Linux Kernel Training: Lecture 1

Building the Software for BeagleBone Black

Sam Protsenko

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GlobalLogic

Agenda

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

Organization

Linux Kernel ProCamp Details

- Tue/Fri, 9 am - 11 pm
- Schedule: https://docs.google.com/spreadsheets/d/16dcTo2irL5ZUQTrBJF7Kjia8v-J--IezS5GyD0MPB74/edit#gid=129771073
- 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

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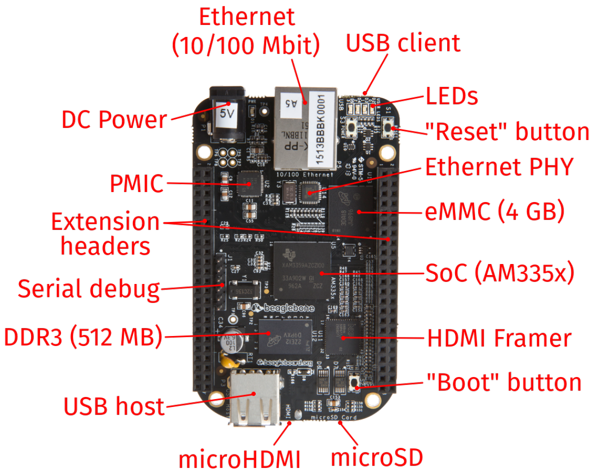
Hardware Overview

Embedded Programming

- What is an embedded system?
- Differences from regular system:
  - Cross-compiling
  - Flashing
  - Serial console
  - Testing concerns
  - Working with hardware
  - Non discoverable buses on board (device tree, platform drivers)


Ethernet
(10/100 Mbit)
USB client
LEDs
"Reset" button
Ethernet PHY
eMMC (4 GB)
SoC (AM335x)
HDMI Framer
"Boot" button
DC Power
PMIC
Extension
headers
Serial debug
DDR3 (512 MB)
USB host
microHDMI
microSD

AM335x SoC

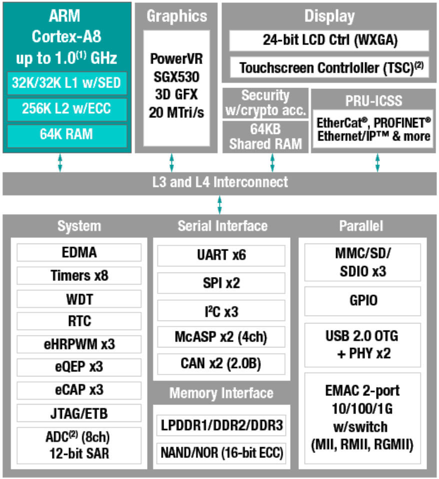


Figure 1: AM335x Functional Diagram

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

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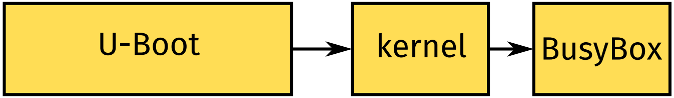

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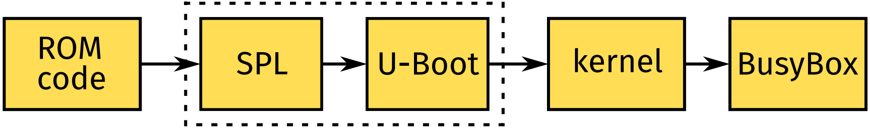

