Linux Kernel Training: Lecture 1

Building the Software for BeagleBone Black

Sam Protsenko
<joe.skb7@gmail.com>

June 1, 2020

Agenda

1. Hardware Overview
2. Software Overview
3. Perspective on Building

Organization

Linux Kernel ProCamp Details

- Mon/Fri, 3pm - 5pm
- Schedule: link
- Target: BeagleBone Black and QEMU
- Host: Personal laptop (Ubuntu 18.04) or Training Centre PC
- Training Centre PC:
  - Press F9 on boot (show boot menu)
  - Select second drive (TS64GSSD370S, 64 GB)
  - Login: Lin-Ker
  - Password: 123

Mentors

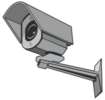
- Oleksandr Redchuk <oleksandr.redchuk@globallogic.com>
- Sam Protsenko <joe.skb7@gmail.com>
- Andrii Lukin <andrii.lukin@globallogic.com>
- Vitaliy Vasylskyy <vitaliy.vasylskyy@globallogic.com>
- Illia Smyrnov <illia.smyrnov@globallogic.com>
- Ruslan Bilovol <ruslan.bilovol@globallogic.com>

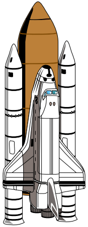
Hardware Overview

Embedded Systems

Embedded Systems:

- Mobile
- Automotive
- Networking
- Smart TVs, game consoles, set-top boxes
- IoT
- Medical
- Aerospace
- Industry





Embedded Programming

Differences from regular system:

- Cross-compiling
- Flashing
- Serial console
- Testing concerns
- Working with hardware
- Non discoverable buses on board (device tree, platform drivers)

Kernel: Big Picture

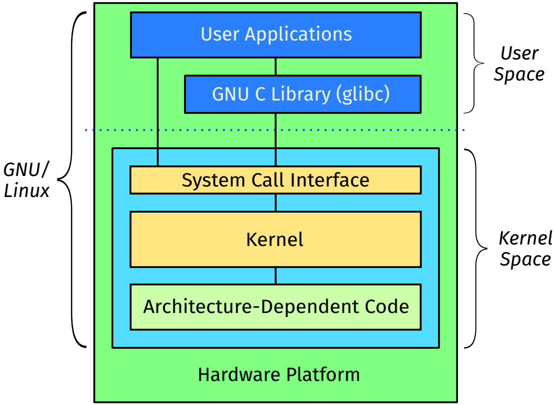
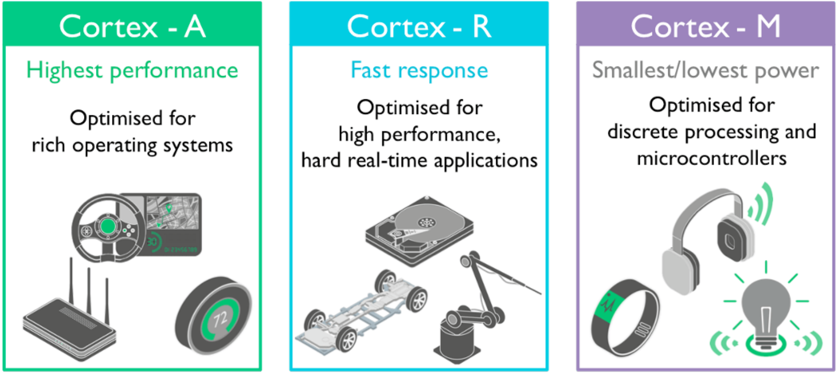


