

# Embedded Linux Systems Programming Buildroot

Norman McEntire

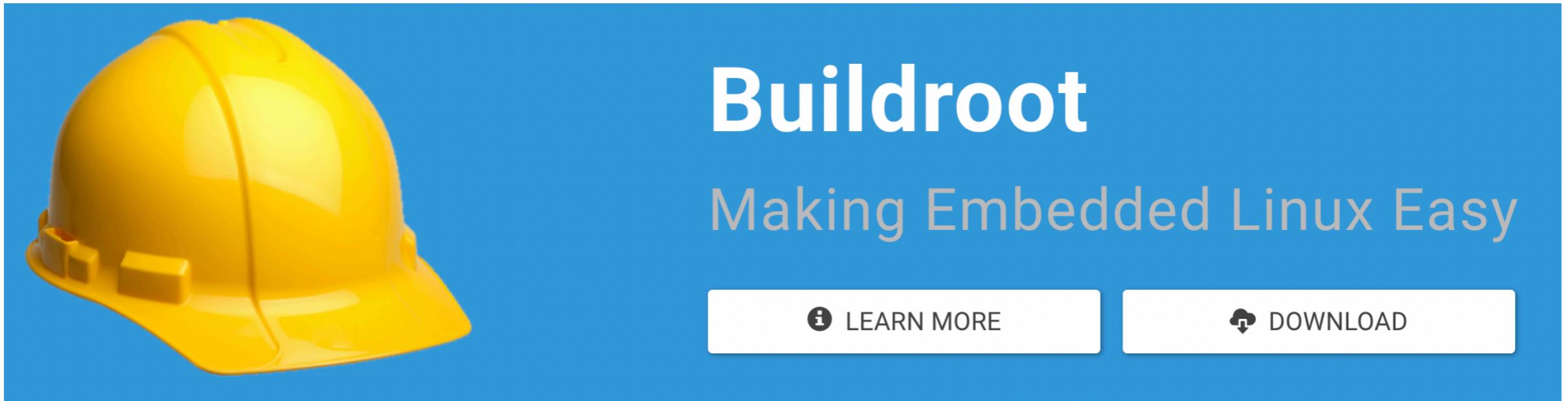
# Reference

- <https://buildroot.org/>
- <https://buildroot.org/docs.html>

# Opening Remarks!

- You are about to do what few people have done!
- Create, from scratch, a complete Embedded Linux System!
  - Boot Loader
  - Linux Kernel
  - Root Filesystem (rfs)
  - Busybox
- And it will boot from the SDCard on your RPi!
- Exciting!

# Introduction - Part 1



**Hardware => Bootloader => Linux Kernel => RootFileSystem => CLI/Services**



# Introduction - Part 2

Buildroot is a simple, efficient and easy-to-use **tool** to generate embedded Linux systems through **cross-compilation**.



Can handle everything



Is very easy



Supports several thousand packages

**Bootloader => Linux Kernel => RootFileSystem => CLI/Services**

# Download

Latest stable / long term support release: **2023.02**



[buildroot-2023.02.tar.gz](#)

PGP signature



[buildroot-2023.02.tar.xz](#)

PGP signature

# Results of Download

```
$ ls build*
buildroot-2023.02.tar.gz

$ tar tf buildroot-2023.02.tar.gz | head
buildroot-2023.02/
buildroot-2023.02/.checkpackageignore
buildroot-2023.02/.clang-format
buildroot-2023.02/.defconfig
buildroot-2023.02/.flake8
buildroot-2023.02/.gitignore
buildroot-2023.02/.gitlab-ci.yml
buildroot-2023.02/.shellcheckrc
buildroot-2023.02/CHANGES
buildroot-2023.02/COPYING
```

# Extract tarball

```
$ tar xf buildroot-2023.02.tar.gz
```

```
$ ls buildroot-2023.02 | wc -l
```

```
20
```

```
$ ls buildroot-2023.02
arch    boot      Config.in          configs   DEVELOPERS   fs        Makefile       package
support  toolchain
board   CHANGES   Config.in.legacy   COPYING    docs         linux     Makefile.legacy README
system   utils
```

**Key Observation: Directory structure similar to Linux Kernel**

# README

To build and use the buildroot stuff, do the following:

- 1) run 'make menuconfig'
- 2) select the target architecture and the packages you wish to compile
- 3) run 'make'
- 4) wait while it compiles
- 5) find the kernel, bootloader, root filesystem, etc. in output/images

You do not need to be root to build or run buildroot. Have fun!

**Step 1: make menuconfig**

**Step 2: make**

**Step 3: Place files onto embedded system**

# make help - Part 1

```
$ make help
```

Cleaning:

clean

distclean

- delete all files created by build
- delete all non-source files (including .config)

Build:

all

toolchain

sdk

- make world
- build toolchain
- build relocatable SDK

# make help - Part 2

## Configuration

### Configuration:

menuconfig

nconfig

xconfig

gconfig

oldconfig

syncconfig

olddefconfig

value

randconfig

defconfig

savedefconfig

update-defconfig

allyesconfig

allnoconfig

alldefconfig

randpackageconfig

allyespackageconfig

allnopackageconfig

- interactive curses-based configurator
- interactive ncurses-based configurator
- interactive Qt-based configurator
- interactive GTK-based configurator
- resolve any unresolved symbols in .config
- Same as oldconfig, but quietly, additionally update deps
- Same as syncconfig but sets new symbols to their default
  
- New config with random answer to all options
- New config with default answer to all options;  
    BR2\_DEFCONFIG, if set on the command line, is used as input
- Save current config to BR2\_DEFCONFIG (minimal config)
- Same as savedefconfig
- New config where all options are accepted with yes
- New config where all options are answered with no
- New config where all options are set to default
- New config with random answer to package options
- New config where pkg options are accepted with yes
- New config where package options are answered with no

# make help - Part 3

## Package Specific

Package-specific:

- <pkg>
  - <pkg>-source
  - <pkg>-extract
  - <pkg>-patch
  - <pkg>-depends
  - <pkg>-configure
  - <pkg>-build
  - <pkg>-show-info
  - <pkg>-show-dependents
  - <pkg>-show-rdependents
  - <pkg>-show-recursive-dependents
  - <pkg>-show-recursive-rdependents
  - <pkg>-graph-dependents
  - <pkg>-graph-rdependents
  - <pkg>-dirclean
  - <pkg>-reconfigure
  - <pkg>-rebuild
  - <pkg>-reinstall
- Build and install <pkg> and all its dependencies
  - Only download the source files for <pkg>
  - Extract <pkg> sources
  - Apply patches to <pkg>
  - Build <pkg>'s dependencies
  - Build <pkg> up to the configure step
  - Build <pkg> up to the build step
  - generate info about <pkg>, as a JSON blurb
  - List packages on which <pkg> depends
  - List packages which have <pkg> as a dependency
  - Recursively list packages on which <pkg> depends
  - Recursively list packages which have <pkg> as a dependency
  - Generate a graph of <pkg>'s dependencies
  - Generate a graph of <pkg>'s reverse dependencies
  - Remove <pkg> build directory
  - Restart the build from the configure step
  - Restart the build from the build step
  - Restart the build from the install step

# make help - Part 4

## Busybox

### busybox:

- |                       |   |
|-----------------------|---|
| busybox-menuconfig    | – Run busybox menuconfig  |
| busybox-xconfig       | – Run busybox xconfig   |
| busybox-gconfig       | – Run busybox gconfig   |
| busybox-update-config | – Save the busybox configuration as a full .config file<br>to package/busybox/busybox.config<br>(or override with BUSYBOX_KCONFIG_FILE) |

# make help - Part 5

## Linux Kernel

```
linux:  
  linux-menuconfig      - Run linux menuconfig  
  linux-xconfig        - Run linux xconfig  
  linux-gconfig        - Run linux gconfig  
  linux-nconfig        - Run linux nconfig
```

# make help - Part 6

## Documentation

### Documentation:

- |                   |  |
|-------------------|--|
| manual            | - build manual in all formats                          |
| manual-html       | - build manual in HTML                                 |
| manual-split-html | - build manual in split HTML                           |
| manual-pdf        | - build manual in PDF                                  |
| manual-text       | - build manual in text                                 |
| manual-epub       | - build manual in ePUB                                 |
| graph-build       | - generate graphs of the build times                   |
| graph-depends     | - generate graph of the dependency tree                |
| graph-size        | - generate stats of the filesystem size                |
| list-defconfigs   | - list all defconfigs (pre-configured minimal systems) |