Software Components

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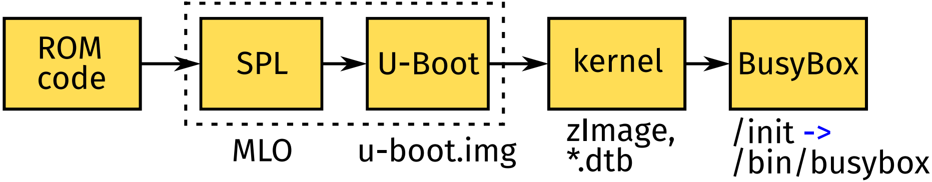
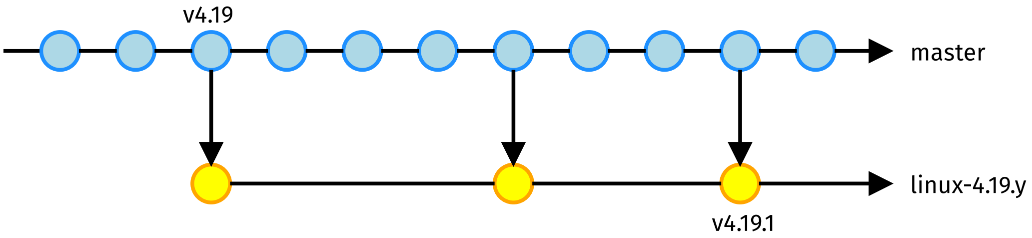


Building Steps

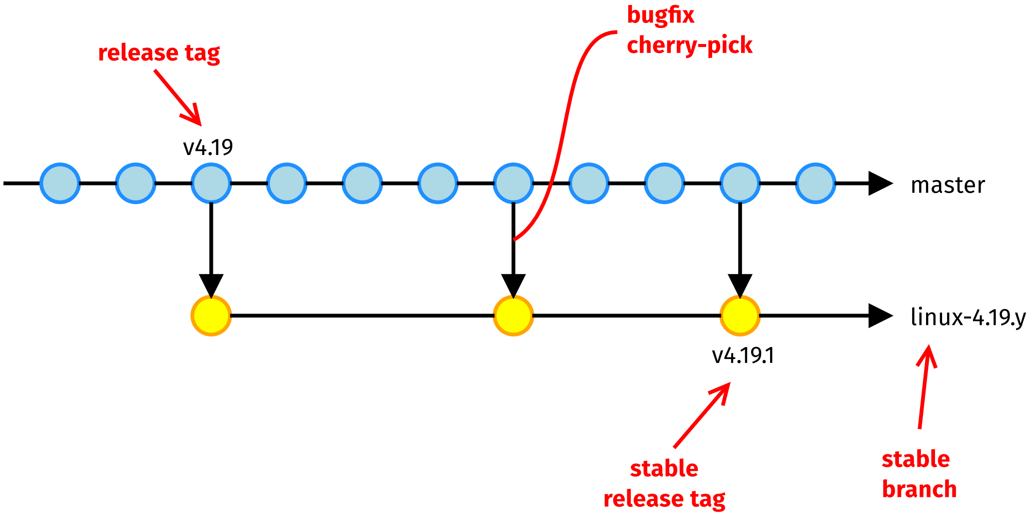
1. Obtain the software
2. Checkout to desired branch or tag
3. Consult with `README` and `INSTALL`
4. Install all build dependencies
5. Configure shell environment for cross-compiling
6. **Configure the software for build with options you desire**
7. **Build the software**
8. **Install/flash the built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

Perspective on Building

Kernel Branching Strategy



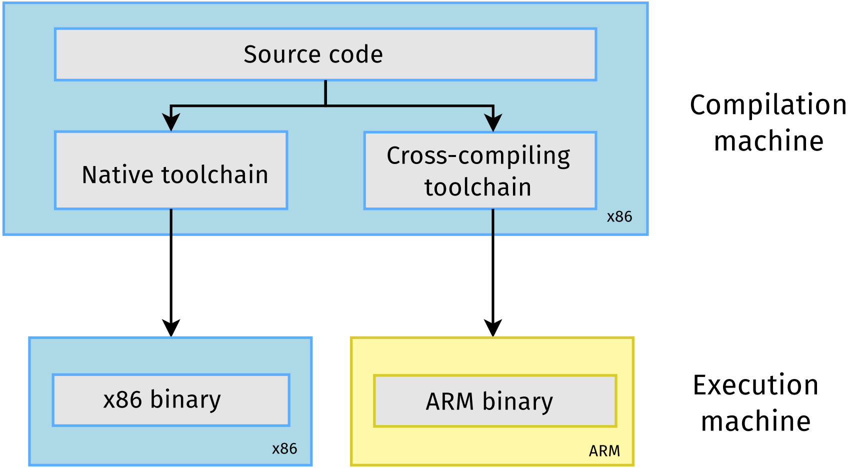
Kernel Branching Strategy



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)