Figure 1: The fundamental architecture of the GNU/Linux operating system

ARM Cortex A/R/M Families



Cortex - A

Highest performance

Optimised for rich operating systems

Cortex - R

Fast response

Optimised for high performance, hard real-time applications

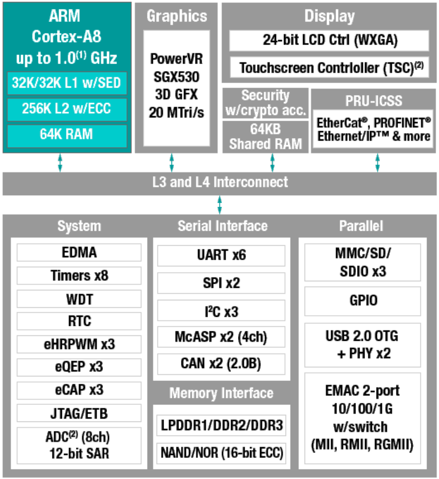
Cortex - M

Smallest/lowest power

Optimised for discrete processing and microcontrollers

Figure 2: ARM Cortex Processor Families

AM335x SoC



ARM Cortex-A8 up to 1.0[1] GHz

32K/32K L1 w/SED

256K L2 w/ECC

64K RAM

Graphics

PowerVR SGX530 3D GFX 20 MTri/s

Display

24-bit LCD Ctrl (WXGA)

Touchscreen Controller (TSC)[2]

Security w/crypto acc.

64KB Shared RAM

PRU-ICSS

EtherCat®, PROFINET® Ethernet/IP™ & more

L3 and L4 Interconnect

System

EDMA

Timers x8

WDT

RTC

eHRPWM x3

eQEP x3

eCAP x3

JTAG/ETB

ADC[2] (8ch) 12-bit SAR

Serial Interface

UART x6

SPI x2

I^{2}C x3

McASP x2 (4ch)

CAN x2 (2.0B)

Memory Interface

LPDDR1/DDR2/DDR3

NAND/NOR (16-bit ECC)

Parallel

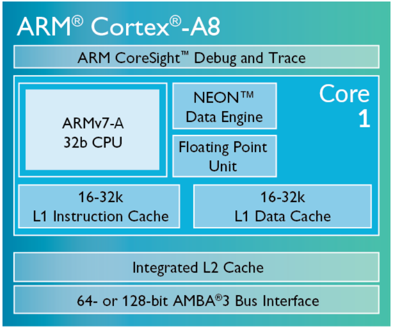
MMC/SD/ SDIO x3

GPIO

USB 2.0 OTG + PHY x2

EMAC 2-port 10/100/1G w/switch (MII, RMII, RGMII)

Figure 3: AM335x Functional Diagram



ARM® Cortex®-A8

ARM CoreSight™ Debug and Trace

ARMv7-A 32b CPU

NEON™ Data Engine

Floating Point Unit

Core 1

16-32k L1 Instruction Cache

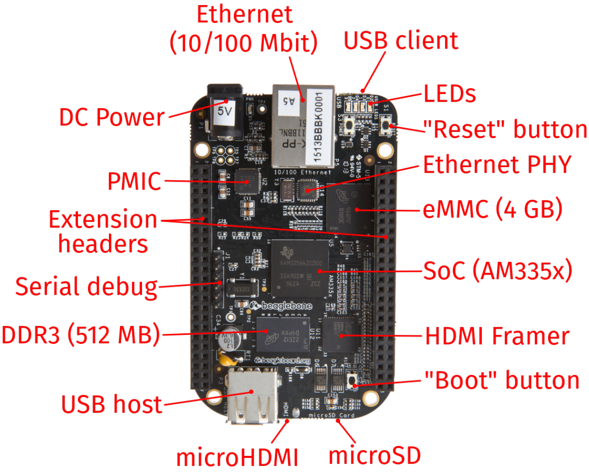
16-32k L1 Data Cache

Integrated L2 Cache

64- or 128-bit AMBA®3 Bus Interface

Figure 4: Cortex-A8 Processor Architecture

BeagleBone Black



BeagleBone Black: Pros and Cons

Pros:

- Open Hardware
  - Public TRM
  - Schematic
  - PCB files
- Supported in upstream
  - Kernel
  - U-Boot
- Conventional ARM architecture
- Very popular
- Low cost ($55)

Cons:

- Old 32-bit architecture
- Single core processor
- Android is not supported officially
- No WiFi