# make help - Part 7

## Documentation

### Miscellaneous:

source  
external-deps  
legal-info  
show-info  
pkg-stats  
missing-cpe  
printvars  
show-vars

make V=0|1  
make O=dir

- download all sources needed for offline-build
- list external packages used
- generate info about license compliance
- generate info about packages, as a JSON blurb
- generate info about packages as JSON and HTML
- generate XML snippets for missing CPE identifiers
- dump internal variables selected with VARS=...
- dump all internal variables as a JSON blurb; use VARS=... to limit the list to variables names matching that pattern
  
- 0 => quiet build (default), 1 => verbose build
- Locate all output files in "dir", including .config

For further details, see README, generate the Buildroot manual, or consult it on-line at <http://buildroot.org/docs.html>

# **make menuconfig**

# 1st Attempt

```
$ make menuconfig
mkdir -p /home/nmcentire/Downloads/buildroot-2023.02/output/build/buildroot-config/lxdialog
PKG_CONFIG_PATH="" make CC="/usr/bin/gcc" HOSTCC="/usr/bin/gcc" \
    obj=/home/nmcentire/Downloads/buildroot-2023.02/output/build/buildroot-config -C support/kconfig -f Makefile.br
mconf
make[1]: Entering directory '/home/nmcentire/Downloads/buildroot-2023.02/support/kconfig'
/usr/bin/gcc -DCURSES_LOC=<curses.h> -DLOCALE -I/home/nmcentire/Downloads/buildroot-2023.02/output/build/buildroot-
config -DCONFIG_=\"\" -MM *.c > /home/nmcentire/Downloads/buildroot-2023.02/output/build/buildroot-config/.depend 2>
/dev/null || :
/usr/bin/gcc -DCURSES_LOC=<curses.h> -DLOCALE -I/home/nmcentire/Downloads/buildroot-2023.02/output/build/buildroot-
config -DCONFIG_=\"\" -c conf.c -o /home/nmcentire/Downloads/buildroot-2023.02/output/build/buildroot-config/conf.o
*** Unable to find the ncurses libraries or the
*** required header files.
*** 'make menuconfig' requires the ncurses libraries.
***
*** Install ncurses (ncurses-devel or libncurses-dev
*** depending on your distribution) and try again.
***
make[1]: *** [Makefile:253: /home/nmcentire/Downloads/buildroot-2023.02/output/build/buildroot-config/dochecklxdialog]
Error 1
make[1]: Leaving directory '/home/nmcentire/Downloads/buildroot-2023.02/support/kconfig'
make: *** [Makefile:959: /home/nmcentire/Downloads/buildroot-2023.02/output/build/buildroot-config/mconf] Error 2
```

# apt-cache search libncurses

```
$ apt-cache search libncurses
centerim-utf8 - A text-mode multi-protocol instant messenger client
libncurses-dev - developer's libraries for ncurses
libncurses-gst - Ncurses bindings for GNU Smalltalk
libncurses5 - shared libraries for terminal handling (legacy version)
libncurses5-dev - transitional package for libncurses-dev
libncurses6 - shared libraries for terminal handling
libncursesada-doc - Ada binding to the ncurses text interface library: documentation
libncursesada6.2.3 - Ada binding to the ncurses text interface library: shared library
libncursesada9-dev - Ada binding to the ncurses text interface library: development
libncursesw5 - shared libraries for terminal handling (wide character legacy version)
libncursesw5-dev - transitional package for libncurses-dev
libncursesw6 - shared libraries for terminal handling (wide character support)
libtinfo-dev - transitional package for libncurses-dev
```

# **sudo apt-get install libncurses-dev**

```
$ sudo apt-get install libncurses-dev
Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
Suggested packages:
  ncurses-doc
The following NEW packages will be installed:
  libncurses-dev
0 upgraded, 1 newly installed, 0 to remove and 29 not upgraded.
Need to get 288 kB of archives.
After this operation, 1,818 kB of additional disk space will be used.
Get:1 http://raspbian.raspberrypi.org/raspbian bullseye/main armhf libncurses-dev armhf 6.2+20201114-2
[288 kB]
Fetched 288 kB in 1s (240 kB/s)
Selecting previously unselected package libncurses-dev:armhf.
(Reading database ... 112599 files and directories currently installed.)
Preparing to unpack .../libncurses-dev_6.2+20201114-2_armhf.deb ...
Unpacking libncurses-dev:armhf (6.2+20201114-2) ...
Setting up libncurses-dev:armhf (6.2+20201114-2) ...
Processing triggers for man-db (2.9.4-2) ...
```

# make menuconfig

```
/home/nmcentire/Downloads/buildroot-2023.02/.config - Buildroot 2023.02 Configuration

Buildroot 2023.02 Configuration
Arrow keys navigate the menu. <Enter> selects submenus ---> (or empty submenus ----). Highlighted letters
are hotkeys. Pressing <Y> selects a feature, while <N> excludes a feature. Press <Esc><Esc> to exit, <?>
for Help, </> for Search. Legend: [*] feature is selected [ ] feature is excluded

Target options --->
Toolchain --->
Build options --->
System configuration --->
Kernel --->
Target packages --->
Filesystem images --->
Bootloaders --->
Host utilities --->
Level config options --->
```

**Target Options**

**Toolchain**

**Build Options**

**System Configuration**

**Kernel**

**Target Packages**

**Filesystem Images**

**Bootloaders**

**Host Utilities**

**Legacy Config Options**

**Before going through all the options,  
you can build a default option for  
Raspberry Pi and other boards -  
located under configs directory**

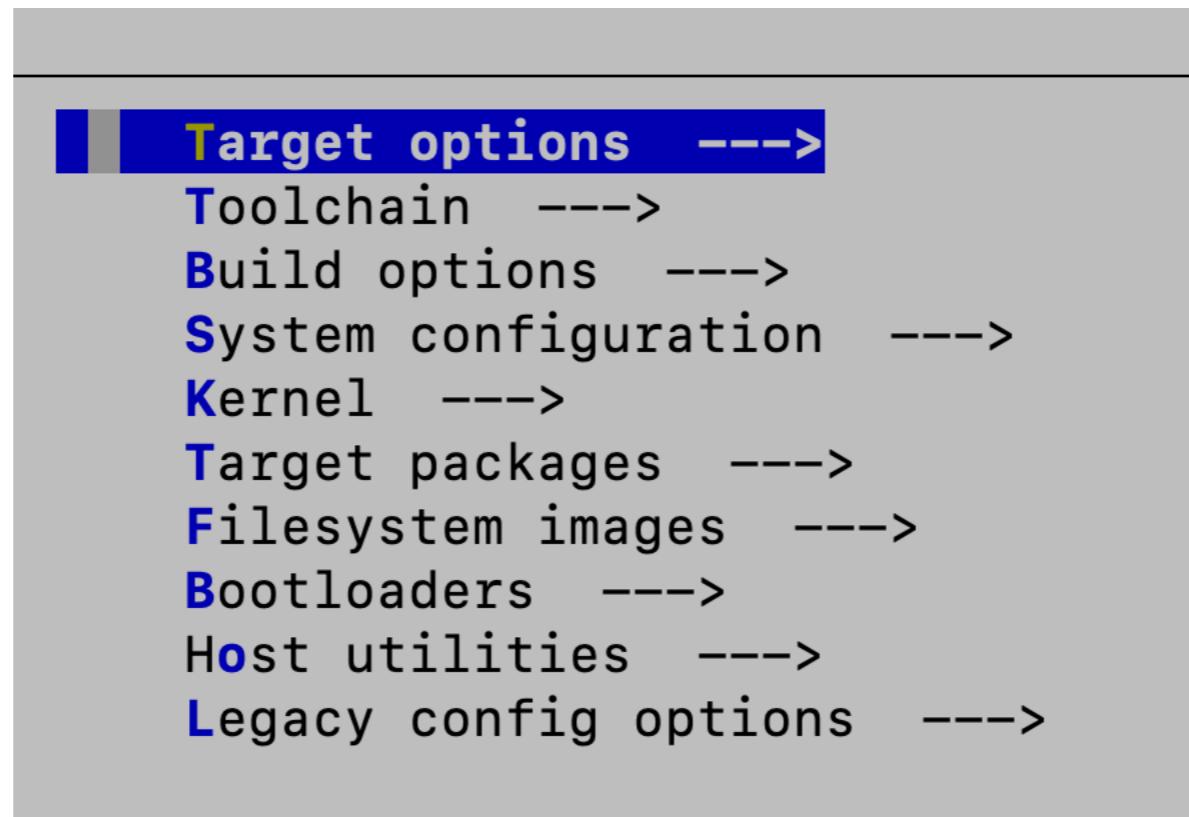
# configs Directory

```
$ ls configs/
aarch64_efi_defconfig
acmesystems_acqua_a5_256mb_defconfig
acmesystems_acqua_a5_512mb_defconfig
acmesystems_aria_g25_128mb_defconfig
acmesystems_aria_g25_256mb_defconfig
acmesystems_arietta_g25_128mb_defconfig
acmesystems_arietta_g25_256mb_defconfig
amarula_vyasa_rk3288_defconfig
. . .
. . .
freescale_imx8qmmek_defconfig
freescale_imx8qxpmek_defconfig
freescale_p1025twr_defconfig
freescale_t1040d4rdb_defconfig
freescale_t2080_qds_rdb_defconfig
friendlyarm_nanopi_r2s_defconfig
galileo_defconfig
globalscale_espressobin_defconfig
grinn_chiliboard_defconfig
grinn_liteboard_defconfig
hifive_unleashed_defconfig
imx23evk_defconfig
odroidxu4_defconfig
olimex_a10_olinuxino_lime_defconfig
olimex_a13_olinuxino_defconfig
olimex_a20_olinuxino_lime2_defconfig
olimex_a20_olinuxino_lime_defconfig
olimex_a20_olinuxino_micro_defconfig
olimex_a33_olinuxino_defconfig
olimex_a64_olinuxino_defconfig
raspberrypi0_defconfig
raspberrypi0w_defconfig
raspberrypi2_defconfig
raspberrypi3_64_defconfig
raspberrypi3_defconfig
raspberrypi3_qt5we_defconfig
raspberrypi4_64_defconfig
raspberrypi4_defconfig
raspberrypicm4io_64_defconfig
raspberrypicm4io_defconfig
raspberrypi_defconfig
raspberrypizero2w_defconfig
```

