Advanced Workshop: Linux from Scratch

pcy

ULYSSIS

Sponsored by emweb

10 May 2023

Prerequisites

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Knowledge about these topics assumed:

- Basic shell usage: **cd**, **ls**, **tar**, **wget**, …
  Ideally, also **mount**, **fdisk**, …
- Know how to clone a git repository
- Must have compiled at least one C program before: **make**,
  `gcc -o outfile stuff.c -lm`
- Optional: have used QEMU before

Prerequisites

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Some packages required:

Arch Linux: `qemu wget grub base-devel dosfstools bc git rsync libelf musl`

Ubuntu, Debian: `qemu-system-x86 wget grub-pc-bin grub2-common build-essential libncurses-dev bc git rsync libelf-dev musl{,-dev,-tools} bison flex`

Fedora: `wget qemu grub2-pc make gcc kernel-devel ncurses-devel bc musl-gcc bison flex`

Void Linux: `qemu wget grub base-devel ncurses-devel bc git rsync libelf musl-bootstrap`

Prerequisites

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2 GB of disk space required.

Arch users: reboot if you updated your kernel after last powering on your computer (need loopback module, may cause issues when not loaded yet after a kernel update)

Introduction

We will dive right in: compilation takes a while, explanation will follow

Repository

Clone this repository:

`https://gitlab.ulyssis.org/pcy/workshop-linux`

Kernel and Busybox config files from it will be used

Also a useful reference for when you fall behind

If at any point you fall behind too much: grab binaries from `https://pcy.be/tmp/miscbin/lfs23-binaries.tar.xz`

Downloading the kernel

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Available at `https://www.kernel.org/`

```
wget linux-6.2.14.tar.{sign,xz}
tar xf linux-6.2.14.tar.xz
```

Downloading the kernel

ULYSSIS

Available at `https://www.kernel.org/`

```
wget linux-6.2.14.tar.{sign,xz}
tar xf linux-6.2.14.tar.xz
```

Signature check (optional):

```
xz -cd linux-6.2.14.tar.xz \
    | gpg --verify linux-6.2.14.tar.sign -
```

Configuring the kernel

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The kernel has lots of configuration options:

- Target hardware
- Modes of operation (eg. fast vs slower task switching)
- Enable/disable support for certain hardware
- Configure feature as builtin/module/disabled (*/M/)
- ...

Configuring the kernel

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What are kernel modules?

- Usually, most kernel code is in a single binary (the kernel image)
- Modules are separate files that can be loaded into the kernel at runtime
- Only load drivers when the hardware is attached
- Smaller kernel image $\Rightarrow$ faster booting
- Distros: one kernel image for multiple scenarios, different modules
- `lsmod`, `insmod`, `rmmod`, `modprobe`

Configuring the kernel

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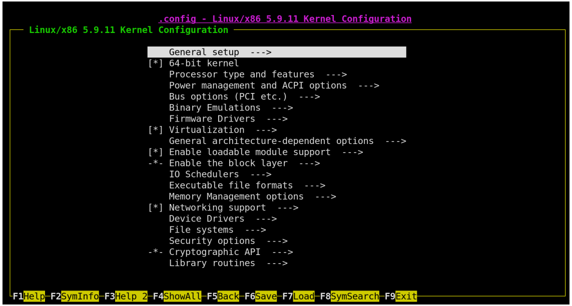
- Generate a default configuration: `make defconfig`
- Edit configuration: `make nconfig`

A quick demo:



Configuring the kernel

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- Generate a default configuration: `make defconfig`
- Edit configuration: `make nconfig`
- Enable *current* modules only: `make localyesconfig`
  `lsmod > mods && LSMOD=mods make localyesconfig`
- Above, but as modules: `make localmodconfig`
- Enable everything: `make allyesconfig`
- Enable everything as modules: `make allmodconfig`
- Random config: `make randconfig`

Configuring the kernel

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For cross-compiling:
(not in this workshop)

`ARCH=arch CROSS_COMPILE=target-triple-`
In *every* `make` invocation!
Example: **`ARCH=sparc64 CROSS_COMPILE=sparc-linux-gnu-`**

Boot medium formats differ *wildly* from platform to platform!

