Porting mainline Linux to mobile phones

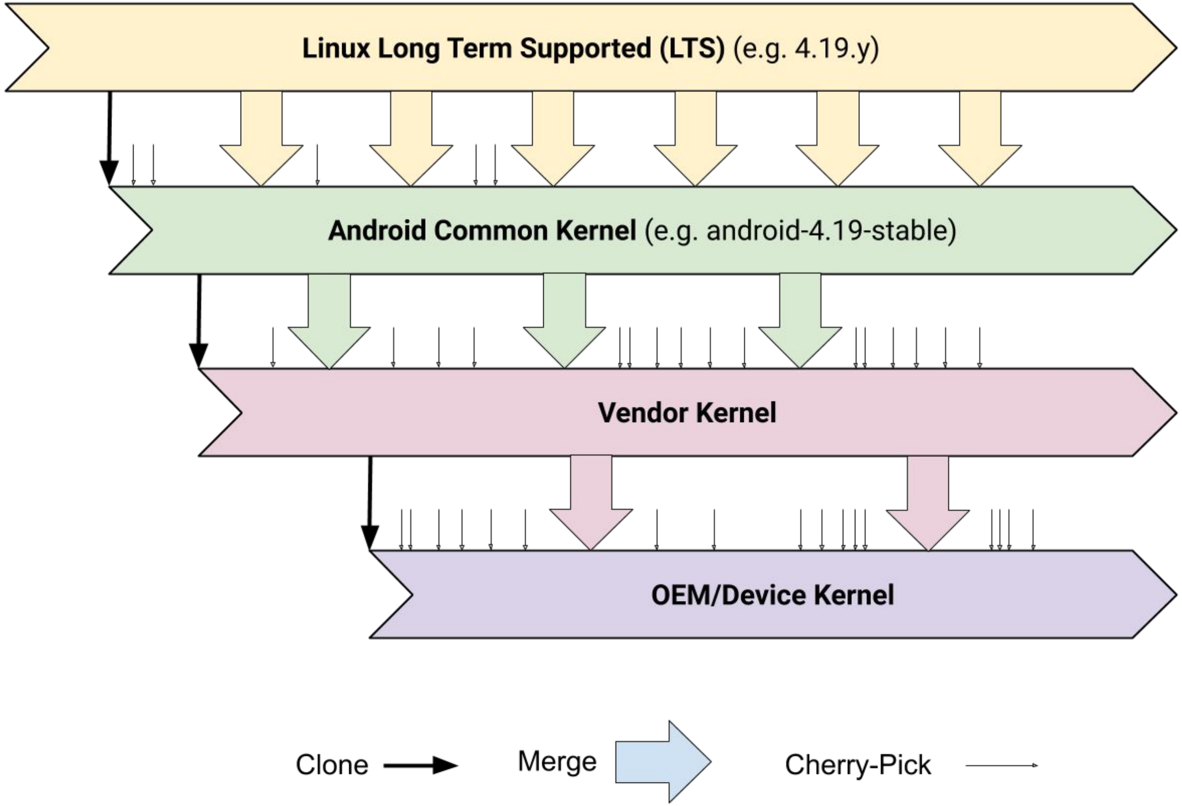
FOSDEM 2022

Who am I?

- Luca Weiss (z3ntu)
- Mainlining phones since 2017 for fun
- postmarketOS core team member
- Also OpenRazer maintainer amongst other things
- Android Platform Engineer at Fairphone
    - but here on my own

The Android kernel situation

- Every device has their own kernel source tree
- Security issues need to be patched in each kernel
- Greg K-H: apply all “fixes”, not just “security fixes”
- Lots of out-of-tree code
- Questionable code quality



https://source.android.com/devices/architecture/kernel/generic-kernel-image

The Android Mess

- Linux kernel is licensed under GPL-2.0
  - Every modified Linux kernel must be open-source as well
  - Some vendors don’t seem to care much… (but that’s another topic)
- SoC vendors implement drivers in user space
  - Gets around license requirements, potentially easier to hire people
  - Camera, Bluetooth amongst others
  - Most have kernel component but need user space counterpart
  - Qualcomm has some open-source parts **but** important parts are proprietary
- Building 100% open-source operating system is basically impossible with that
  - Ubuntu Touch reuses Android binaries through libhybris
- Unless you get a proper kernel using standardized interfaces
  - Be gone, proprietary bits!