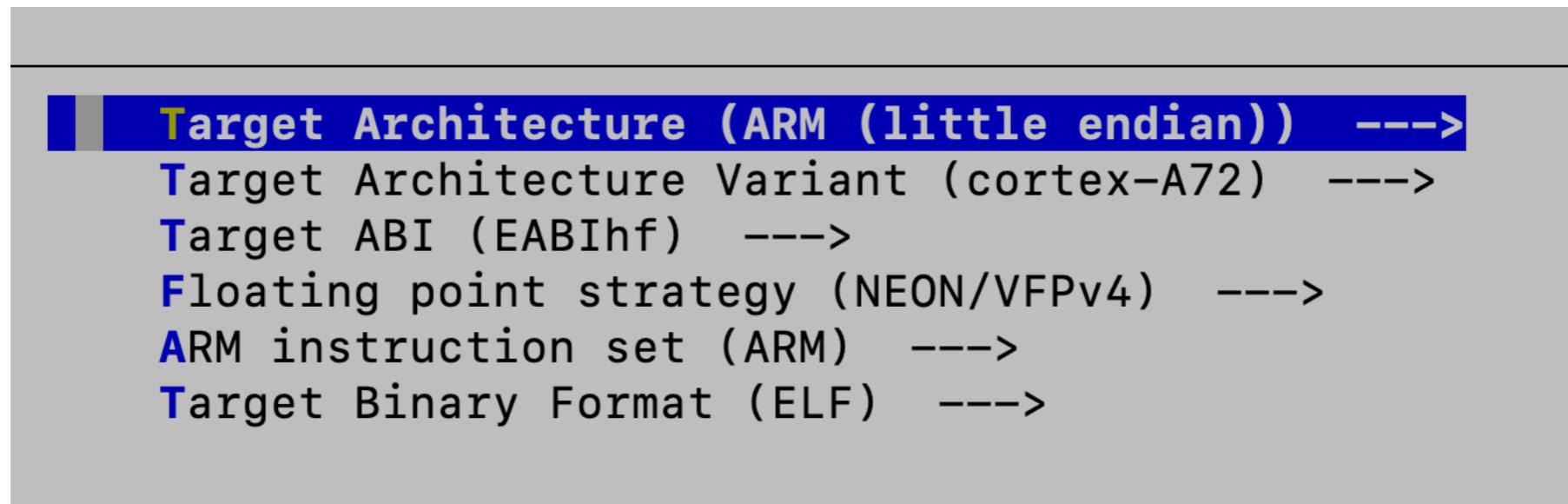
# make raspberrypi4\_defconfig

```
$ make raspberrypi4_defconfig
mkdir -p /home/nmcentire/Downloads/buildroot-2023.02/output/build/buildroot-config/lxdialog
PKG_CONFIG_PATH="" make CC="/usr/bin/gcc" HOSTCC="/usr/bin/gcc" \
    obj=/home/nmcentire/Downloads/buildroot-2023.02/output/build/buildroot-config -C support/kconfig -f
Makefile.br conf
make[1]: Entering directory '/home/nmcentire/Downloads/buildroot-2023.02/support/kconfig'
/usr/bin/gcc -D_DEFAULT_SOURCE -D_XOPEN_SOURCE=600 -DCURSES_LOC=<ncurses.h> -DCURSES_WIDECHAR=1
-DLOCALE -I/home/nmcentire/Downloads/buildroot-2023.02/output/build/buildroot-config -DCONFIG_=\"\" \
/home/nmcentire/Downloads/buildroot-2023.02/output/build/buildroot-config/conf.o /home/nmcentire/
Downloads/buildroot-2023.02/output/build/buildroot-config/zconf.tab.o -o /home/nmcentire/Downloads/
buildroot-2023.02/output/build/buildroot-config/conf
make[1]: Leaving directory '/home/nmcentire/Downloads/buildroot-2023.02/support/kconfig'
#
# configuration written to /home/nmcentire/Downloads/buildroot-2023.02/.config
#
```

# make menuconfig



# Target Options



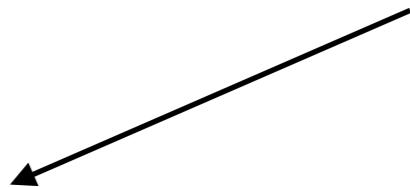
## EABI - Embedded Application Binary Interface Hardware Floating Point

Note: The Raspberry Pi 4 uses a Broadcom BCM2711 SoC, which features a Cortex-A72 CPU based on the ARMv8-A architecture.

# Observe that default build for RPI was ARM 32-bit in Buildroot!

```
$ arch  
aarch64
```

```
$ file /bin/bash  
/bin/bash: ELF 32-bit LSB executable, ARM, EABI5 version 1 (SYSV), dynamically linked,  
interpreter /lib/ld-linux-armhf.so.3,  
BuildID[sha1]=f12e6d40fb262ad0037b6ec43162208b76d4da71, for GNU/Linux 3.2.0, stripped
```



# Why Does RPi (aarch64) Build 32-Bit armv7l code?

- Backward Compatibility
  - The RPi has been around for many years and has lots of 32-bit armv7l code
- Smaller Code Size
  - A 64-bit code base typically larger than a 32-bit code base
- Ecosystem
  - Large body of developers familiar with RPi and the 32-bit code base

# Toolchain

```
| Toolchain type (Buildroot toolchain) --->
|   *** Toolchain Buildroot Options ***
| (buildroot) custom toolchain vendor name
|   C library (glibc) --->
|     *** Kernel Header Options ***
|     Kernel Headers (Same as kernel being built) --->
|     Custom kernel headers series (5.10.x) --->
|       *** Glibc Options ***
|       [ ] Enable compatibility shims to run on older kernels
|       [ ] Install glibc utilities
|         *** Binutils Options ***
|         Binutils Version (binutils 2.38) --->
|         () Additional binutils options
|           *** GCC Options ***
|           GCC compiler Version (gcc 11.x) --->
|           () Additional gcc options
|           [*] Enable C++ support
|             [ ] Enable Fortran support
|             [ ] Enable D language support
|             ↓(+)
```