Configuring the kernel

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For now, use a minimal `.config`:

- Very small, minimum requirement to boot
- Useless for real hardware: no USB, no network, no …
- Still works in QEMU
- Faster to compile!

```
cp path/to/repo/linux-workshop-minimal.config .config
```

Compiling the kernel

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`make -j<N>`

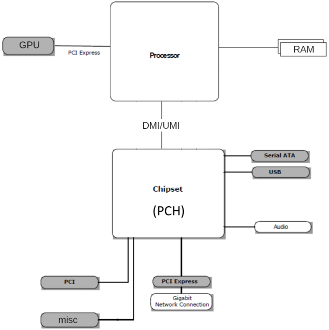
If dialog questions appear: enter the default

usually won't hurt

- `N`: number of CPU cores to use
- optimal: `N` equal to number of cores available

Intermezzo 1: PC boot process

What is a PC?



Source: "Advanced x86: Introduction to BIOS & SMM"
`https://opensecuritytraining.info/IntroBIOS.html`

Intermezzo 1: PC boot process

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Extremely simplified:

1. Hardware powers up CPU
2. CPU boots into firmware (BIOS or UEFI)
3. Firmware inits other hardware (disks, GPU, ...)
4. Firmware loads OS or bootloader from disk

Intermezzo 1: PC boot process

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- BIOS: boots into disk MBR (first 512b)
  → Too small to contain a kernel!
- UEFI: boots EFI executable from EFI System Partition
  → Kernel image is in a different format!

⇒ We need a bootloader!

Note on embedded

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- This was PC
- Other things: much different, lots of variety
- Ask me for details if you want

While our kernels are compiling...

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It's time for questions!

Ask me (almost) anything!

Running the kernel

Kernel image in `arch/x86/boot/bzImage`, let's try it out!

```
qemu-system-x86_64 -kernel arch/x86/boot/bzImage
```

To make QEMU stop grabbing your cursor: `ctrl+alt+g`

Running the kernel

Kernel image in `arch/x86/boot/bzImage`, let's try it out!

```
qemu-system-x86_64 -kernel arch/x86/boot/bzImage
```

To make QEMU stop grabbing your cursor: `ctrl+alt+g`

```
[    2.467374] Kernel panic - not syncing: VFS: Unable to mount root fs on unkno
wn-block(0,0)
[    2.467684] CPU: 0 PID: 1 Comm: swapper/0 Not tainted 5.9.11 #1
[    2.467742] Hardware name: QEMU Standard PC (i440FX + PIIX, 1996), BIOS rel-1
.14.0-0-g155821a1990b-prebuilt.qemu.org 04/01/2014
[    2.467915] Call Trace:
[    2.468739]  dump_stack+0x57/0x6a
[    2.468841]  panic+0xf6/0x2b7
[    2.468900]  mount_block_root+0x196/0x21a
[    2.469022]  mount_root+0xec/0x10a
[    2.469064]  prepare_namespace+0x136/0x165
[    2.469120]  kernel_init_freeable+0x1c8/0x1d3
[    2.469161]  ? rest_init+0x9a/0x9a
[    2.469197]  kernel_init+0x5/0x106
[    2.469235]  ret_from_fork+0x22/0x30
[    2.469711] Kernel Offset: 0x1ba00000 from 0xffffffff81000000 (relocation ran
ge: 0xffffffff80000000-0xffffffffbfffffff)
[    2.470051] ---[ end Kernel panic - not syncing: VFS: Unable to mount root fs
 on unknown-block(0,0) ]---
```

What went wrong?