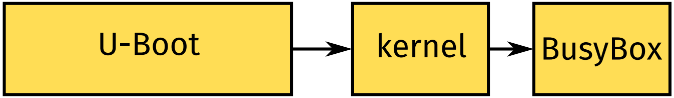
Software Overview

Software Components

- U-Boot
- Linux kernel
- BusyBox

Software Components

- U-Boot
- Linux kernel
- BusyBox

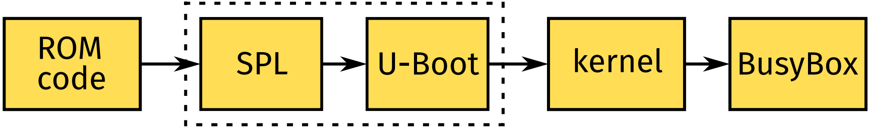

U-Boot

kernel

BusyBox

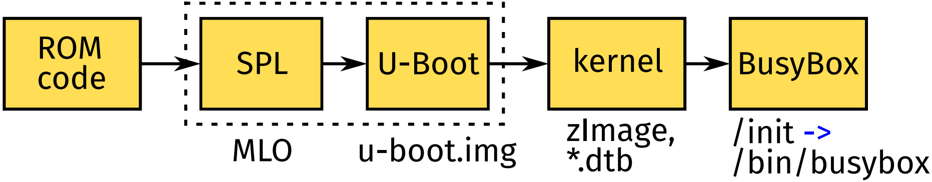
Software Components

- U-Boot
- Linux kernel
- BusyBox



Software Components

- U-Boot
- Linux kernel
- BusyBox

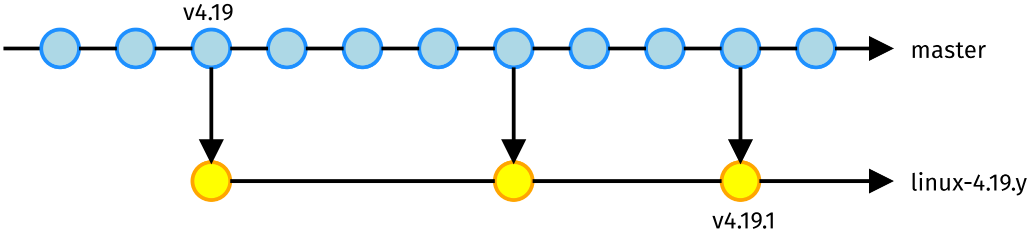


Building Steps

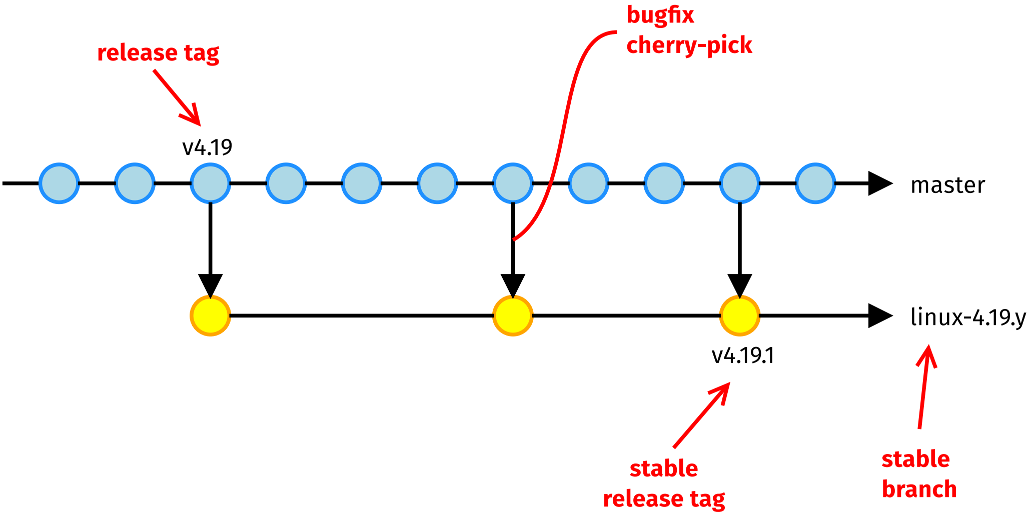
1. Obtain the software
2. Checkout to desired branch or tag
3. Consult with `README` and `INSTALL`
4. Install all build dependencies
5. Configure shell environment for cross-compiling
6. **Configure the software for build with options you desire**
7. **Build the software**
8. **Install/flash the built software**

