LJHua-MyMan/linux/samples/rust$ cd ../../src_e1000/rootfs/
ljh@ljh-vm:~/linux/rust/cicv-r4l-3-LJHua-MyMan/src_e1000/rootfs$ ls
bin dev etc linuxrc proc r4l_e1000_demo.ko rust_helloworld.ko sbin sys usr
ljh@ljh-vm:~/linux/rust/cicv-r4l-3-LJHua-MyMan/src_e1000/rootfs$ cd ..
ljh@ljh-vm:~/linux/rust/cicv-r4l-3-LJHua-MyMan/src_e1000$ ./build_image.sh
make -C .. /linux M=$PWD
make[1]: Entering directory '/home/ljh/linux/rust/cicv-r4l-3-LJHua-MyMan/linux'
make[1]: Leaving directory '/home/ljh/linux/rust/cicv-r4l-3-LJHua-MyMan/linux'

5321 blocks
SeaBIOS (version 1.15.0-1)

iPXE (https://ipxe.org) 00:03.0 CA00 PCI2.10 PnP PMM+07F8B340+07ECB340 CA00

Booting from ROM...
[ 0.000000] Linux version 6.1.0-rc1 (ljh@ljh-vm) (Ubuntu clang version 14.0.0-1ubuntu1.1, Ubuntu LLD 14.0.0) #3 S4

```

6. 进入内核，并执行 `insmod rust_helloworld.ko`

```
[ 1.509452] Loading compiled-in X.509 certificates
[ 1.515809] cryptomgr_test (44) used greatest stack depth: 15584 bytes left
[ 1.522339] PM: Magic number: 0:450:612
[ 1.522751] tty tty: hash matches
[ 1.523959] printk: console [netcon0] enabled
[ 1.524253] netconsole: network logging started
[ 1.593993] ata2: found unknown device (class 0)
[ 1.598769] ata2.00: ATAPI: QEMU DVD-ROM, 2.5+, max UDMA/100
[ 1.608180] scsi 1:0:0:0: CD-ROM QEMU QEMU DVD-ROM 2.5+ PQ: 0 ANSI: 5
[ 1.646863] sr 1:0:0:0: [sr0] scsi3-mmc drive: 4x/4x cd/rw xa/form2 tray
[ 1.647464] cdrom: Uniform CD-ROM driver Revision: 3.20
[ 1.665531] sr 1:0:0:0: Attached scsi generic sg0 type 5
[ 2.099062] input: ImExPS/2 Generic Explorer Mouse as /devices/platform/i8042/seri0/input/input3
[ 2.225639] tsc: Refined TSC clocksource calibration: 2303.978 MHz
[ 2.226067] clocksource: tsc: mask: 0xffffffffffff max_cycles: 0x2135e30d8d2, max_idle_ns: 440795222959 ns
[ 2.226438] clocksource: Switched to clocksource tsc
[ 14.385777] cfg80211: Loading compiled-in X.509 certificates for regulatory database
[ 14.447034] modprobe (67) used greatest stack depth: 14272 bytes left
[ 14.460525] cfg80211: Loaded X.509 cert 'sforshee: 00b28ddf47ae9cea7'
[ 14.462541] platform regulatory.0: Direct firmware load for regulatory.db failed with error -2
[ 14.463235] cfg80211: failed to load regulatory.db
[ 14.465192] ALSA device list:
[ 14.465464] No soundcards found.
[ 14.514622] Freeing unused kernel image (initmem) memory: 1324K
[ 14.515446] Write protecting the kernel read-only data: 24576K
[ 14.518766] Freeing unused kernel image (text/rodata gap) memory: 2032K
[ 14.519895] Freeing unused kernel image (rodata/data gap) memory: 840K
[ 14.700628] x86/mm: Checked W+X mappings: passed, no W+X pages found.
[ 14.701498] Run sbn/init as init process
[ 14.748189] mount (72) used greatest stack depth: 14160 bytes left
[ 14.890514] mdev (74) used greatest stack depth: 13960 bytes left
```

Please press Enter to activate this console.

```
~ # ls
bin          proc      sbin
dev          r4l_e1000_demo.ko  sys
etc          root      usr
linuxrc      rust_helloworld.ko
~ # insmod rust_helloworld.ko
[ 36.872710] rust_helloworld: Hello World from Rust module
~ #
```