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- "Kernel panic: unable to mount root fs"
- The kernel has no root filesystem, but it needs one to run user code!
- Other than that, everything went fine!
- Let's create one

rootfs overview (BIOS)

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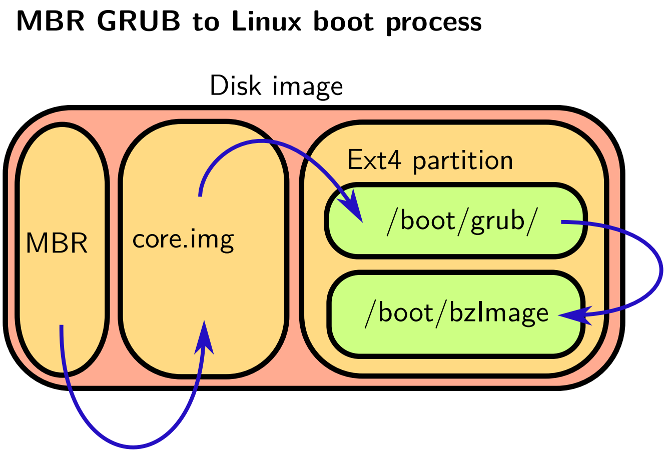

rootfs overview (UEFI)

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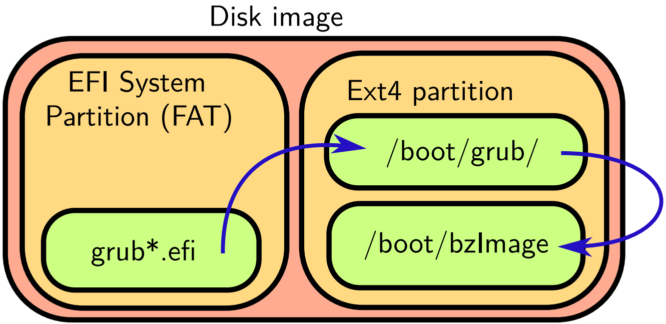
For informational purposes, this workshop is BIOS-only.

EFI GRUB to Linux boot process



Generating the rootfs

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`fallocate -l 32M root.img`	Create a large file
`fdisk root.img`	Format it
`n p 1 [empty] [empty] t 83 w`	

Now we need to put files on the partition *inside this file*

losetup

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Most commands here might be ‘obvious’, except for `losetup`. It turns regular files into “loopback disk devices”, so you can mount them like other disks and partitions.

```
$ lsblk
sda 8:0 0 465,8G 0 disk

$ sudo losetup -P -f disk.img && lsblk
loop0 7:0 0 32M 0 loop
‘-loop0p1 259:0 0 31M 0 part
sda 8:0 0 465,8G 0 disk
```

Generating the rootfs

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Now we use `losetup` to populate the root filesystem:

`sudo losetup -P -f --show root.img`	Make a device out of it
`sudo mkfs.ext4 /dev/loop0p1`	Format the partition

```
mkdir -p rootfs && sudo mount /dev/loop0p1 ./rootfs
```

Supplying a kernel

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Copy over the kernel we just compiled into `/boot`:

```
cd ./rootfs && sudo mkdir boot
sudo cp ../linux-6.2.14/arch/x86/boot/bzImage boot/
```

Supplying a bootloader

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Install GRUB:

```
sudo grub-install --modules=part_msdos \
   --target=i386-pc --boot-directory="$PWD/boot" \
   /dev/loop0
```

Fedora users: `grub2-install`

Configuring the bootloader

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We still need to tell GRUB how to find our kernel image

```
$ fdisk -l ../root.img
```

⇒

```
Disk root.img:  32 MiB, 33554432 bytes, 65536 sectors
...
Disk identifier:  0x7b258ad4
...
```

Configuring the bootloader

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We still need to tell GRUB how to find our kernel image

```
$ sudo -e boot/grub/grub.cfg
⇐
linux /boot/bzImage root=PARTUUID=7b258ad4-01
boot
```