Perspective on Building

Kernel Branching Strategy



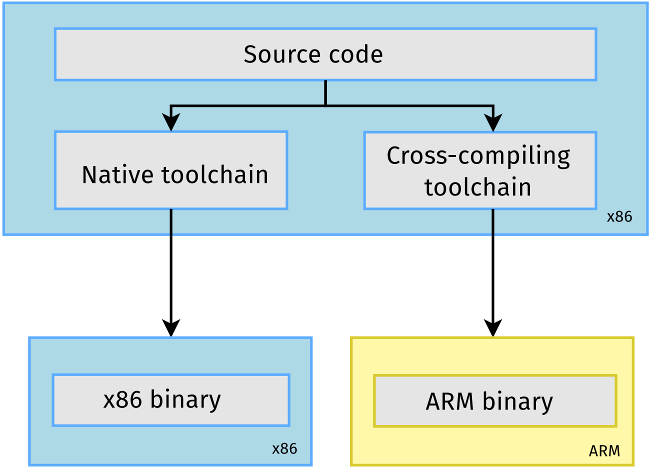
Kernel Branching Strategy



Stable Trees

- Git tags: for releases (e.g. `v4.19`)
- Git branches: for stable releases (e.g. `linux-4.19.y`)
- Some stable branches are LTS (Long Term Support)
- When possible, let’s use stable branches (for reliability)
- When stable branches are not available, let’s use release tags

Toolchain (page 1)



Source code

Native toolchain

Cross-compiling toolchain

x86

x86 binary

x86

ARM binary

ARM

Compilation machine

Execution machine

Toolchain (page 2)

- Set of tools for cross-compiling:
    1. `gcc`
    2. binutils: `ld`, `as`, `objdump`, `objcopy`, `readelf`, etc.
    3. `glibc` and other system libraries (optional)
    4. Linux kernel headers (optional)
    5. `gdb` (optional)

Toolchain (page 2)

- Set of tools for cross-compiling:
  1. `gcc`
  2. binutils: `ld`, `as`, `objdump`, `objcopy`, `readelf`, etc.
  3. `glibc` and other system libraries (optional)
  4. Linux kernel headers (optional)
  5. `gdb` (optional)
- Toolchain types:
  - Bare-metal targeted (`arm-eabi`): for U-Boot and kernel
  - Linux targeted (`arm-linux-gnueabihf`): for BusyBox
- In our case: host = x86_64, target = ARMv7-A
- We use only GNU (GCC-based) toolchains

Toolchain (page 3)

Toolchain tuple examples:

- arm-foo-none-eabi, bare-metal toolchain targeting the ARM architecture, from vendor *foo*
- arm-unknown-linux-gnueabihf, Linux toolchain targeting the ARM architecture, using the EABIhf ABI and the glibc C library, from an *unknown* vendor
- armeb-linux-uclibcgnueabi, Linux toolchain targeting the ARM big-endian architecture, using the EABI ABI and the uClibc C library
- mips-img-linux-gnu, Linux toolchain targeting the MIPS architecture, using the glibc C library, provided by Imagination Technologies

Toolchain (page 4)

- Regular compilation on host system (using *native toolchain*):

```
$ gcc main.c
```

Toolchain (page 4)

- Regular compilation on host system (using *native toolchain*):

```
$ gcc main.c
```

- Cross-compilation for ARM target (part before `gcc` is called *prefix*):

```
$ /toolchain/path/bin/arm-eabi-gcc main.c
```

Toolchain (page 4)

- Regular compilation on host system (using *native toolchain*):

```
$ gcc main.c
```

- Cross-compilation for ARM target (part before `gcc` is called *prefix*):

```
$ /toolchain/path/bin/arm-eabi-gcc main.c
```

- More universal way:

```
$ PATH=/toolchain/path/bin:$PATH
$ CROSS_COMPILE=arm-eabi-
$ ${CROSS_COMPILE}gcc main.c
```