# C Library

## C library

Use the arrow keys to navigate this window or press the hotkey of the item you wish to select followed by the <SPACE BAR>. Press <?> for additional information about this

- 
- ( ) uClibc-ng
  - (X) glibc**
  - ( ) musl

# Build Options

```
| Commands ---->
(/home/nmcentire/Downloads/buildroot-2023.02/configs/raspberryp
($TOPDIR)/dl) Download dir
($BASE_DIR)/host) Host dir
    Mirrors and Download locations ---->
(0) Number of jobs to run simultaneously (0 for auto)
[ ] Enable compiler cache
[ ] build packages with debugging symbols
[ ] build packages with runtime debugging info
[*] strip target binaries
()   executables that should not be stripped
()   directories that should be skipped when stripping
    gcc optimization level (optimize for size) ---->
[ ] build packages with link-time optimisation
[ ] Enable google-breakpad support
    libraries (shared only) ---->
($CONFIG_DIR)/local.mk) location of a package override file
() global patch directories
    Advanced ---->
↓(+)
```

# System Configuration

```
→ [ ] Root FS skeleton (default target skeleton) ---->
→ (buildroot) System hostname
→ (Welcome to Buildroot) System banner
→     Passwords encoding (sha-256) ---->
→     Init system (BusyBox) ---->
→         /dev management (Dynamic using devtmpfs only) ---->
→ (system/device_table.txt) Path to the permission tables
→ [ ] support extended attributes in device tables
→ [ ] Use symlinks to /usr for /bin, /sbin and /lib
→ → [*] Enable root login with password
→     () Root password
→         /bin/sh (busybox' default shell) ---->
→     [*] Run a getty (login prompt) after boot ---->
→     [*] remount root filesystem read-write during boot
→ (eth0) Network interface to configure through DHCP
→ (/bin:/sbin:/usr/bin:/usr/sbin) Set the system's default PATH
→ [*] Purge unwanted locales
→ (C en_US) Locales to keep
→     () Generate locale data
↓(+)
```

# Kernel

```
→ [*] Linux Kernel
      Kernel version (Custom tarball) --->
      $(call github,raspberrypi,linux,0b54dbda3cca2beb51e236a2573878
      ()  Custom kernel patches
          Kernel configuration (Using an in-tree defconfig file) -
      (bcm2711) Defconfig name
      ()  Additional configuration fragment files
      ()  Custom boot logo file path
          Kernel binary format (zImage) --->
          Kernel compression format (gzip compression) --->
      → [*] Build a Device Tree Blob (DTB)
      [ ]  DTB is built by kernel itself
      → (bcm2711-rpi-4-b) In-tree Device Tree Source file names
      ()  Out-of-tree Device Tree Source file paths
      [ ]  Keep the directory name of the Device Tree
      -*  Build Device Tree with overlay support
      [ ]  Install kernel image to /boot in target
      [*] Needs host OpenSSL
      [ ]  Needs host libelf
↓(+)
```

# Packages

## -\*- BusyBox

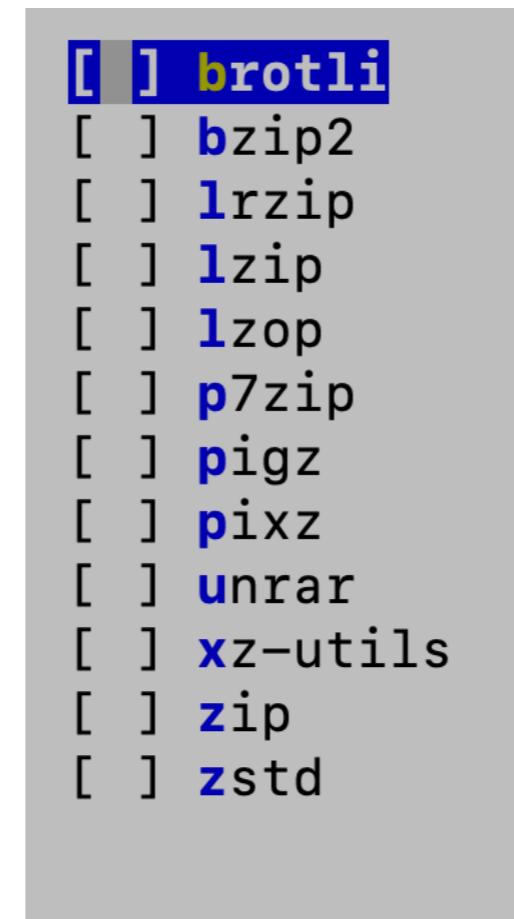
```
(package/busybox/busybox.config) BusyBox configuration file to use? (NEW)
()    Additional BusyBox configuration fragment files (NEW)
[ ]    Show packages that are also provided by busybox (NEW)
[ ]    Individual binaries (NEW)
[ ]    Install the watchdog daemon startup script (NEW)
      Audio and video applications    --->
      Compressors and decompressors    --->
      Debugging, profiling and benchmark    --->
      Development tools    --->
      Filesystem and flash utilities    --->
      Fonts, cursors, icons, sounds and themes    --->
      Games    --->
      Graphic libraries and applications (graphic/text)    --->
      Hardware handling    --->
      Interpreter languages and scripting    --->
      Libraries    --->
      Mail    --->
      Miscellaneous    --->
```

↓(+)

# Packages / Audio and Video

```
[ ] als-utils  ----  
[ ] atest  
[ ] aumix  
[ ] bluez-alsa  
[ ] dvblast  
[ ] dvdauthor  
[ ] dvdrw-tools  
[ ] espeak  
[ ] faad2  
[ ] ffmpeg  ----  
[ ] flac  
[ ] flite  
[ ] fluid-soundfont  
[ ] fluidsynth  
[ ] gmrender-resurrect  
[ ] gstreamer 1.x  
[ ] jack1  
[ ] jack2
```

# Packages / Compressors and Decompressors



# Packages / Debugging, Profiling and Benchmark

```
[ ] babeltrace2 (NEW)
[ ] blktrace (NEW)
    *** bonnie++ needs a toolchain w/ C++ ***
[ ] bpftrace (NEW)
[ ] cache-calibrator (NEW)
    *** clinfo needs an OpenCL provider ***
    *** clpeak needs an OpenCL provider, a toolchain w/ C++, gcc >= 4.8 ***
[ ] coremark (NEW)
[ ] coremark-pro (NEW)
    *** dacapo needs OpenJDK ***
[ ] delve (NEW)
[ ] dhrystone (NEW)
[ ] dieharder (NEW)
[ ] dmalloc (NEW)
[ ] dropwatch (NEW)
[ ] dstat (NEW)
[ ] dt (NEW)
    *** numa needs a toolchain w/ C++, threads, dynamic library ***
[ ] fio (NEW)
```

# Packages / Development Tools

```
[ ] avocado (NEW)
[ ] binutils (NEW)
[ ] bitwise (NEW)
[ ] bsdiff (NEW)
[ ] check (NEW)
    *** ctest needs a toolchain w/ C++, wchar, dynamic library, gcc >= 4.7, N
    *** cppunit needs a toolchain w/ C++, dynamic library ***
[ ] cukinia (NEW)
[ ] cunit (NEW)
[ ] cvs (NEW)
    ***cxxtest needs a toolchain w/ C++ support ***
[ ] flex (NEW)
[ ] gettext (NEW)
[ ] git (NEW)
    *** git-crypt needs a toolchain w/ C++, gcc >= 4.9 ***
    *** gperf needs a toolchain w/ C++ ***
[ ] jo (NEW)
[ ] jq (NEW)
[ ] libtool (NEW)
```

# Filesystem and Flash Utilities

```
[ ] abootimg
[ ] aufs-util
[ ] autofs
[ ] btrfs-progs
[ ] cifs-utils
[ ] cpio
[ ] cramfs
[ ] curlftpfs (FUSE)
[ ] davfs2
[ ] dosfstools
[ ] e2fsprogs -----
[ ] e2tools
[ ] ecryptfs-utils
[ ] eroofs-utils
[ ] exFAT (FUSE)
[ ] exfat-utils
[ ] exfatprogs
[ ] f2fs-tools
[ ] firmware-utils
```

