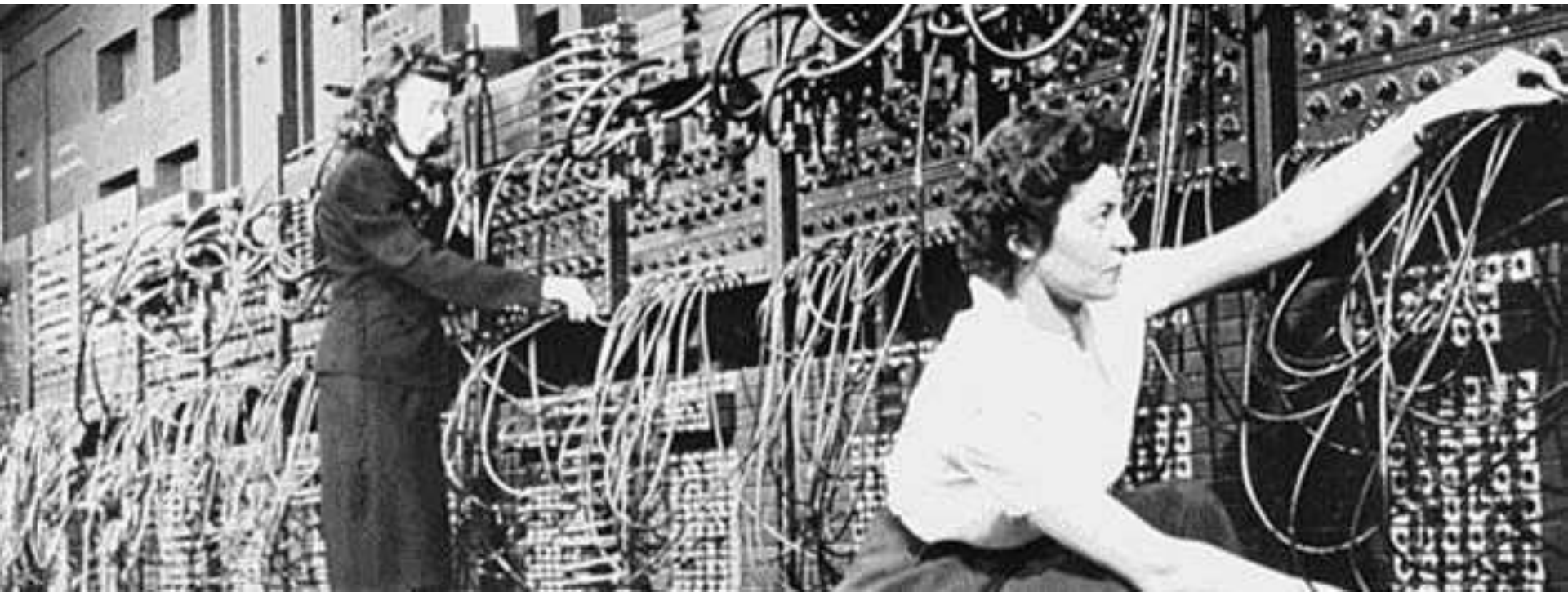
12 Lessons learnt in boot time reduction