Specifying Architecture

- Kernel supports many CPU architectures:

```
linux/
├── arch/                      -- platform-dependent code
│   ├── arm/
│   ├── arm64/
│   ├── x86/
│   └── ...
└── drivers/                   -- platform-independent code
```

- We need to choose which architecture to build for:

```
$ export ARCH=arm
```

Shell Environment

- Shell environment configuration for building U-Boot/kernel/BusyBox:

```
$ export ARCH=arm
$ export PATH=/toolchain/path/bin:$PATH
$ export CROSS_COMPILE=arm-eabi-
```

- Makefile utilizes those env vars

Take Five

Kbuild: User’s Perspective

Building: General Steps

- All projects (U-Boot, Linux kernel and BusyBox) use Kbuild
- Build steps: configuration, build, installation
- Configuration (generate `.config` file):

  ```
  $ make defconfig
  ```

- Build:

  ```
  $ make
  ```

- Installation:

  ```
  $ make install
  ```

Building: Custom Configuration

- Sometimes existing `defconfig` is not enough
- How can we customize our configuration?
  - Using `make menuconfig`
  - Using `merge_config.sh` script
  - Using old `.config` file

Building: Custom Configuration

- Sometimes existing `defconfig` is not enough
- How can we customize our configuration?
  - Using `make menuconfig`
  - Using `merge_config.sh` script
  - Using old `.config` file

- Example: kernel configuration using `merge_config.sh`:

```
$ ./scripts/kconfig/merge_config.sh   \
  arch/arm/configs/multi_v7_defconfig \
  fragments/bbb.cfg
```

Building: .config Example

Excerpt from `.config` file:

```
CONFIG_USE_OF=y
CONFIG_DEFAULT_HOSTNAME="(none)"
CONFIG_CMDLINE=""
# CONFIG_PREEMPT is not set
CONFIG_I2C_GPIO=m
CONFIG_LOG_BUF_SHIFT=17
# CONFIG_SLAB is not set
CONFIG_USB=y
CONFIG_SND_USB_AUDIO=m
```

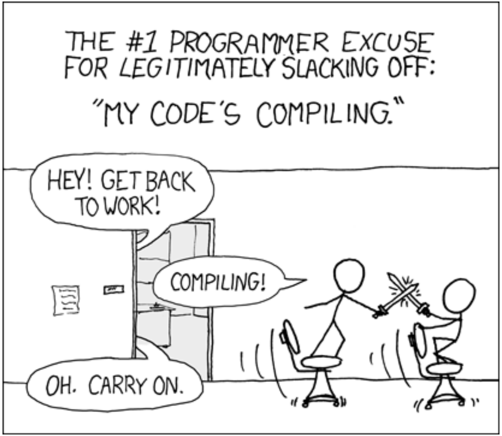
Kernel Modules

- Every driver is a module
- Kernel modules can be:
    - Loadable: “`=m`”
    - Built-in: “`=y`”
- Kernel loadabe module (`.ko` file) is some code that can be loaded into kernel space (i.e. added to running kernel as a plugin)

Kernel Modules

- Every driver is a module
- Kernel modules can be:
  - Loadable: “`=m`”
  - Built-in: “`=y`”
- Kernel loadabe module (`.ko` file) is some code that can be loaded into kernel space (i.e. added to running kernel as a plugin)
- How it works:
  - `multi_v7_defconfig` is common for all ARMv7 systems (so the single `zImage` can be used)
  - Device Tree file covers SoC and board differences
  - Needed modules (for particular board) can be loaded in run-time
- It’s not always convenient to load a lot of modules

How to Speed-Up the Build? (page 1)



How to Speed-Up the Build? (page 2)

- Kbuild tracks all dependencies very well!
- *Clean build* (try to avoid it):

```
$ make
// Do some changes to source code
$ make distclean
$ make
```

- Use *incremental build* instead:

```
$ make
// Do some changes to source code
$ make
```

How to Speed-Up the Build? (page 3)