# Fonts, Cursors, Icons, Sounds, and Themes

```
*** Cursors ***
[ ] comix-cursors
[ ] obsidian-cursors
    *** Fonts ***
[ ] Bitstream Vera
[ ] cantarell
[ ] DejaVu fonts
[ ] font-awesome
[ ] ghostscript-fonts
[ ] inconsolata
[ ] Liberation (Free fonts)
[ ] wqy-zenhei
    *** Icons ***
[ ] google-material-design-icons
[ ] hicolor icon theme
    *** Sounds ***
[ ] sound-theme-borealis
[ ] sound-theme-freedesktop
```

# Games

```
[ ] ascii_invaders
[ ] chocolate-doom
[ ] flare-engine
[ ] frotz
[ ] gnuchess
[ ] LBreakout2
[ ] LTris
    *** minetest needs X11 and an OpenGL provider ***
[ ] OpenTyrian
[ ] prboom
[ ] sl
    *** solarus needs OpenGL and a toolchain w/ C++, gcc >= 4.9, NPTL, dynamic library, an
[ ] stella
[ ] xorcurses
```

# Graphics Libraries and Applications

## \*\*\* Graphic applications \*\*\*

```
*** cage needs udev, EGL w/ Wayland backend and OpenGL ES support ***
*** cog needs wpewebkit and a toolchain w/ threads ***
[ ] fswebcam
[ ] ghostscript
    *** glmark2 needs an OpenGL or an openGL ES and EGL backend ***
    *** glslsandbox-player needs openGL ES and EGL driver ***
[ ] gnuplot
[ ] jhead
    *** kmscube needs EGL, GBM and OpenGL ES, and a toolchain w/ thread support ***
[ ] libva-utils
[ ] netsurf
[ ] pngquant
[ ] rrdtool
    *** stellarium needs Qt5 and an OpenGL provider ***
    *** sway needs systemd, udev, EGL w/ Wayland backend and OpenGL ES support ***
[ ] tesseract-ocr ----
[ ] tinifier
```

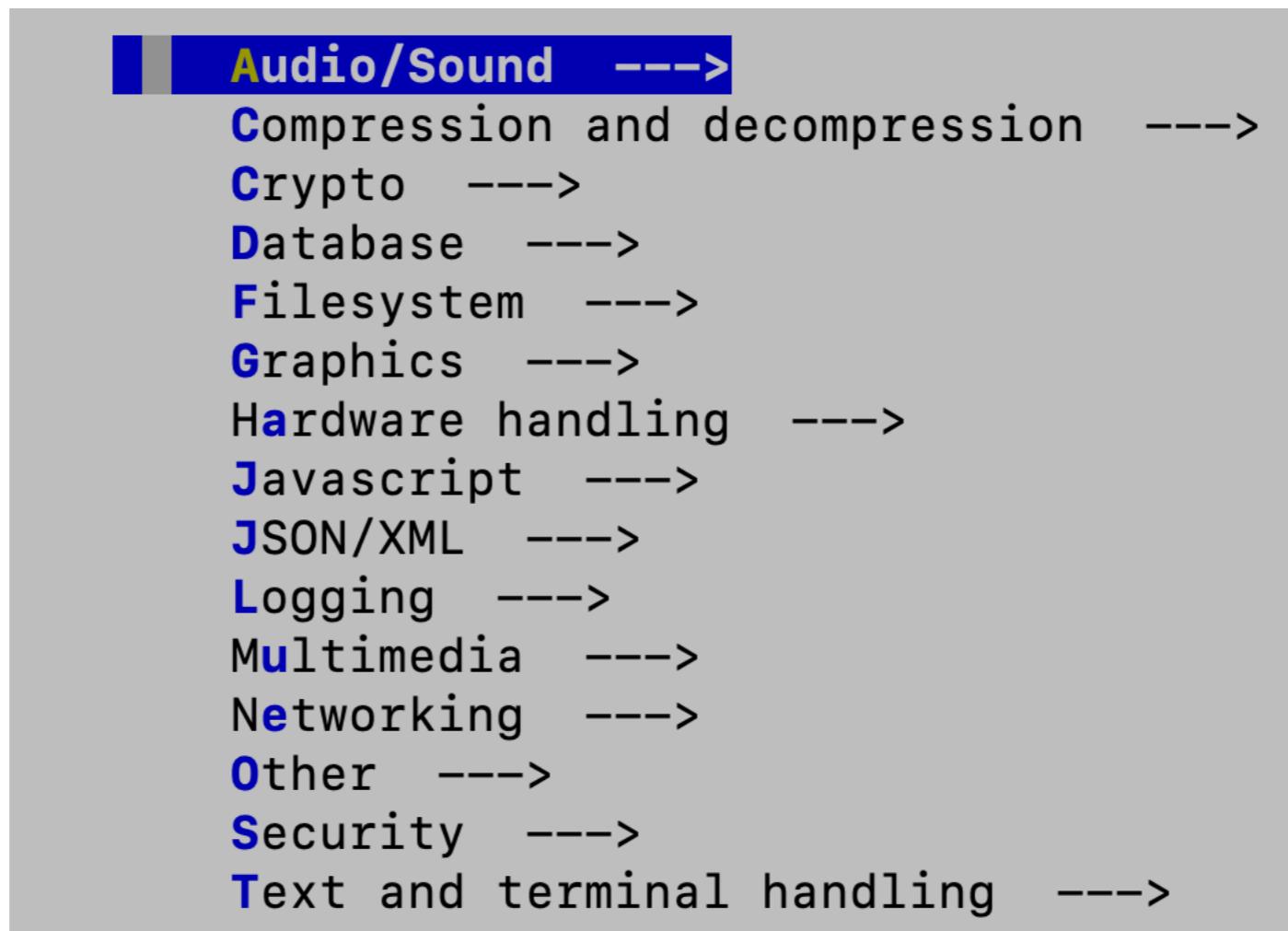
# Hardware Handling

```
■ Firmware --->
[ ] 18xx-ti-utils (NEW)
[ ] acpica (NEW)
[ ] acpid (NEW)
    *** acpitool needs a toolchain w/ threads, C++, dynamic library ***
[ ] aer-inject (NEW)
[ ] altera-stapl (NEW)
    *** apcupsd needs a toolchain w/ C++, threads ***
[ ] avrdude (NEW)
    *** bcache-tools needs udev /dev management ***
    *** brickd needs udev /dev management, a toolchain w/ threads, wchar ***
[ ] brltty (NEW)
    *** cc-tool needs a toolchain w/ C++, threads, wchar, gcc >= 4.9 ***
[ ] cdrkit (NEW)
[ ] crucible (NEW)
[ ] cryptsetup (NEW)
```

# Interpreter Languages and Scripting

```
[ ] 4th (NEW)
[ ] enscript (NEW)
[ ] execline (NEW)
[ ] ficl (NEW)
[ ] guile (NEW)
[ ] haserl (NEW)
[ ] janet (NEW)
[ ] jimtcl (NEW)
[ ] lua (NEW)
[ ] micropython (NEW)
[ ] moarvm (NEW)
    *** nodejs needs a to
    *** octave needs a to
[ ] perl (NEW)
[ ] php (NEW)
[ ] python3 (NEW)
[ ] quickjs (NEW)
[ ] ruby (NEW)
[ ] tcl (NEW)
```

# Libraries - Many Categories



# Mail

```
[ ] dovecot (NEW)
[ ] exim (NEW)
[ ] fetchmail (NEW)
[ ] heirloom-mailx (NEW)
[ ] libesmtp (NEW)
[ ] msmtplib (NEW)
[ ] mutt (NEW)
```