Andrew Murray

Embedded Bits

1 Understand why and how



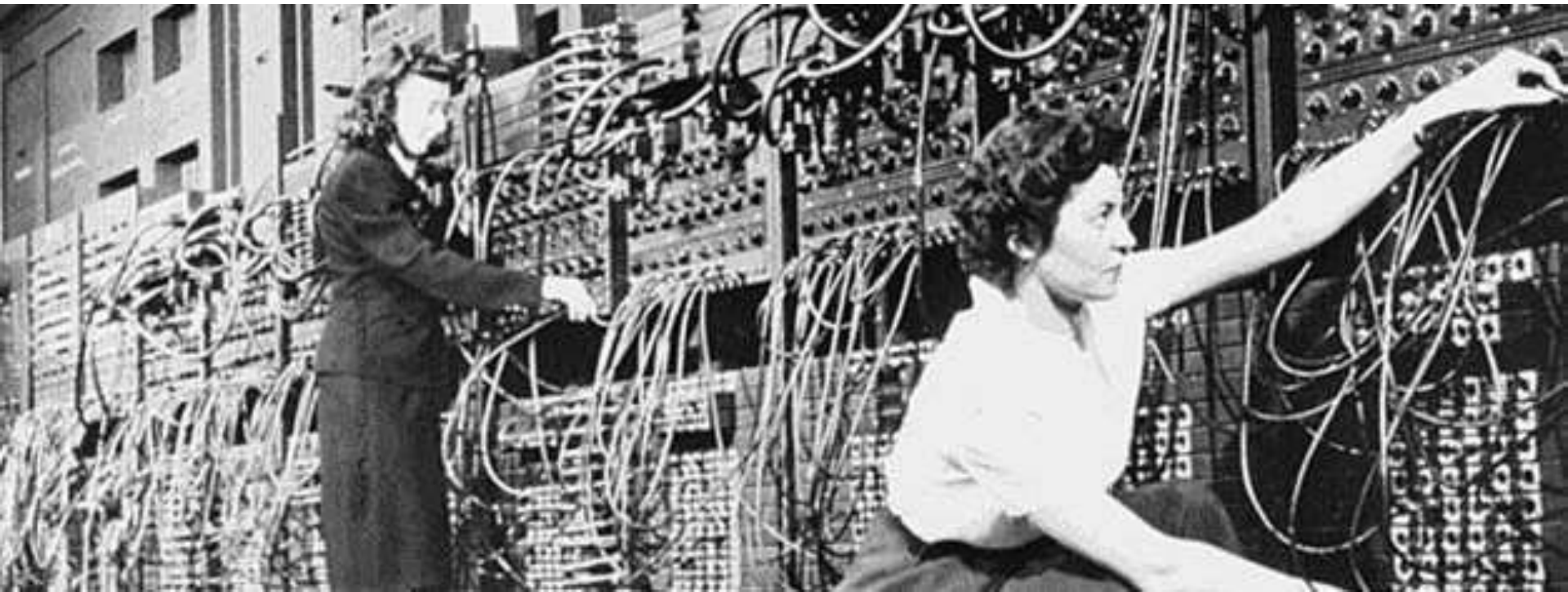
Why minimal boot times?

- There are lots of good reasons, why are you here?
- Common reasons are:
  - To improve user experience in mobile devices
  - To respond quickly after power loss

How

- Starting point:
  - We have a product that achieves required functionality after an unacceptable delay
  - The required functionality is achieved through a number of software tasks that we've defined and so can change
  - We can't change the hardware or the required functionality
  - Software is generalised
- We reduce the cold boot time by:
  - Ensuring that we perform nothing more than the essential tasks required to achieve the required functionality whilst making efficient use of the hardware resources.
  - Thus:
    - Remove tasks that aren't required
    - Optimise tasks that are required
    - Use all the hardware all the time
    - Challenge how we provide the functionality

2 Know your hardware



Know your hardware

- Understand the performance limits of the hardware
  - Determine what you can expect to achieve and strive to achieve it
  - How quickly can you expect to execute instructions? read data from storage? send I2C/SPI commands?
  - Software will rarely already be optimised for your hardware
- Focus on I/O
  - I/O is always a bottleneck

How much data?

- Use /proc/diskstats to measure userspace I/O at the end of boot

```
cat /proc/diskstats | grep mmcblk0p6
179 6 mmcblk0p6 1366 871 122870 42690 0 0 0 0 4 4590 42650
```

122870 sectors read x 512 = 60MB

- Data needed for boot is read from your hardware and takes time
- If you can read at 10MB/S, then your boot will certainly be greater than 6 seconds.
  - Ignoring compression for now
- Thus we optimise by **maximising I/O rate** and **minimising data amount**