Testing the rootfs

Ok, will it work this time?

```
cd ..  && sudo umount rootfs && sudo losetup -d \
    /dev/loop0
```

```
qemu-system-x86_64 root.img
```

```
[    1.230259] devtmpfs: mounted
[    1.266552] Freeing unused kernel image (initmem) memory: 728K
[    1.266858] Write protecting the kernel read-only data: 12288k
[    1.269080] Freeing unused kernel image (text/rodata gap) memory: 2044K
[    1.269656] Freeing unused kernel image (rodata/data gap) memory: 484K
[    1.269907] Run /sbin/init as init process
[    1.277385] Run /etc/init as init process
[    1.278578] Run /bin/init as init process
[    1.279246] Run /bin/sh as init process
[    1.279576] Kernel panic - not syncing: No working init found.  Try passing i
nit= option to kernel. See Linux Documentation/admin-guide/init.rst for guidance
.
[    1.279811] CPU: 0 PID: 1 Comm: swapper Not tainted 5.9.11 #1
[    1.279867] Hardware name: QEMU Standard PC (i440FX + PIIX, 1996), BIOS rel-1
.14.0-0-g155821a1990b-prebuilt.qemu.org 04/01/2014
[    1.280028] Call Trace:
[    1.280773]  panic+0xde/0x273
[    1.281186]  ? rest_init+0x7a/0x7a
[    1.281231]  kernel_init+0xe8/0xf6
[    1.281300]  ret_from_fork+0x1f/0x30
[    1.281494] Kernel Offset: disabled
[    1.281768] ---[ end Kernel panic - not syncing: No working init found.  Try
passing init= option to kernel. See Linux Documentation/admin-guide/init.rst for
 guidance. ]---
```

Enter Busybox

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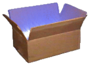
Implementation of a full userspace, small binary size



We will use it only for `/bin/sh`, even though it provides lots of utilities, as well as an init system.

Generating kernel headers

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Before compiling, Busybox needs to know about our kernel:

```
mkdir linux-headers && cd linux-6.2.14

make CC=false V=1 INSTALL_HDR_PATH=../linux-headers \
   headers_install
```

Downloading Busybox

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Available at https://busybox.net/downloads/

```
wget busybox-1.36.0.tar.bz2{.sig,.sha256,}
tar xf busybox-1.36.0.tar.bz2
```

Signature check (optional):

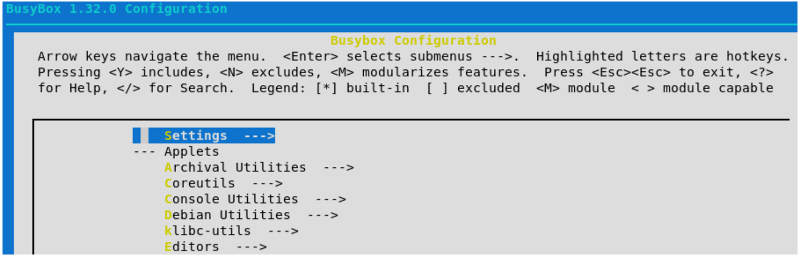
```
wget https://busybox.net/~vda/vda_pubkey.gpg && \
    gpg --import vda_pubkey.gpg && \
    sha256sum -c busybox-1.36.0.tar.bz2.sha256 &&\
    gpg --verify busybox-1.36.0.tar.bz2{.sig,}
```

Configuring Busybox

Similar config system as Linux:

```
make defconfig
make menuconfig
```

A quick demo:



Configuring Busybox

Similar config system as Linux:

```
make defconfig
make menuconfig

cp path/to/repo/busybox-workshop-minimal.config \
   .config
```

Configuring Busybox

Busybox needs our kernel headers:

$EDITOR .config

⇐

```
CONFIG_EXTRA_CFLAGS="-I../linux-headers/include/"
```

Compiling Busybox

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```
make CC=musl-gcc -j<N>
```

- N: number of CPU cores to use
- optimal: N equal to number of cores available
- musl needed here: Busybox is picky (static glibc build breaks, passing musl as cross-compile prefix breaks on some distros, so using CC like this is the only option)

Intermezzo 2: userspace boot process

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1. Kernel spawns PID 1 (‘init’)
   - If PID 1 dies, the kernel panics
   - PID 1 is responsible for garbage-collecting finished processes
   - Needs to start everything else

Intermezzo 2: userspace boot process

ULYSSIS

1. Kernel spawns PID 1 (‘init’)
   - If PID 1 dies, the kernel panics
   - PID 1 is responsible for garbage-collecting finished processes
   - Needs to start everything else
2. `init` forks, child carries out initialization (“early userspace”)
3. Init interfaces to kernel, filesystem, devices, ...
4. Start and manage daemons
5. Present login screen

While our Busyboxes are compiling...

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It's time for questions again!

Ask me (almost) anything!

Installing busybox

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Copy ./busybox to rootfs/bin/busybox:

```
cd ..  && sudo losetup -P -f --show root.img
sudo mount /dev/loop0p1 ./rootfs
sudo mkdir -p rootfs/bin
sudo cp busybox-1.36.0/busybox rootfs/bin/busybox
```

Installing busybox (2)

Basic shell utilities (from Busybox):

```
sudo ln -s bin rootfs/sbin
for x in $(rootfs/bin/busybox --list-full); do
  sudo ln -s /bin/busybox $x
done
```

Reconfigure bootloader

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Tell GRUB to boot into `/bin/sh`:

```
sudo -e rootfs/boot/grub/grub.cfg
⇐
linux /boot/bzImage root=...  init=/bin/sh

sudo umount rootfs
sudo losetup -d /dev/loop0
```

Testing init

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Third time is the charm:

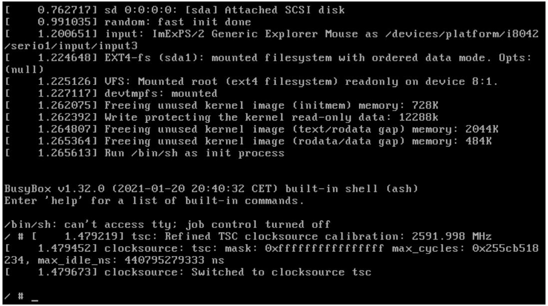
```
qemu-system-x86_64 root.img
```

Testing init

ULYSSIS

Third time is the charm:

`qemu-system-x86_64 root.img`



```
[    0.762717] sd 0:0:0:0: [sda] Attached SCSI disk
[    0.991035] random: fast init done
[    1.200651] input: ImExPS/2 Generic Explorer Mouse as /devices/platform/i8042
/serio1/input/input3
[    1.224648] EXT4-fs (sda1): mounted filesystem with ordered data mode. Opts:
(null)
[    1.225126] VFS: Mounted root (ext4 filesystem) readonly on device 8:1.
[    1.227117] devtmpfs: mounted
[    1.262075] Freeing unused kernel image (initmem) memory: 728K
[    1.262392] Write protecting the kernel read-only data: 12288k
[    1.264807] Freeing unused kernel image (text/rodata gap) memory: 2044K
[    1.265364] Freeing unused kernel image (rodata/data gap) memory: 484K
[    1.265613] Run /bin/sh as init process


BusyBox v1.32.0 (2021-01-20 20:40:32 CET) built-in shell (ash)
Enter 'help' for a list of built-in commands.

/bin/sh: can't access tty; job control turned off
/ # [    1.479219] tsc: Refined TSC clocksource calibration: 2591.998 MHz
[    1.479452] clocksource: tsc: mask: 0xffffffffffffffff max_cycles: 0x255cb518
234, max_idle_ns: 440795279333 ns
[    1.479673] clocksource: Switched to clocksource tsc

/ # _
```

Final notes

For a real usable system, you need a few more things:

- More standard directories: `/bin /dev /etc /home /lib /proc /sys /var/lib /var/lock /var/log /var/run /root /tmp /usr`
- Standard files: `/etc/hostname /etc/passwd /etc/shadow /etc/group /etc/hosts /etc/fstab`
- Set up init and daemon supervision system
- $\Rightarrow$ Buildroot!

Final notes

If you want to learn more:

- Documentation in the kernel repository, LWN
- Arch, Gentoo wikis, LFS book
- Search engine!
- Some IRC, Matrix, ... channels

That's all folks!

Thanks to our sponsor:

Please fill in the feedback form!

https://ulyssis.org/
https://gitlab.ulyssis.org/pcy/workshop-linux/