# Misc

```
[ ] aespipe (NEW)
[ ] bc (NEW)
    *** bitcoin needs a toolchain w/ C++, threads, wchar ***
    *** clamav needs a toolchain w/ C++, dynamic library, threads, wchar ***
[ ] collectd (NEW) ----
[ ] collectl (NEW)
    *** domoticz needs lua 5.3 and a toolchain w/ C++, gcc >= 6, NPTL, wchar, dynamic libr
[ ] empty (NEW)
[ ] gitlab-runner (NEW)
    *** gnuradio needs a toolchain w/ C++, NPTL, wchar, dynamic library, gcc >= 8 ***
[ ] Google font directory (NEW)
    *** gqrx needs a toolchain w/ C++, threads, wchar, dynamic library, gcc >= 8 ***
    *** gqrx needs qt5 ***
[ ] gsettings-desktop-schemas (NEW)
[ ] haveged (NEW)
[ ] linux-syscall-support (lss) (NEW)
[ ] mobile-broadband-provider-info (NEW)
[ ] netdata (NEW)
    *** proj needs a toolchain w/ C++, gcc >= 4.7, threads, wchar ***
```

# Networking Applications

```
*** aircrack-ng needs a toolchain w/ dynamic library, threads, C++ ***
[ ] alfred (NEW)
[ ] aoetools (NEW)
[ ] apache (NEW)
[ ] argus (NEW)
[ ] arp-scan (NEW)
[ ] arptables-legacy (NEW)
    *** asterisk needs a glibc or uClibc toolchain w/ C++, dynamic library, threads, wchar
[ ] atftp (NEW)
[ ] avahi (NEW)
[ ] axel (NEW)
[ ] babeld (NEW)
[ ] bandwidthd (NEW)
[ ] batctl (NEW)
    *** bcusdk needs a toolchain w/ C++ ***
[ ] bind (NEW)
[ ] bird (NEW)
[ ] bluez-utils (NEW)
[ ] bmon (NEW)
[ ]
```

# Package Managers

```
*** ----- ***
*** Please note: ***
*** - Buildroot does *not* generate binary packages, ***
*** - Buildroot does *not* install any package database. ***
*** *
*** It is up to you to provide those by yourself if you ***
*** want to use any of those package managers. ***
*** *
*** See the manual: ***
*** http://buildroot.org/manual.html#faq-no-binary-packages ***
*** ----- ***
```

- [ ] **opkg** (NEW)
- [ ] **opkg-utils** (NEW)

# Real-time

[ ] **Xenomai Userspace (NEW)**

**Note: The Linux kernel is not a real-time kernel.  
The Xenomai project uses a dual-kernel approach.  
More info below**

**<https://source.denx.de/Xenomai/xenomai/-/wikis/home>**

# Security

```
  [ ] *** apparmor needs a toolchain w/
  [ ] checkpolicy (NEW)
  [ ] ima-evm-utils (NEW)
  [ ] optee-benchmark (NEW)
  [ ] optee-client (NEW)
  [ ] paxtest (NEW)
  [ ] policycoreutils (NEW)
  [ ] refpolicy (NEW)
  [ ] restorecond (NEW)
  [ ] selinux-python (NEW)
  [ ] semodule-utils (NEW)
      *** setools needs python3 ***
[*] urandom-initscripts (NEW)
```

# Shells and Utilities

```
*** Shells ***
[ ] mksh (NEW)
[ ] zsh (NEW)
*** Utilities ***
[ ] apg (NEW)
[ ] at (NEW)
[ ] catatonit (NEW)
[ ] ccrypt (NEW)
[ ] dialog (NEW)
[ ] dtach (NEW)
[ ] easy-rsa (NEW)
[ ] file (NEW)
[ ] gnupg (NEW)
[ ] gnupg2 (NEW)
[ ] inotify-tools (NEW)
[ ] lockfile programs (NEW)
[ ] logrotate (NEW)
[ ] logsurfer (NEW)
[ ] pdmenu (NEW)
```

# System Tools

```
[ ] acl (NEW)
[ ] android-tools (NEW)
[ ] atop (NEW)
[ ] attr (NEW)
[ ] audit (NEW)
[ ] balena-engine (NEW)
[ ] bubblewrap (NEW)
[ ] cgroupfs-mount (NEW)
    *** circus needs Python 3 and a toolchain w/ C++, threads ***
[ ] containerd (NEW)
[ ] cpulimit (NEW)
[ ] cpuload (NEW)
[ ] crun (NEW)
[ ] daemon (NEW)
[ ] dc3dd (NEW)
    *** ddrescue needs a toolchain w/ C++ ***
[ ] docker-cli (NEW)
    *** docker-compose needs docker-cli and a toolchain w/ threads ***
[ ] docker-engine (NEW)
```

# Text Editors and Viewers

```
[ ] ed (NEW)
[ ] joe (NEW)
[ ] mc (NEW)
[ ] mg (NEW)
[ ] most (NEW)
[ ] nano (NEW)
[ ] uemacs (NEW)
```

# Filesystem Images

# Filesystem Images

```
[ ] axfs root filesystem
[ ] btrfs root filesystem
[ ] cloop root filesystem for the target device
[ ] cpio the root filesystem (for use as an initial RAM filesystem)
[ ] cramfs root filesystem
[ ] erofs root filesystem
[*] ext2/3/4 root filesystem
      ext2/3/4 variant (ext4) --->
(rootfs) filesystem label
(120M) exact size
(0) exact number of inodes (leave at 0 for auto calculation)
(256) inode size
(5) reserved blocks percentage
(-0 ^64bit) additional mke2fs options
      Compression method (no compression) --->
[ ] f2fs root filesystem
[ ] initial RAM filesystem linked into linux kernel
[ ] jffs2 root filesystem
[ ] oci image
```

# Boot Loaders

# Boot Loaders

```
[ ] ARM Trusted Firmware (ATF) (NEW)
[ ] Barebox (NEW)
[ ] binaries-marvell (NEW)
    *** boot-wrapper-aarch64 needs a Linux kernel to be built ***
[ ] EDK2 (NEW)
[ ] grub2 (NEW)
[ ] mv-ddr-marvell (NEW)
[ ] optee_os (NEW)
[ ] shim (NEW)
[ ] ti-k3-r5-loader (NEW)
[ ] U-Boot (NEW)
[ ] vexpress-firmware (NEW)
```

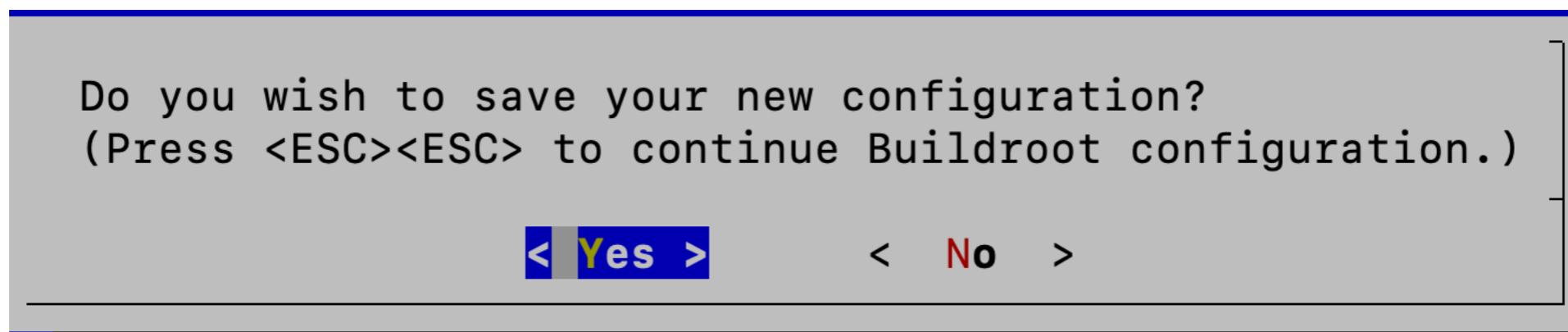
# Host Utilities

# Host Utilities

```
[ ] host abootimg (NEW)
[ ] host aespipe (NEW)
[ ] host agent-proxy (NEW)
[ ] host android-tools (NEW)
[ ] host asn1c (NEW)
[ ] host babeltrace2 (NEW)
[ ] host bmap-tools (NEW)
[ ] host bootgen (NEW)
[ ] host btrfs-progs (NEW)
[ ] host checkpolicy (NEW)
[ ] host checksec (NEW)
[ ] host cmake (NEW)
[ ] host cramfs (NEW)
[ ] host crudini (NEW)
[ ] host cryptsetup (NEW)
[ ] host dbus-python (NEW)
[ ] host delve (NEW)
[ ] host dfu-util (NEW)
[ ] host dos2unix (NEW)
```