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)

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  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 = ARM

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

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

  ```
  $ gcc main.c
  ```

Toolchain (page 4)

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

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

Toolchain (page 4)

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$ gcc main.c
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- 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 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

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

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

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)

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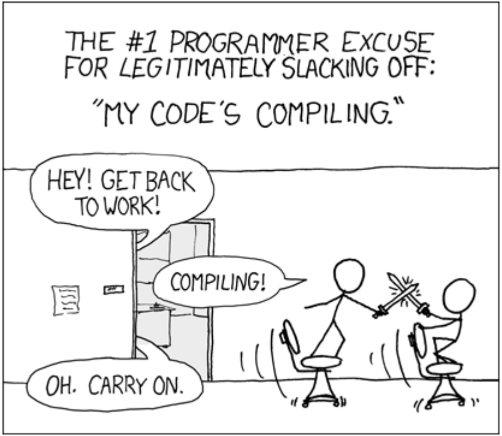
- How it works:
  - `multi_v7_defconfig` is common for all ARMv7 systems (so the single `zImage` can be used)
  - Device Tree file covers SoC and board differences
  - Needed modules (for particular board) can be loaded in run-time
- It’s not always convenient to load a lot of modules

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



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

- Kbuild tracks all dependencies very well!
- Try to avoid the *clean build*:

```
$ 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)

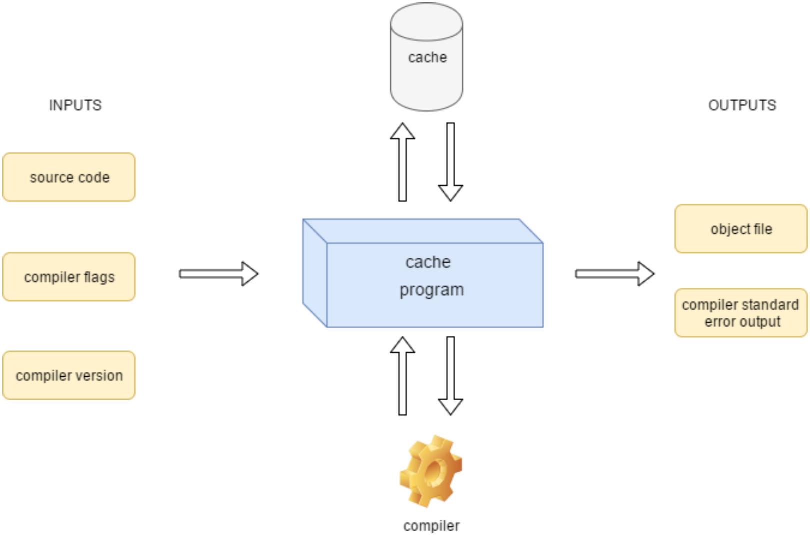
- Distribute the compilation between CPU cores using multi-threading build:

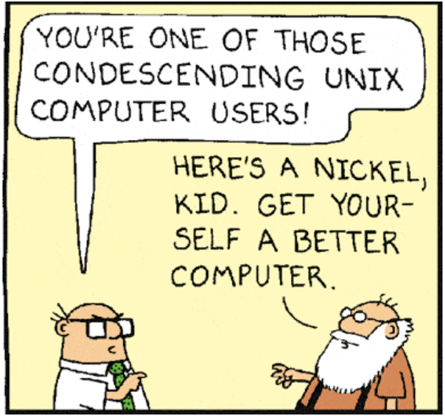
  ```
  $ make -j4
  ```

- 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)




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...

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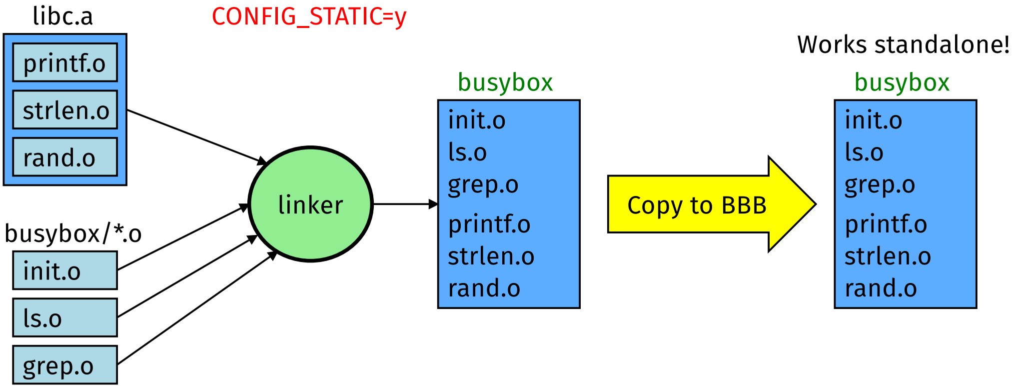
- Mounted to "/"
- Crucial component is `init` tool
- Besides of that: libc, kernel modules, tools, config files...

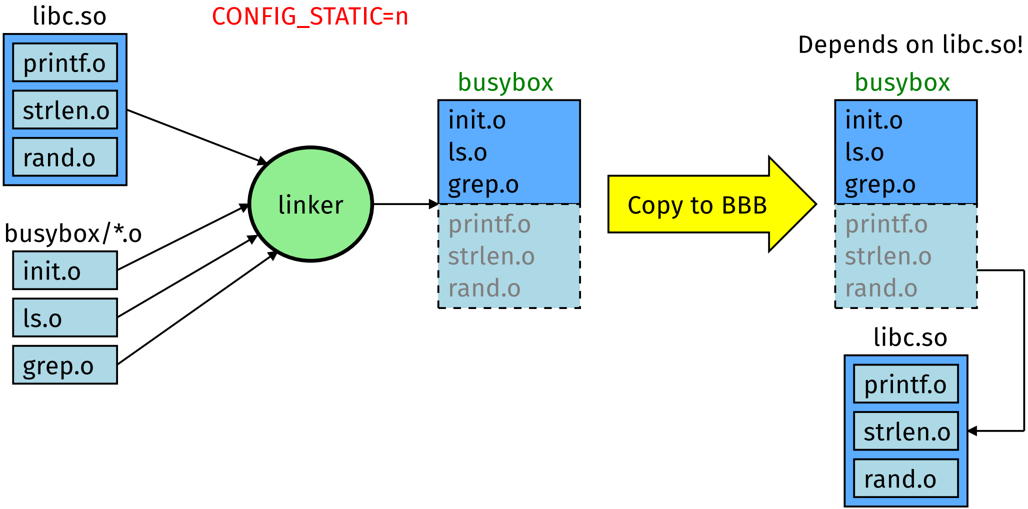
Known rootfs's for BBB:

- 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
```

