A pragmatic guide to boot-time optimization

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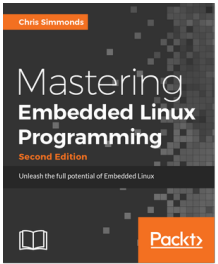
About Chris Simmonds



- Consultant and trainer
- Author of *Mastering Embedded Linux Programming*
- Working with embedded Linux since 1999
- Android since 2009
- Speaker at many conferences and workshops

"Looking after the Inner Penguin" blog at `http://2net.co.uk/`

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Overview

- Shorter boot time is always desirable
- It is always possible to reduce boot time
  - This is software: there is always more you can do
- So, the real issues are:
  - How much effort do you want to put in?
  - How big a mess will you leave when you are done?

Where it all goes wrong

- The more effort you put in to reducing boot time, the higher the future maintenance burden

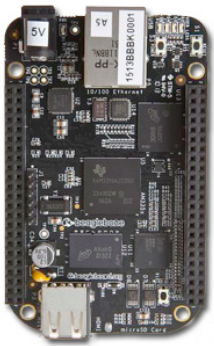
Before

After

Getting it right

- This is a **pragmatic** guide to reducing boot time
- Using the three guiding principles
  - Measure
  - Evaluate
  - Modify

Example system



- BeagleBone Black (single core Cortex A-8, 1GHz)
- Built using Yocto Project Pyro
- Qt app
- systemd init

Measuring boot time

Commonly used tools:

- **Grabserial**: adds timstamps to all serial console output
- **Bootchart**: graphs running time of user-space processes
- **Bootgraph**: graphs running time of kernel functions

You can also change outputs (GPIOs) at certain points in the code and use an **oscilloscope** to monitor them. This is the only way you can measure the time from *power-on*

Grabserial

- Get it from https://elinux.org/Grabserial (written Tim Bird)
- You will need to install python-serial as well

```
sudo apt install python-serial
```

Then:

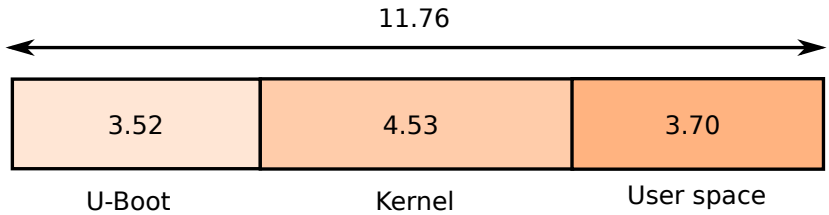
```
grabserial -d /dev/ttyUSB0 -t -m "U-Boot SPL" -e 30 -o boot.log
```

```
-d = serial device
-t = print timestamps
-m = match string before starting to log
-e = number of seconds to capture for
    (useful when redirecting to a file: makes sure file is closed cleanly
     and all output is recorded)
-o [filename] = output to file
```

Grabserial output

```
[0.000000 0.000000]
[0.000398 0.000398] U-Boot SPL 2017.01 (Oct 17 2017 - 11:10:21)
[0.095607 0.095607] Trying to boot from MMC1MMC partition switch failed
[0.188577 0.092970] *** Warning - MMC partition switch failed, using default
[0.190962 0.002385]
[0.203591 0.012629] reading u-boot.img
[0.204300 0.000709] reading u-boot.img
[0.259620 0.055320]
[0.259727 0.000107]
[0.259781 0.000054] U-Boot 2017.01 (Oct 17 2017 - 11:10:21 +0100)
[0.261334 0.001553]
[0.261384 0.000050] CPU  : AM335X-GP rev 2.0
[...]
11.756176 0.080002] Started qtdemo.
```


Baseline measurement



From power-on to starting qtdemo app, in seconds

Reducing user-space boot time

- User-space is often simplest to change, so we start here
- Typical modifications
  - Easy: running order in init
  - Quite easy: build optimizations, e.g. compile flags
  - Difficult: library optimizations to reduce load time

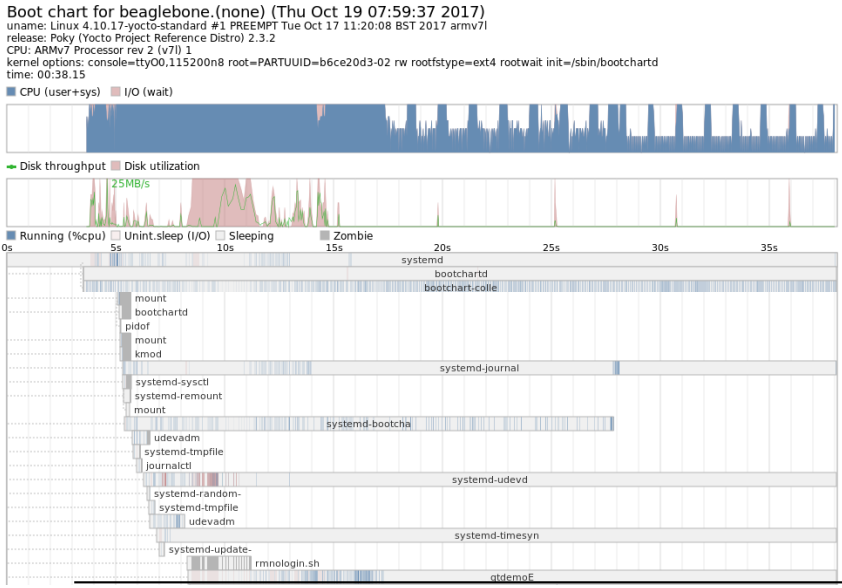
Measuring init boot time using Bootchart