# **Save Your Configuration When Done**

# Prompt To Save Configuration



```
configuration written to /home/nmcentire/Downloads/buildroot-2023.02/.config
*** End of the configuration.
*** Execute 'make' to start the build or try 'make help'.
```

# Type “make” to begin build

```
$ time make
/usr/bin/make -j1 O=/home/nmcentire/Downloads/buildroot-2023.02/output HOSTCC="/usr/bin/gcc" HOSTCXX="/usr/bin/g++"
syncconfig
make[1]: Entering directory '/home/nmcentire/Downloads/buildroot-2023.02'
make[1]: Leaving directory '/home/nmcentire/Downloads/buildroot-2023.02'
>>> host-skeleton Extracting
>>> host-skeleton Patching
>>> host-skeleton Configuring
>>> host-skeleton Building
>>> host-skeleton Installing to host directory
>>> host-pkgconf 1.6.3 Downloading
wget --passive-ftp -nd -t 3 -O '/home/nmcentire/Downloads/buildroot-2023.02/output/build/.pkgconf-1.6.3.tar.xz.vJMnOS/
output' 'https://distfiles.dereferenced.org/pkgconf/pkgconf-1.6.3.tar.xz'
--2023-04-11 21:06:24-- https://distfiles.dereferenced.org/pkgconf/pkgconf-1.6.3.tar.xz
Resolving distfiles.dereferenced.org (distfiles.dereferenced.org)... 2602:fd37:1::83, 170.39.20.83
Connecting to distfiles.dereferenced.org (distfiles.dereferenced.org)|2602:fd37:1::83|:443... connected.
HTTP request sent, awaiting response... 200 OK
Length: 291216 (284K) [application/octet-stream]
Saving to: '/home/nmcentire/Downloads/buildroot-2023.02/output/build/.pkgconf-1.6.3.tar.xz.vJMnOS/output'

. . .
. . .
```

# CC - C Compiler

```
...  
...  
CC  lib/libcommon_la-crc32.lo  
CC  lib/libcommon_la-crc32c.lo  
CC  lib/libcommon_la-c strtod.lo  
CC  lib/libcommon_la-encode.lo  
CC  lib/libcommon_la-env.lo  
CC  lib/libcommon_la-fileutils.lo  
CC  lib/libcommon_la-idcache.lo  
CC  lib/libcommon_la-jsonwrt.lo  
CC  lib/libcommon_la-mangle.lo  
CC  lib/libcommon_la-match.lo  
CC  lib/libcommon_la-mbsalign.lo  
CC  lib/libcommon_la-mbsedit.lo  
CC  lib/libcommon_la-md5.lo  
CC  lib/libcommon_la-pager.lo  
CC  lib/libcommon_la-pwdutils.lo  
CC  lib/libcommon_la-randutils.lo  
...  
...
```

# Linker

```
· · ·  
· · ·  
LD badblocks  
LD tune2fs  
LD dumpe2fs  
LD logsave  
LD e2image  
LD e2undo  
LD chattr  
LD lsattr  
LD mklost+found  
LD filefrag  
LD e2freefrag  
LD e4crypt  
LD e2fuzz  
· · ·  
· · ·
```

# Downloading

```
>>> host-acl 2.3.1 Downloading
wget --passive-ftp -nd -t 3 -O '/home/nmcentire/Downloads/buildroot-2023.02/output/build/.acl-2.3.1.tar.xz.Er6daJ/
output' 'http://download.savannah.gnu.org/releases/acl/acl-2.3.1.tar.xz'
--2023-04-11 21:11:11-- http://download.savannah.gnu.org/releases/acl/acl-2.3.1.tar.xz
Resolving download.savannah.gnu.org (download.savannah.gnu.org)... 2001:470:142:5::200, 209.51.188.200
Connecting to download.savannah.gnu.org (download.savannah.gnu.org)|2001:470:142:5::200|:80... connected.
HTTP request sent, awaiting response... 302 Moved Temporarily
Location: http://nongnu.askapache.com/acl/acl-2.3.1.tar.xz [following]
--2023-04-11 21:11:11-- http://nongnu.askapache.com/acl/acl-2.3.1.tar.xz
Resolving nongnu.askapache.com (nongnu.askapache.com)... 50.87.145.190
Connecting to nongnu.askapache.com (nongnu.askapache.com)|50.87.145.190|:80... connected.
HTTP request sent, awaiting response... 200 OK
Length: 355676 (347K) [application/x-xz]
Saving to: '/home/nmcentire/Downloads/buildroot-2023.02/output/build/.acl-2.3.1.tar.xz.Er6daJ/output'

/home/nmcentire/Downloads/bui 100%[=====>] 347.34K --.-KB/s in 0.1s
```

After about 6 minutes of  
building...

```
libfakeroot.c:2665:27: error: expected '=', ',', ';', 'asm' or '__attribute__' before
'FSTATAT64_TIME64_ARG'
2665 | int WRAP_FSTATAT64_TIME64 FSTATAT64_TIME64_ARG(int ver,
|           ^~~~~~
libtool: link: ( cd ".libs" && rm -f "libmacosx.la" && ln -s "../libmacosx.la"
"libmacosx.la" )
make[3]: *** [Makefile:673: libfakeroot.lo] Error 1
make[3]: *** Waiting for unfinished jobs....
make[3]: Leaving directory '/home/nmcentire/Downloads/buildroot-2023.02/output/build/
host-fakeroot-1.30.1'
make[2]: *** [Makefile:691: all-recursive] Error 1
make[2]: Leaving directory '/home/nmcentire/Downloads/buildroot-2023.02/output/build/
host-fakeroot-1.30.1'
make[1]: *** [Makefile:460: all] Error 2
make[1]: Leaving directory '/home/nmcentire/Downloads/buildroot-2023.02/output/build/
host-fakeroot-1.30.1'
make: *** [package/pkg-generic.mk:293: /home/nmcentire/Downloads/buildroot-2023.02/
output/build/host-fakeroot-1.30.1/.stamp_built] Error 2

real 5m53.558s
user 9m56.442s
sys 3m17.145s
```

**The errors are typical, i.e. it  
has been rare that on my first  
build I have not had any errors**

# Look at the location of the error

```
wrapped.h:231:40: error: expected '=', ',', ';', 'asm' or '__attribute__' before  
'LSTAT64_TIME64_ARG'  
231 | extern int (*NEXT_LSTAT64_TIME64_NOARG)LSTAT64_TIME64_ARG(int ver, const char  
*file_name, struct stat64 *buf);  
|  
^~~~~~
```

```
$ find . | grep wrapped.h  
.output/build/host-fakeroot-1.30.1/wrapped.h
```

```
$ ls output/build/  
buildroot-config build-time.log host-acl-2.3.1 host-attr-2.5.1  
host-fakeroot-1.30.1 host-skeleton
```

```
#ifdef TIME64_HACK  
extern int (*NEXT_LSTAT64_TIME64_NOARG)LSTAT64_TIME64_ARG(int ver, const char *file_name, struct stat64 *buf);  
extern int (*NEXT_STAT64_TIME64_NOARG)STAT64_TIME64_ARG(int ver, const char *file_name, struct stat64 *buf);  
extern int (*NEXT_FSTAT64_TIME64_NOARG)FSTAT64_TIME64_ARG(int ver, int fd, struct stat64 *buf);  
extern int (*NEXT_FSTATAT64_TIME64_NOARG)FSTATAT64_TIME64_ARG(int ver, int dir_fd, const char *path, struct stat64  
int flags);  
#endif /* TIME64_HACK */
```

# Before you edit - Always check to see if this is an auto-generated file!

```
/* Automatically generated file. Do not edit. Edit wrapawk/wrapfunc.inp. */  
#ifndef WRAPPED_H  
#define WRAPPED_H
```

```
$ find output/build/host-fakeroot-1.30.1/ | grep wrapfunc.inp  
output/build/host-fakeroot-1.30.1/wrapfunc.inp
```