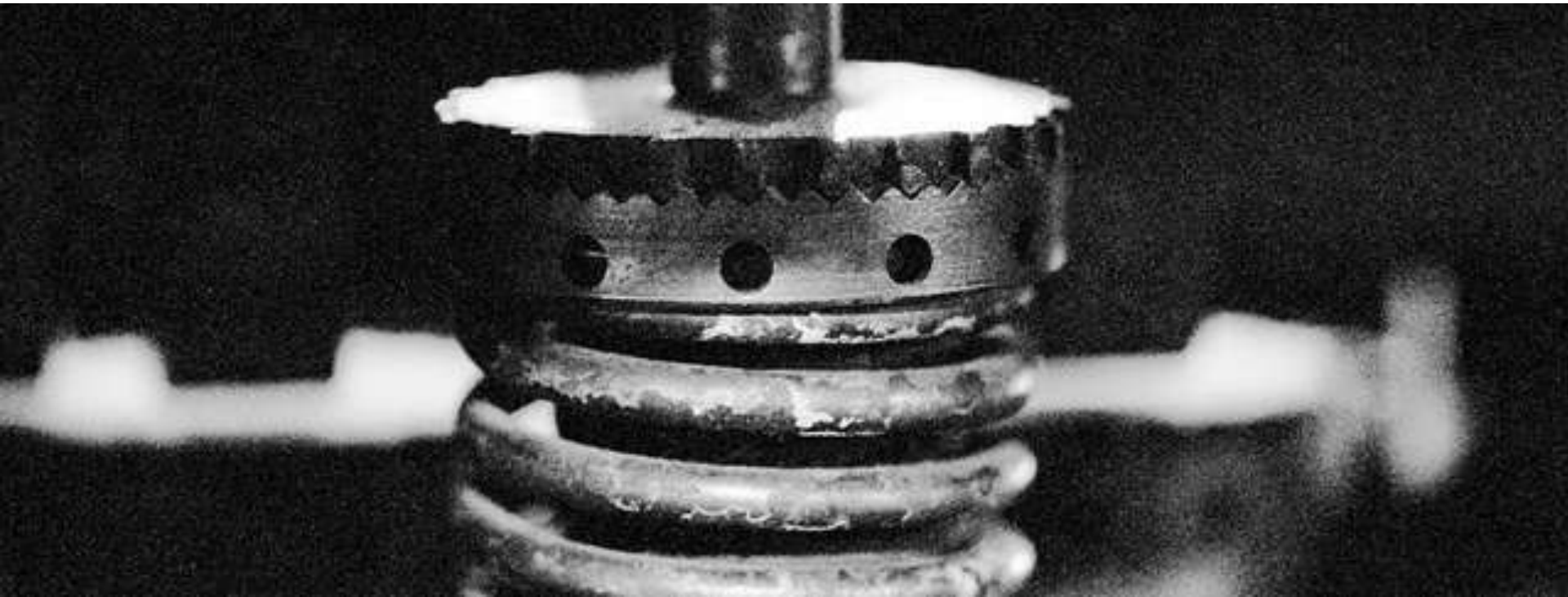
Optimise I/O

- Read the specs for your hardware
- Calculate any necessary timings
- Ensure the driver is optimal
  - Consider supporting additional hardware features
- You will need to do this for both kernel and boot loader
- Optimising I/O comes first – later optimisations will depend on the performance of I/O.

Know your hardware

- Ensure you can use:
  - DMA
  - Hardware accelerators
  - Additional CPU cores
  - Caches
- Utilise maximum bus/clock rates
  - CPU
  - I2C/SPI

3 Use compression wisely



Use compression wisely

- I/O is often a bottle neck – it's slow to read data from storage
- Compression is a trade off between CPU and I/O use
- Determine throughput of reading data directly and reading data with compression to determine optimal solution
- Performance of I/O and algorithms may vary between kernel and bootloader
- Compression is littered everywhere:
  - Compressed kernels (self decompressed, boot loader decompressed)
  - Filesystems
  - Applications
  - Compressibility?

4 The future is quicker

The future is quicker

- Your product development may not be using the latest versions of open source components
  - This wouldn't be uncommon
- The platform vendors version of software is often used
  - It probably 'just works'
  - It probably demonstrates the key hardware features you will use
  - It's probably old