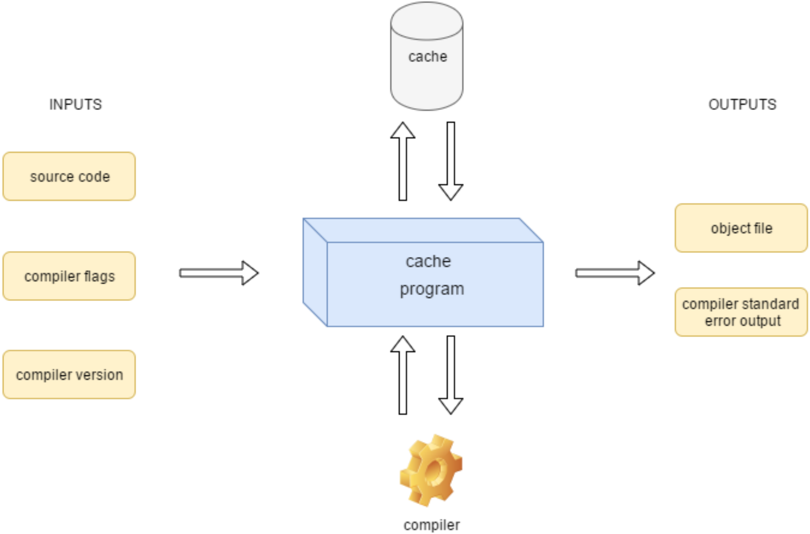
- Distribute the compilation between CPU cores using multi-threading build:

  ```
  $ make -j4
  ```

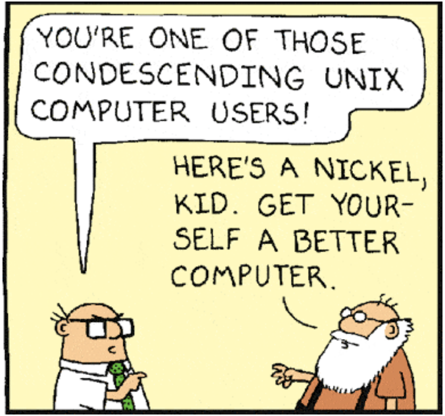
- Use `ccache` tool:
  - Caches `.o` files on the first build
  - On next build, if some `.o` files are unchanged, cached versions will be used
  - `ccache` creates a hash by `.c` file content and by build command
  - …So if you change the toolchain, cache won’t be used
  - Speed up for clean build is usually 5 times
  - Can be used as a wrapper:

    ```
    $ ccache gcc main.c
    ```

How to Speed-Up the Build? (page 4)



How to Speed-Up the Build? (page 5)


YOU'RE ONE OF THOSE CONDESCENDING UNIX COMPUTER USERS!
HERE'S A NICKEL, KID. GET YOURSELF A BETTER COMPUTER.

RootFS

RootFS

What is RootFS?

- Filesystem that is needed to make userspace work
- Mounted to “/”
- Crucial component is `init` tool
- Besides of that: libc, kernel modules, tools, config files…

RootFS

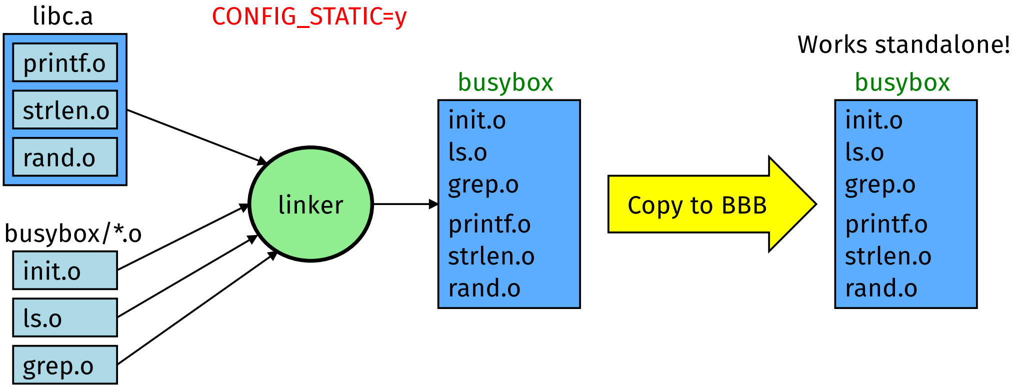
What is RootFS?