- Two parts
  - **bootchard** captures process stats, starting with init
    - part of Busybox, and also a package in Yocto Project/OpenEmbedded
  - **bootchart** analyses offline, and creates a graph
- http://www.bootchart.org
- Launch it in place of init; it will fork and then exec `/sbin/init`

```
init=/sbin/bootchard
```

- Logs are put in `/var/log/bootchart.tgz`
- Example on next slide: you are not expected to be able to read it!

Bootchart



Optimizing user space

- Careful analysis of bootchart shows that qtdemo is not started until 3.5 seconds after init begins
- Since this is the most important thing to run, we need to move it up the batting order
- Some options:
  - If using systemV init, use a lower number for the "S" script, e.g. "S01"
  - If using systemd, change the dependencies of the unit (example at end of slides)
  - Or, run qtdemo ahead of init (*)

(*) be aware that the rootfs will most likely be ro, that other fs will not be mounted, and that the network will not be started

Running the app as init

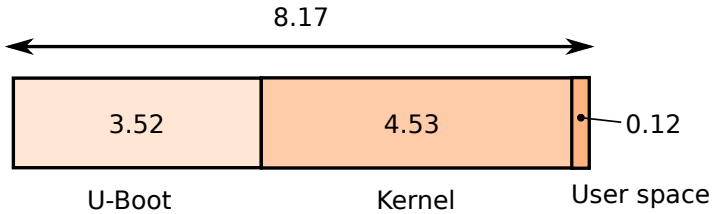
- This Script runs qtdemo in the background and then *exec*s the normal init so that it is still PID 1:

```
#!/bin/sh
echo "Starting qtdemo"

/usr/bin/qtdemoE -qws &
exec /sbin/init
```

- Change kernel command line:

```
init=/usr/bin/run-qtdemo.sh
```


First pass



Launching qtdemo ahead of init saves **3.5 s**

Reducing kernel boot time

- Typical modifications
  - Easy: reduce console messages by adding `quiet` to cmdline
  - Moderate: slim down kernel by removing drivers, filesystems, subsysems
  - Moderate: slim down device tree by removing hardware interfaces that are not used
  - Tricky: set about optimizing badly behaved drivers

Measuring kernel boot time: Bootgraph

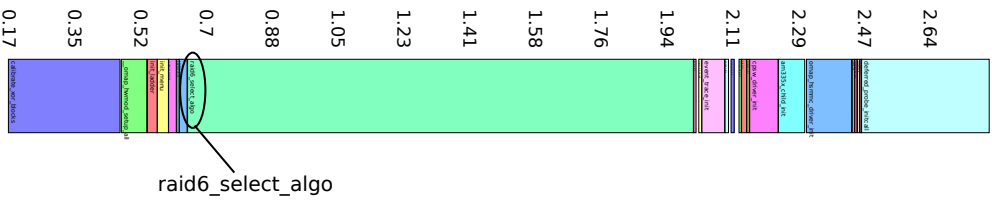
- **Bootgraph** analyses kernel functions during boot
- Configure kernel with `CONFIG_PRINTK_TIME` and `CONFIG_KALLSYMS`
- Add `initcall_debug` to kernel cmdline
- Then boot, and get the kernel log

```
dmesg > boot.log
```

- Back on the host, create the graph using

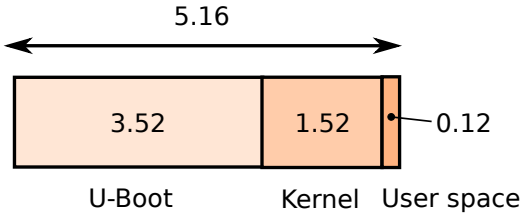
```
linux/scripts/bootgraph.pl boot.log > boot.svg
```

Bootgraph



- Note: almost 2 seconds in `raid6_select_algo`
- RAID6 is selected by `CONFIG_BTRFS_FS`, which we are not using. So, rip it out!