Vendor provided BSPs

Platform	Linux version	U-Boot version
Mainline	v3.17 (Oct ‘14)	v2014.07 (Jul ‘14)
Freescale i.MX6	v3.0.35 (Jul ‘11) v3.10.17 (Jun ‘13)	v2009.08 (Aug ‘09) v2013.04 (Apr ‘13)
Variscite OMAP4	v3.4.x (May ‘12)	v2012.07 (Jul ‘12)
Gumstix Oveo DM37xx/OMAP35xx	v3.5.x (Jul ‘12)	v2013.10 (Oct ‘13)
Gumstix DuoVero OMAP4430	v3.6.x (Sep ‘12)	
Gumstix Verdex Pro PXA270	v2.6.37 (Jan ‘11)	
DVSDK 4 02 DM3730 OMAPL-138	v2.6.37 (Jan ‘11)	v2010.12 (Dec ’10)

As of Oct ‘14

Take from the future

- Software often gets optimized over time
  - Upstream versions may be quicker with fewer bugs
  - Upstream versions may be slower with more bugs
- Look to the future and backport before reinventing the wheel
- Example…

```
commit 34fe8281d7323784544e94d2f7218f52b8a2899d
Author: Matthias Weisser <weisserm@arcor.de>
Date:   Sun May 22 23:06:50 2011 +0000

    arm: lib: memcpy: Do not copy to same address

    In some cases (e.g. bootm with a elf payload which is already at the right
    position) there is a in place copy of data to the same address. Catching this
    saves some ms while booting.

    Signed-off-by: Matthias Weisser <weisserm@arcor.de>

commit d8834a1323af72f6145bc81adadd75185ef6065f
Author: Matthias Weisser <weisserm@arcor.de>
Date:   Thu Mar 10 21:36:32 2011 +0000

    arm: Use optimized memcpy and memset from linux

    Using optimized versions of memset and memcpy from linux brings a quite
    noticeable speed (x2 or better) improvement for these two functions.

    Here are some numbers for test done with jadecpu

                              | HEAD(1)| HEAD(1)| HEAD(2)| HEAD(2)|
                              |        | +patch |        | +patch |
    --------------------------+--------+--------+--------+--------+
    Reset to prompt           |  438ms |  330ms |  228ms |  120ms |
                              |        |        |        |        |
    TFTP a 3MB img            | 4782ms | 3428ms | 3245ms | 2820ms |
                              |        |        |        |        |
    FATLOAD USB a 3MB img*    | 8515ms | 8510ms | ------ | ------ |
                              |        |        |        |        |
    BOOTM LZO img in RAM      | 3473ms | 3168ms |  592ms |  592ms |
     where CRC is             |  615ms |  615ms |   54ms |   54ms |
```

The usual suspects

- String routines get called a lot
  - mem[chr|cpy|move|set|zero]
- OMAP4 Linux boot statistics:
  - 133,356 times transferring 34MB
- Over time these functions have improved
- Other functions in the kernel
  - memcpy_fromio
    - See arch/sh/kernel/io.c
    - See arch/powerpc/kernel/io.c

5 Ignore FS benchmarks

Ignore filesystem benchmarks

- Benchmarks are valuable but shouldn't be used exclusively to determine choice
- It's not easy to find a relevant benchmark
- Software evolves over time
  - Benchmark may not be relevant to your filesystem version – optimisations may be missing/present
- Lots of filesystem choice
  - Filesystem type
  - Block size
  - Use of compression
- There isn't a best – each option balances CPU vs I/O in some way
  - So it depends on how fast/slow your CPU and I/O is (or how busy your system is)

Ignore filesystem benchmarks

- Boot time consists of:
  - Init time
  - Mount time
  - Read/write time
- Thus depends on your use case
- Of course your usecase, I/O and possibly CPU performance may improve over the course of optimisation effecting your filesystem choice
- Thus measure yourself – you can automate it

6 The right approach

The right approach

- Measure, measure, measure
- Instrument your software
  - Printk timestamps, host timestamps, initcall_debug, printk's, tracing
  - But watch out for unintended side effects
- Identify long delays and tackle them first
- Change one thing at a time and measure the full effect
- Make notes, keep log and be prepared to start over
- Order is important
- Goal:
  - 1. Ensure I/O and CPU is 100% utilised during boot
  - 2. Ensure the I/O and CPU utilisation is efficient and necessary
- Consider full effect of a change

Don’t focus on the kernel

- If you perform any measurement you’ll quickly realise that the kernel is rarely the worse offender
- Typically the bootloader and userspace take up the majority of boot time