- Filesystem that is needed to make userspace work
- Mounted to "/"
- Crucial component is `init` tool
- Besides of that: libc, kernel modules, tools, config files...

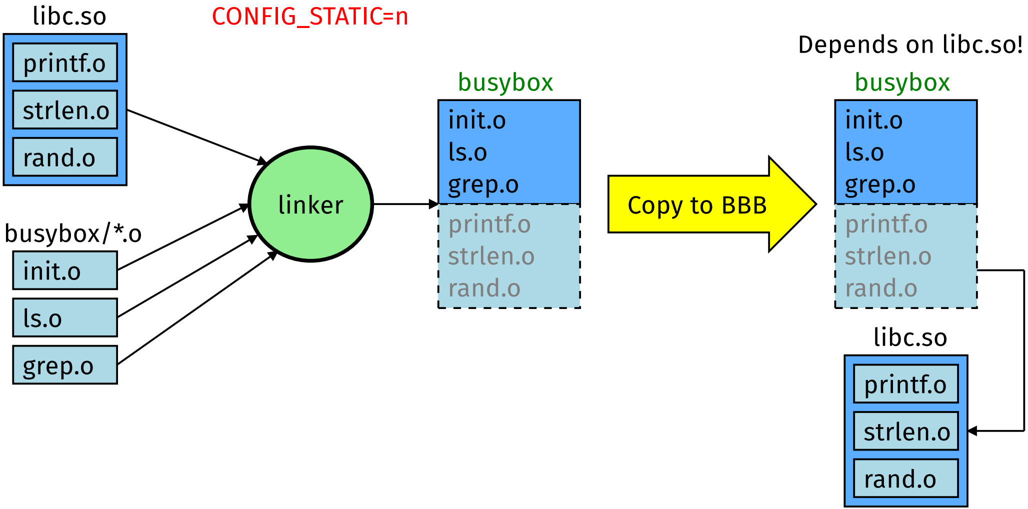
Known rootfs's for BBB:

- Debian
- Yocto/OpenEmbedded
- BuildRoot
- BusyBox

BusyBox Linking: Static



BusyBox Linking: Dynamic



BusyBox Linking: Static vs Dynamic

- Static linking: libc (.a) is compiled in your binary
  - Only “`busybox`” binary is needed in rootfs
  - Easier to build and minimal
  - Some networking functions won’t work (like `nslookup`, see libnss)
- Dynamic linking: libc used as a shared library (.so)
  - Only one copy of libc is used (for all possible apps)
  - Dynamic libraries must be copied in rootfs `/lib` (libc and its dependencies)

BusyBox Applets

- BusyBox is a multi-call binary
- Apps in BusyBox rootfs are just symbolic links:

```
/bin
├── busybox
├── grep -> busybox
└── ls   -> busybox
```