Hardware description on x86

- Kernel needs to know what hardware is available
- On x86 ACPI and ACPI tables exist
  - Used to discover and configure hardware components
  - And power management bits
- Also USB & PCI enumeration
  - USB: Touchpad, SD card reader, webcam
  - PCI: Wifi card, ethernet controller, GPU
  - Both use vendor ID - product ID identifier
  - Various USB device classes (e.g. HID)

```
static const struct pci_device_id rtl8169_pci_tbl[] = {
        // ...
        { PCI_VDEVICE(REALTEK,  0x8168) },
        // ...
        {}
};
```

Why it’s so difficult on (ARM) phones

- ARM doesn’t use ACPI
- Historically Linux used board files
  - C file compiled into the kernel describing the hardware
  - Kernel image can run on this specific board only
- Since around Linux 3.x device tree!
  - Originally used in SPARC computers
  - “Open Firmware” project
- Structured format to describe hardware
  - e.g. clocks, GPIOs, memory addresses and more!
- Loaded by (theoretically) generic kernel
  - Drivers get instantiated and used based on this information
  - Operating-system independent

Why mainline Linux

- Tremendous learning opportunity
  - Understand how hardware works from kernel perspective
  - Outside of formal education and jobs this is hard to acquire
- Run open-source software without proprietary user space
  - postmarketOS!
  - Mobian
  - Android (aospm)
- Code maintained at kernel.org
  - Fixes and features have a place to go
- Learn valuable engineering skills
  - Constant problem solving and debugging
- Brag about it online!

A devicetree file

.dts (**d**evice**t**ree **s**ource) => .dtb (**d**evice**t**ree **b**inary)

.dts: `#include “foobar.dtsi”`

```
/dts-v1/;

/ {
	#address-cells = <2>;
	#size-cells = <2>;

	soc: soc@0 {
		#address-cells = <2>;
		#size-cells = <2>;
		ranges = <0 0 0 0 0x10 0>;
		dma-ranges = <0 0 0 0 0x10 0>;
		compatible = "simple-bus";

		rng@793000 {
			compatible = "qcom,prng-ee";
			reg = <0 0x00793000 0 0x1000>;
		};
	};
};
```

A devicetree node

Basic node has some or all of:

- Compatible string: `compatible = "qcom,prng-ee";`
- Memory address (with size): `reg = <0x00793000 0x1000>;`
- Clocks: `clocks = <&gcc GCC_PRNG_AHB_CLK>;`
- Pinctrl:
  - `pinctrl-names = "default";`
  - `pinctrl-0 = <&qup_uart2_default>;`
- GPIOs: `gpios = <&pm6350_gpios 2 GPIO_ACTIVE_LOW>;`
- Many other properties - check binding docs!

Let’s get it running with mainline!

- Focusing on Qualcomm
  - Probably best mainstream phone SoC vendor for mainline
- Age of device matters
  - New SoCs have ground work done by paid people
  - Old SoCs had time to mature to get features and iron out bugs
- SoC bringup is more involved
  - Pinctrl, clocks, basic devicetree parts
  - Cannot recommend as first target
- Many SoCs exist, not all are supported
  - Check postmarketOS wiki and Linux repo for existing work done
  - Much code exists in random repos - ask people!

Preparations

- Unlocked bootloader
  - obviously
- Stock firmware
  - In case something goes wrong
  - For charging the battery
- TWRP
  - Fast uncomplicated environment as reference
- Know the device features
  - e.g. notification LED, NFC, video out over USB-C
- Downstream kernel sources
  - Ready to build and modify
- Know your UART
  - If you can

Reconnaissance

- Input devices (touchscreen & physical buttons): `/dev/input`
- Display panel: `/proc/cmdline`
- Backlight: Check `/sys` for file `brightness`
- Fuel gauge: Check `/sys` for file `capacity`
- Internal storage & SD card
  - On which bus (SDHCI or UFS)
  - Also note down partition labels
- Vibration motor
- Wifi chipset/driver
- Bluetooth chipset/driver

Full devicetree

- Newer devices contain DTBO partition
- DTBO = **d**evice**t**ree **b**inary **o**verlay
- Combines base dtb + dtbo to form full devicetree
- Extract from running device to get full dtb
  - /sys/firmware/fdt or tar’ing /sys/firmware
  - Use `dtc` to get dtb/dts
  - Also keep original .dts handy!