8 Low hanging fruit

Low Hanging Fruit

- There are trivial changes that generally always improve the boot time of the majority of devices
  - These are applied to the majority of boot time reduction projects
- No boot time presentation would be complete without these

U-Boot delay

- Eliminate boot delay with CONFIG_BOOTDELAY
- Allow development with CONFIG_ZERO_BOOTDELAY_CHECK
- Use CONFIG_AUTOBOOT_KEYED to prevent accidents

```
Boot Delay:   CONFIG_BOOTDELAY - in seconds
              Delay before automatically booting the default image;
              set to -1 to disable autoboot.
              set to -2 to autoboot with no delay and not check for abort
              (even when CONFIG_ZERO_BOOTDELAY_CHECK is defined).

              See doc/README.autoboot for these options that
              work with CONFIG_BOOTDELAY. None are required.
              CONFIG_BOOT_RETRY_TIME
              CONFIG_BOOT_RETRY_MIN
              CONFIG_AUTOBOOT_KEYED
              CONFIG_AUTOBOOT_PROMPT
              CONFIG_AUTOBOOT_DELAY_STR
              CONFIG_AUTOBOOT_STOP_STR
              CONFIG_AUTOBOOT_DELAY_STR2
              CONFIG_AUTOBOOT_STOP_STR2
              CONFIG_ZERO_BOOTDELAY_CHECK
              CONFIG_RESET_TO_RETRY
```

Precalculated LPJ

- Use the ‘lpj’ argument in the kernel command line to prevent calibrating a delay loop on each boot

Calibrating delay loop... 1590.23 BogoMIPS (lpj=6213632)

Disable console output

- Add ‘quiet’ to the kernel command line to supress kernel output during boot
- Supress U-Boot output with:
  - CONFIG_SILENT_CONSOLE
  - CONFIG_SILENT_CONSOLE_UPDATE_ON_RELOC
  - CONFIG_SILENT_U_BOOT_ONLY

U-Boot scripts

```
#define CONFIG_BOOTCOMMAND \
        "if mmc rescan ${mmcdev}; then " \
                "if run loadbootenv; then " \
                        "echo Loaded environment from ${bootenv};" \
                        "run importbootenv;" \
                        "if test -n $uenvcmd; then " \
                                "echo Running uenvcmd ...;" \
                                "run uenvcmd;" \
                        "fi;" \
                "elif run loadbootscript; then " \
                        "echo Loaded script from ${bootscr};" \
                        "run bootscript; " \
                "else " \
                        "if run loaduimage; then " \
                                "run mmcboot; " \
                        "fi; " \
                "fi; " \
        "fi; " \
        "if usb start; then " \
                "set autoload no; "\
```

More fruit

- Reduce U-Boot environment size
- Ensure U-Boot reads the right amount of data and puts it in the right place
  - ‘nboot’ can help
- Image verification
- Optimise memset/memcpy
- Reduce size of binaries
  - Kernel (KALLSYMS, IKCONFIG), strip binaries, mklibs, etc
- Device node creation
- Init.d style boot
- Sleeps

9 Make it stick

Make it stick

- Boot time is likely to increase through subsequent development
  - And so boot time reduction can be a repeating exercise
- Reasons boot time doesn't stick:
  - Development of new features doesn’t consider boot time
  - Boot time enhancements can be inflexible, inconvenient and limiting
- Inconvenient optimisations have a habit of disappearing
  - No one ever removes a ‘no side effect’ optimisation such as improved NAND timings
- Maintaining a minimal boot time is difficult

Bad solutions

- Delay: Ethernet initialisation in U-Boot
- Bad solution: Ethernet not used in U-Boot so remove support
- Impact: No-one can TFTP – annoying for development

- Better solution:
  - Defer initialisation
  - Add a custom U-Boot command that re-enables Ethernet
  - Developers can add this command to their ‘bootcmd’
  - If U-Boot size is an issue – it can be conditionally removed for a release build
  - Run time options such as this that default to quick boot are great
  - Compile/Config time options may result in git commit fights
  - Don’t replace - complement

Bad solutions

- Delay: Udev
- Bad solution: Remove it and use hard coded device nodes
- Impact: It works great until the moment the kernel changes then everyone gets odd errors, eventually udev shows up again