- So you can call **ls** tool like this:

```
# busybox ls -l
```

- …which is identical to this form:

```
# ls -l
```

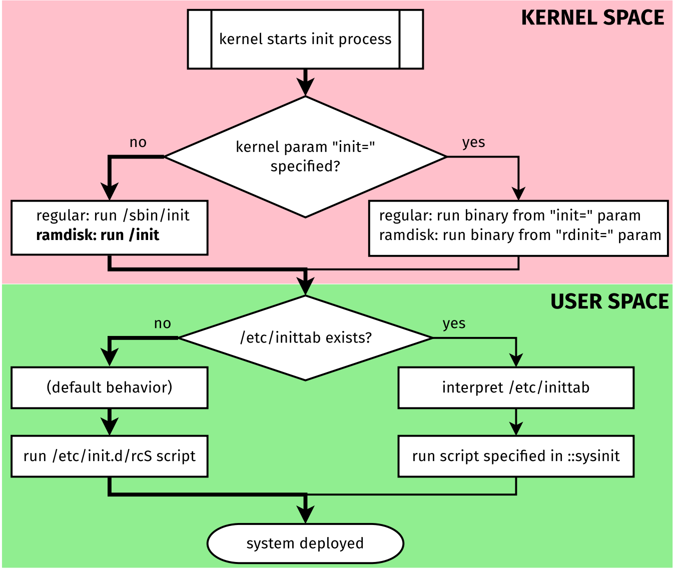
Init process

- First process started during boot (kernel starts it)
- PID = 1, uid = 0 (root)
- It never exits (daemon)
- Init is a parent for all processes
- Automatically adopts all orphaned processes
- Init is started by the kernel using a hard-coded filename (e.g. `/init`)
- A kernel panic will occur if the kernel is unable to start it
- Most popular init implementations:
  - sysvinit
  - openrc
  - upstart
  - systemd

BusyBox init

- `busybox` tool implements init as an applet
- BusyBox's init implementation resembles SysVinit, but more simple
- Doesn't support runlevels (as opposed to SysVinit)
- Starts `/etc/init.d/rcS` script
- (Re)spawns children according to `/etc/inittab` (e.g. **getty**)
- Handles signals (e.g. **reboot** and **poweroff**)

BusyBox init (cont’d)


KERNEL SPACE
kernel starts init process
kernel param "init=" specified?
no
yes
regular: run /sbin/init
ramdisk: run /init
regular: run binary from "init=" param
ramdisk: run binary from "rdinit=" param
USER SPACE
/etc/inittab exists?
no
yes
(default behavior)
run /etc/init.d/rcS script
interpret /etc/inittab
run script specified in ::sysinit
system deployed

BusyBox Device Manager

- No `udev` in BusyBox
- *‘mdev is a mini-udev implementation for dynamically creating device nodes in the /dev directory’*
- Requires SysFS support in kernel; it must be mounted to `/sys`
- Can be also used for hot-plugging (e.g. load needed kernel module when some USB device was inserted)
- `mdev -s`: scan `/sys` and populate `/dev`
- `mdev` without params: kernel hotplug helper
- For more details see: `doc/mdev.txt`

BusyBox init: Script Example

- `rc` = "run commands", `S` = single-user runlevel
- Example of `/etc/init.d/rcS` file:

```
#!/bin/sh

mount -t sysfs none /sys
mount -t proc none /proc
mount -t debugfs none /sys/kernel/debug

echo /sbin/mdev > /proc/sys/kernel/hotplug
mdev -s
```

BusyBox rootfs (static, minimal)

```
/
├── bin
│   └── busybox
├── boot
│   ├── am335x-boneblack.dtb
│   └── zImage
├── dev
├── etc
│   └── init.d
│       └── rcS
│
├── init -> bin/busybox
├── linuxrc -> bin/busybox
├── proc
├── root
├── sbin
├── sys
├── tmp
└── usr
    ├── bin
    └── sbin
```

Demo: menuconfig

Assignments

Assignment

- Using BBB instructions guide (will be sent out):
  - Go through 1st chapter (“Preparing the Tools”)
  - Go through 2nd chapter (“Obtaining and Building the Software”)
  - Run built software on QEMU, using section 3.1 “QEMU Boot”
- Download TRM and datasheet for AM335x
- Download schematic for BBB
- Proof: send me screenshot of `uname -a` output in your QEMU

Advanced assignment (optional)

- Using TRM, figure out:
  - Which module (TRM section?) is used for setting clocks (gating, DPLL)
  - Which module (TRM section?) is used for pin multiplexing
  - Where GPIO output registers are documented
  - Where UART RX/TX registers are documented
- Using schematic, figure out:
  - Which pins (pads) the user LEDs are connected to
  - How to mux those pins for GPIO (use datasheet and TRM)?
  - Which registers to use for pin muxing and then blinking some LED?

References

Recommended Reading

- Karim Yaghmour, Jon Masters and others.
  Building Embedded Linux Systems.
- Brian Ward.
  How Linux Works, 2nd Edition.
- Andrew N. Sloss and others.
  ARM System Developer's Guide.
- Robert Love.
  Linux Kernel Development, 3rd Edition.

Thank you!