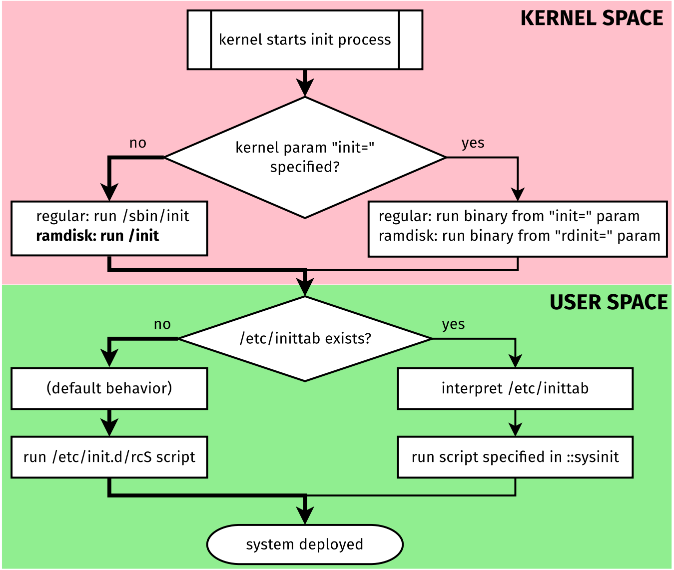
Init process

- 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)



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!