- Better solution:
  - Use devtmpfs
  - Update drivers to use hard coded device number (if you must)

Make it stick

- Make boot time enhancements less annoying
  - It’s easy to use a sledge hammer
  - Find good solutions that preserve or replace ‘unneeded’ functionality
    - Sometimes unavoidable for tiny boot times
  - Aim for run time switches to enable them
    - Maybe use a hardware switch
- Automate boot time measurement
  - Use automation to build, deploy, boot and measure your boot time
  - Tie this in with git hooks
  - Find out at the earliest moment when your boot time increases
    - Helps share ownership of boot time reduction

11 Look in the right places

Look in the right places

- You'll get to a point where…
  - You've read the internet and implemented its suggestions
  - You've implemented the low hanging fruit
  - You've think everything left is needed and it does what it needs to do
  - Where next?

Look in the right places

- You've probably been looking at big delays
  - Don't forget the small delays that happen all the time
  - Harder to find – you need to consider both time and frequency
    - Profiling tools helps here
  - This is probably where the hard work begins
- Google 'instrumentation/tracing' instead of 'reduce boot time'
- Don't forget to group related delays to truly see impact
  - You need to do that fsck because you have chosen a file system that needs it
- Ask yourself if the tasks are really needed?
  - Do they directly contribute to achieving the boot time functionality?
    - Bootloaders, start up scripts, dynamic device nodes – nice but not essential

GStreamer example

- Gstreamer heavily uses plugins (shared libraries)
- When a Gstreamer application starts (gst_init) it will scan GST_PLUGIN_PATH for plugins and populate a registry used to find plugins
  - This takes time
  - This isn't needed on every boot
- Example of a task that isn't needed
- Used GST_REGISTRY_UPDATE to prevent scan and used a pre-provided registry
- Reduced data transfer during boot by 20MB saved 4 seconds
- Found by littering printf's through the application