# wrapfunc.inp

```
/* This file lists the functions that are wrapped by libtricks, their */
/* arguments, and the way to call them. This is then used to generate */
/* the wrapper functions declarations in wrapped.h, the wrapper functions */
/* definitions wrapdef.h (actually, only assignments of the function */
/* variables), the structure of wrapped functions in wrapstruct.h, */
/* and the temporary definitions (that hold until one of them is executed) */
/* in wraptmpf.h */
*/
/*
*/
/*
*/
/*
* each line of this file lists 4 fields, separated by a ";".
* The first field is the name of the wrapped function, then it's return
* value. After that come the function arguments with types, and the fifth
* field contains the function arguments without types.
* A sixth field is a special needed when wrapping the openat syscall.
* Otherwise it's like the third (function arguments with types).
*/

```

# About TIME64\_HACK

**TIME64\_HACK is a macro used to handle 64-bit time values  
on systems that use 32-bit time**

```
$ cat time.c
#include <stdio.h>
#include <time.h>

int main() {
    time_t now = time(NULL);
    printf("sizeof(now): %u\n", sizeof(now));
    printf("now: %lu\n", now);
    return 0;
}
```

```
$ gcc -Wall -o time time.c
$ ./time
sizeof(now): 4
now: 1681263065
```

```
$ file time
time: ELF 32-bit LSB executable, ARM, EABI5 version 1 (SYSV), dynamically linked,
interpreter /lib/ld-linux-armhf.so.3,
BuildID[sha1]=906fd62d2460dc6b856a0deb6a327487502c958a, for GNU/Linux 3.2.0, not
stripped
```

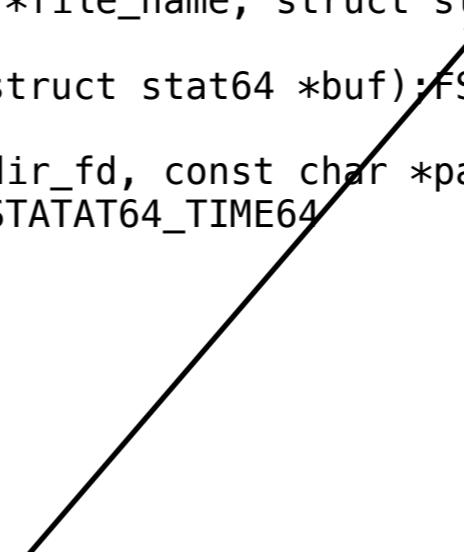
**Even though we are building  
on aarch64 RPi, the toolchain  
is 32-bit**

# Why Does RPi (aarch64) Build 32-Bit armv7l code?

- Backward Compatibility
  - The RPi has been around for many years and has lots of 32-bit armv7l code
- Smaller Code Size
  - A 64-bit code base typically larger than a 32-bit code base
- Ecosystem
  - Large body of developers familiar with RPi and the 32-bit code base

# Looking at the code again

```
#ifdef TIME64_HACK
WRAP_LSTAT64_TIME64;int;LSTAT64_TIME64_ARG(int ver, const char *file_name, struct stat64 *buf);LSTAT64_TIME64_ARG(ver,
file_name, buf);LSTAT64_TIME64
WRAP_STAT64_TIME64;int;STAT64_TIME64_ARG(int ver, const char *file_name, struct stat64 *buf);STAT64_TIME64_ARG(ver,
file_name, buf);STAT64_TIME64
WRAP_FSTAT64_TIME64;int;FSTAT64_TIME64_ARG(int ver, int fd, struct stat64 *buf);FSTAT64_TIME64_ARG(ver, fd,
buf);FSTAT64_TIME64
WRAP_FSTATAT64_TIME64;int;FSTATAT64_TIME64_ARG(int ver, int dir_fd, const char *path, struct stat64 *buf, int
flags);FSTATAT64_TIME64_ARG(ver, dir_fd, path, buf, flags);FSTATAT64_TIME64
#endif /* TIME64_HACK */
```



**This is the issue! The RPi we are building on  
Does not have struct stat64 but rather struct stat!**

**NOTE: See man page next slide**

# Looking at the man page

STAT(2)

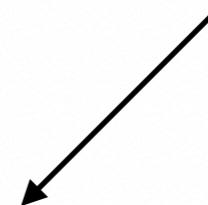
Linux Programmer's Manual

## NAME

stat, fstat, lstat, fstatat – get file status

## SYNOPSIS

```
#include <sys/types.h>
#include <sys/stat.h>
#include <unistd.h>
```



```
int stat(const char *pathname, struct stat *statbuf);
int fstat(int fd, struct stat *statbuf);
int lstat(const char *pathname, struct stat *statbuf);
```

```
#include <fcntl.h>           /* Definition of AT_* constants */
#include <sys/stat.h>
```

```
int fstatat(int dirfd, const char *pathname, struct stat *statbuf,
            int flags);
```

# So if we want to build for RPi as it exists today, we need to choose ARM 32-bit in Buildroot!

```
$ arch  
aarch64
```

```
$ file /bin/bash  
/bin/bash: ELF 32-bit LSB executable, ARM, EABI5 version 1 (SYSV), dynamically linked,  
interpreter /lib/ld-linux-armhf.so.3,  
BuildID[sha1]=f12e6d40fb262ad0037b6ec43162208b76d4da71, for GNU/Linux 3.2.0, stripped
```

# Updated time.c

```
#include <stdio.h>
#include <time.h>

#define __USE_LARGEFILE64

#include <sys/types.h>
#include <sys/stat.h>
#include <unistd.h>

//int stat(const char *pathname, struct stat *statbuf);

int main() {
    time_t now = time(NULL);
    printf("sizeof(now): %u\n", sizeof(now));
    printf("now: %lu\n", now);

    struct stat64 statbuf;
    int result = stat64("time.c", &statbuf);
    printf("stat64 result: %d\n", result);
    if (result < 0) {
        perror("stat64");
    }
    return 0;
}
```

**IMPORTANT:** The previous demo was “real life” - you often make choices in Buildroot that you then go back and change

**But let's assume that the  
build process did work,  
here is what you do next**

# Copy Root Filesystem to SDCard

```
sudo dd if=output/images/sdcard.img of=/dev/sdX bs=4M conv=fsync status=progress
```

**Important! Replace sdX with your SDCard!**

**Back to solving the  
problem...**

# Three Options to Solve Our Build Issue

- The options are in order of “ease of use”
  - Option 1: Redo make default config with aarch64 version of RPi config
  - Option 2: Build on “armv7l” RPi
  - Option 3: Solve the build problem on this machine

# Option 2: Rebuilding on “armv7l” Raspberry Pi

```
$ arch
armv7l
$ 
$ uname -a
Linux raspberrypi 5.4.79-v7l+ #1373 SMP Mon Nov 23 13:27:40 GMT 2020 armv7l GNU/Linux
$ 
$ file /bin/bash
/bin/bash: ELF 32-bit LSB executable, ARM, EABI5 version 1 (SYSV), dynamically linked,
interpreter /lib/ld-linux-armhf.so.3, for GNU/Linux 3.2.0,
BuildID[sha1]=3e5e2847bbc51da2ab313bc53d4bdcff0faf2462, stripped
$ 
$ cat /etc/os-release
PRETTY_NAME="Raspbian GNU/Linux 10 (buster)"
NAME="Raspbian GNU/Linux"
VERSION_ID="10"
VERSION="10 (buster)"
VERSION_CODENAME=buster
ID=raspbian
ID_LIKE=debian
HOME_URL="http://www.raspbian.org/"
SUPPORT_URL="http://www.raspbian.org/RaspbianForums"
BUG_REPORT_URL="http://www.raspbian.org/RaspbianBugs"
```

# Option 1: make

```
$ ls configs/ras*
configs/raspberrypi0_defconfig      configs/raspberrypi3_defconfig      configs/
raspberrypicm4io_64_defconfig       configs/raspberrypi3_qt5we_defconfig   configs/
configs/raspberrypi0w_defconfig     configs/raspberrypi4_64_defconfig      configs/
raspberrypicm4io_defconfig         configs/raspberrypi4_defconfig        configs/
configs/raspberrypi2_defconfig      .
.
.
$ make clean
.
.
.

$ make raspberrypi4_64_defconfig
.
.
.

$ make
.
.
.
```

# Copy Root Filesystem to SDCard

```
sudo dd if=output/images/sdcard.img of=/dev/sdX bs=4M conv=fsync status=progress
```

**Important! Replace sdX with your SDCard!**

# **Questions/Answers**