Second pass



- Remove BTRFS: saves 1860 ms
- Add "quiet" to cmdline: saves 700 ms
- Cut out unused drivers (e.g. WiFi), reducing zImage from 5.6 MiB to 3.2 MiB: saves 450 ms
- Total saving: **3.01 s**

Reducing bootloader boot time

- Typical modifications
  - Easy: remove the boot delay
  - Easy(ish): simplify boot scripts
  - Medium: compile out functions you don’t need
  - Harder: use falcon mode

Remove boot delay

- U-Boot usually configured with a delay, during which you can press space bar to stop booting

```
Press SPACE to abort autoboot in 2 seconds
```

- Set the display to zero

```
setenv bootdelay 0
```

- You can still hit space bar to halt boot *if you are quick enough*

OK, this is a bit trivial, but it still needs to be done

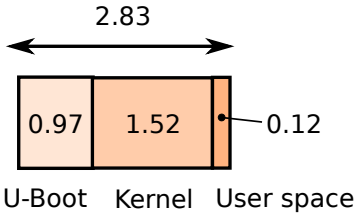
Simplify boot scripts

- Bootscript for BeagleBone is c. 100 lines
  - Testing all possible sources of boot images takes time
  - Loading image from filesystems takes time
- Reduce the script to the cases you support
- Loading from raw MMC sectors is fastest

Falcon mode

- Most SoCs have three stages of bootloader
  - 1: on-chip ROMcode, which loads SPL into static RAM
  - 2: SPL, which has to be small enough to fit in SRAM. Main job is to set up DRAM and load TPL into it
  - 3: TPL: the main bootloader, which loads the kernel (4th stage)
- U-Boot Falcon mode jams everything into the SPL, skipping the TPL
- No user interaction: uses pre-built environment block
- More info in extra slides

Third pass



- Remove boot delay: saves 2000 ms
- Simplify boot script: saves: 230 ms
- Total saving: **2.32 s**

Keep it up!

- Add boot time calculation as a metric in your CI
- Make boot time as a criterion when adding new features

Conclusion

- Boot time reduction need not require massive changes to the platform code
- Bake the changes you do make into the build system
- Look to the future

- Questions?

Systemd unit

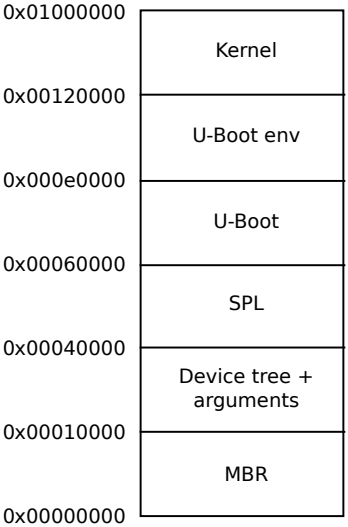
- A systemd unit that will be run early
  - Dependent on basic target; has no default dependencies

```
[Unit]
Description=qtdemo
DefaultDependencies=no

[Service]
ExecStart=/usr/bin/qtdemoE -qws

[Install]
WantedBy=basic.target
```


U-Boot Falcon mode

- See `doc/README.falcon`
- Steps
  - Configure U-Boot
  - Copy to SD card
  - Boot into U-Boot and prepare environment
  - Save environment in MMC

MMC layout



- Typically, place images directory in MMC storage
- This is the layout of the first 16MiB (128K sectors)

Configure U-Boot

- Tell U-Boot where to put things
- Add to `include/configs/am335x_evm.h`:

```
#define CONFIG_SYS_MMC_ENV_DEV          0
#define CONFIG_ENV_OFFSET               0xe0000
```

- Build U-Boot in the normal way

```
$ export CROSS_COMPILE=arm-buildroot-linux-gnueabihf-
$ make am335x_boneblack_defconfig
$ make
```

Copy images to micro SD card

- Using the layout from the diagram shown earlier
- Note: requires a `uImage`, not `zImage`

```
$ sudo dd if=am335x-boneblack.dtb of=/dev/mmcblk0 bs=1 seek=65536
$ sudo dd if=MLO of=/dev/mmcblk0 bs=1 seek=262144
$ sudo dd if=u-boot.img of=/dev/mmcblk0 bs=1 seek=393216
$ sudo dd if=uImage of=/dev/mmcblk0 bs=1 seek=1179648
```

Prepare Falcon boot 1/2

```
=> mmc read 82000000 900 2000
=> mmc read 83000000 80 180
=> spl export fdt 82000000 - 83000000
## Booting kernel from Legacy Image at 82000000 ...
   Image Name:   Linux-4.10.17-yocto-standard
   Created:      2017-10-21  13:12:02 UTC
   Image Type:   ARM Linux Kernel Image (uncompressed)
   Data Size:    3365704 Bytes = 3.2 MiB
   Load Address: 80008000
   Entry Point:  80008000
   Verifying Checksum ... OK
## Flattened Device Tree blob at 83000000
   Booting using the fdt blob at 0x83000000
   Loading Kernel Image ... OK
   Loading Device Tree to 8fff4000, end 8ffffc86 ... OK
   Loading Device Tree to 8ffe5000, end 8fff3c86 ... OK
Argument image is now in RAM: 0x8ffe5000
```

Prepare Falcon boot 2/2

- Write the modified FDT and parameter block back to MMC:

```
=> write 83000000 80 180
```

- Enable falcon mode:

```
=> setenv boot_os 1
```

- Now re boot and it should jump straight from SPL to kernel:

```
U-Boot SPL 2017.05-rc3-dirty (Oct 21 2017 - 11:27:01)
Trying to boot from MMC1
Booting Linux on physical CPU 0x0
Linux version 4.10.17-yocto-standard (oe-user@oe-host)
```