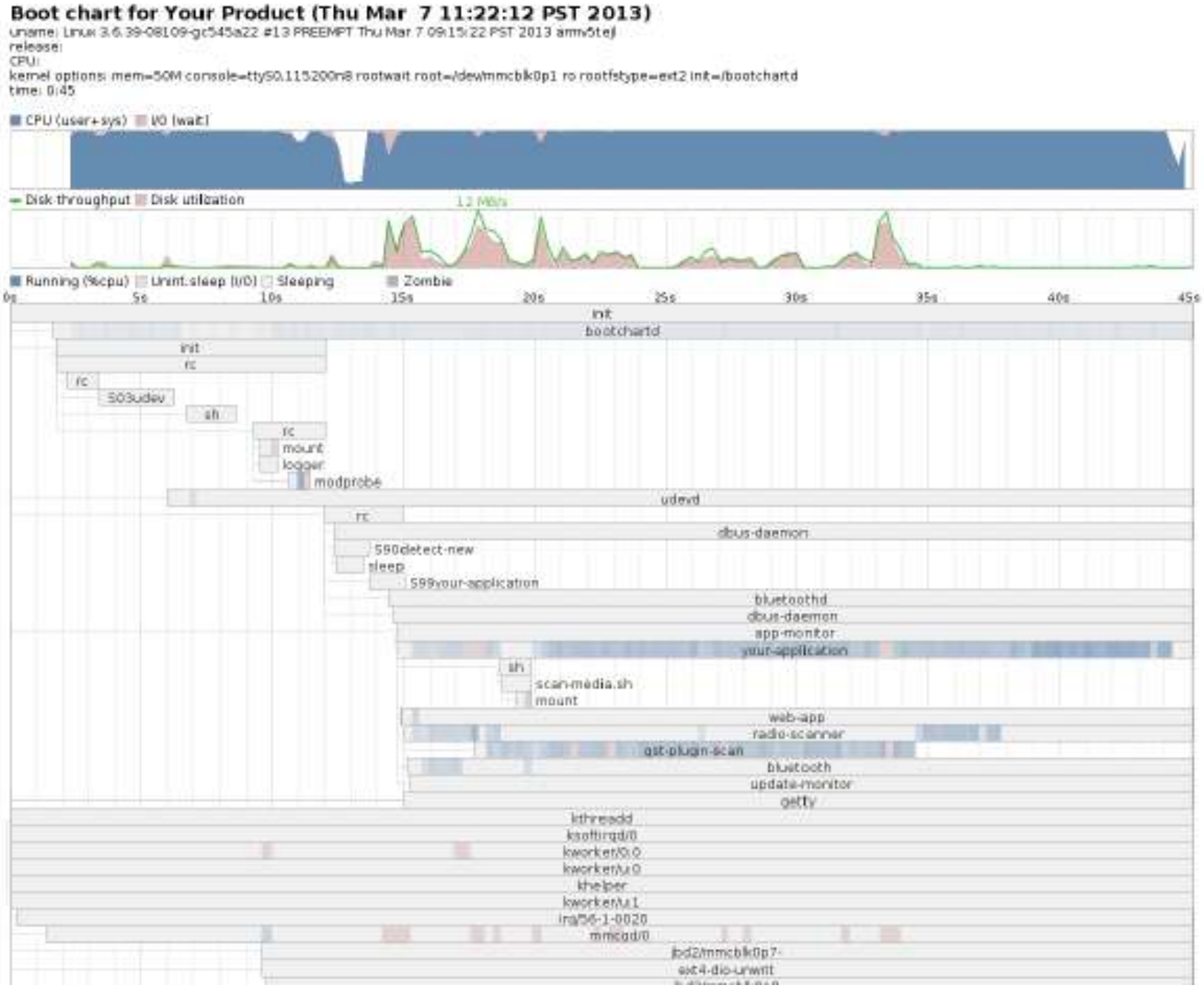
Look in the right places

- Look at:
  - Code you've written
  - Code your team has written
  - Code the board provider has written
  - Code the silicon vendor has written
  - Everything else

10 Find good tools

Tools can help

- Tools can save you time and provide clarity
  - There are a lot of tools available
  - Sometimes they can overwhelm you with information
  - Use them towards end of project
- You can do a lot with printk/printf and timestamps
- Perf, oprofile, strace are helpful too
  - Lots of presentations on these topics
  - “Linux Performance Tools” – Brendan Gregg, Netflix
- Bootchart can help visualise userspace performance


Boot chart for Your Product (Thu Mar 7 11:22:12 PST 2013)
uname: Linux 3.6.39-08109-gc545a22 #13 PREEMPT Thu Mar 7 09:15:22 PST 2013 armv5tejl
release:
CPU:
kernel options: mem=50M console=ttyS0,115200n8 rootwait root=/dev/mmcblk0p1 ro rootfstype=ext2 init=/bootchartd
time: 0:45
CPU (user+sys)
I/O (wait)
Disk throughput
Disk utilization
12 MB/s
Running (%cpu)
Unint.sleep (I/O)
Sleeping
Zombie
0s
5s
10s
15s
20s
25s
30s
35s
40s
45s
init
bootchartd
init
rc
rc
S03udev
sh
rc
mount
logger
modprobe
udevd
rc
dbus-daemon
S90detect-new
sleep
S99your-application
bluetoothd
dbus-daemon
app-monitor
your-application
sh
scan-media.sh
mount
web-app
radio-scanner
gst-plugin-scan
bluetooth
update-monitor
getty
kthreadd
ksoftirqd/0
kworker/0:0
kworker/u:0
khelper
kworker/u:1
irq/56-1-0020
mmcqd/0
jbd2/mmcblk0p7-
ext4-dio-unwrit

11 Create an illusion

Create an illusion

- Why do you want a minimal boot time anyway?
  - Can you achieve it without a minimal boot time?
- Small boot time can be difficult to achieve
  - So why not create an illusion of a small boot time instead
  - ‘Smoke and Mirrors’ have a place
- Defer functionality that isn’t needed straight away

12 Expect disruption

Expect disruption

- Minimal boot times often result in a compromise
- This effects everyone that is developing the product
- Changes you wish to make may conflict with other parts of the product development
- Your changes may have knock on effects
- Be prepared to make and justify your case
  - How important is a minimal boot time?
  - You may find out that minimal boot time isn't everything after all

Thank you

Questions?

Andrew Murray

Embedded Bits <amurray@embedded-bits.co.uk>