Booting

- Start with booting something simple - get boot.img packaging correct
  - lk2nd (if available)
  - Downstream kernel
- Get qcom,board-id / qcom,msm-id / dtbo correct
- Without UART you will need to guess some things
  - Possible to get simple-framebuffer / USB working without it (if you're lucky)
- With UART you can check if kernel is booting at all
- Each bootloader has its own quirks
  - Learn to work with and around their limitations
  - Newer ones tend to be more problematic with dtbo, vendor_boot, etc. support

I²C example - downstream

An I2C bus (defined elsewhere)

Ilitek ILI2120 touchscreen

```
&soc {
    i2c@f9924000 {
        ilitek@41{
            compatible = "ilitek,2120";
            reg = <0x41>;
            interrupt-parent = <&msmgpio>;
            interrupts = <28 0x2>;
            vcc_i2c-supply = <&pm8941_s3>;
            ilitek,name = "ilitek_i2c";
            ilitek,reset-gpio = <&msmgpio 55 0x00>;
            ilitek,irq-gpio = <&msmgpio 28 0x02>;
            ilitek,vbus = "vcc_i2c";
            ilitek,power-enable-gpio = <&msmgpio 25 0>;
        };
    };
};
```

I2C address 0x41

Interrupt on gpio 28

pm8941_s3 supplies power

Reset is gpio 55

Interrupt from above again

And another gpio for power

```
/* Bit 0 express polarity */
#define GPIO_ACTIVE_HIGH 0
#define GPIO_ACTIVE_LOW 1
```

include/dt-bindings/gpio/gpio.h

```
#define IRQ_TYPE_NONE           0
#define IRQ_TYPE_EDGE_RISING    1
#define IRQ_TYPE_EDGE_FALLING   2
```

include/dt-bindings/interrupt-controller/irq.h

Mainline Linux has a driver for us!

```
Ilitek ILI210x/ILI2117/ILI2120/ILI251x touchscreen controller

Required properties:
- compatible:
    ilitek,ili210x for ILI210x
    ilitek,ili2117 for ILI2117
    ilitek,ili2120 for ILI2120
    ilitek,ili251x for ILI251x

- reg: The I2C address of the device

- interrupts: The sink for the touchscreen's IRQ output
    See ../interrupt-controller/interrupts.txt

Optional properties for main touchpad device:

- reset-gpios: GPIO specifier for the touchscreen's reset pin (active low)

Example:

        touchscreen@41 {
                compatible = "ilitek,ili251x";
                reg = <0x41>;
                interrupt-parent = <&gpio4>;
                interrupts = <7 IRQ_TYPE_EDGE_FALLING>;
                reset-gpios = <&gpio5 21 GPIO_ACTIVE_LOW>;
        };
```

Documentation/devicetree/bindings/input/ilitek,ili2xxx.txt

The node in mainline

```
i2c@f9924000 {
    status = "ok";

    touchscreen@41 {
        compatible = "ilitek,ili210x";
        reg = <0x41>;
        interrupt-parent = <&msmgpio>;
        interrupts = <28 IRQ_TYPE_EDGE_FALLING>;
        reset-gpios = <&msmgpio 55 GPIO_ACTIVE_LOW>;
    };
};
```

Same i2c bus as downstream

Enable this i2c bus (most are `status = “disabled”;`)

Compatible for ILI2120 from doc

Same i2c address as downstream

Same interrupt as downstream
(but with proper constant as 2nd arg)

Same reset gpio as downstream
(but again with proper constant)

Sometimes it’s more difficult…

- Bluetooth is defined without direct reference to UART transport

```
bt_nitrous {
    compatible = "goog,nitrous";
    uart-port = <0>;
    power-gpio = <&msmgpio 34 0>;
    host-wake-gpio = <&msmgpio 48 0>;
    host-wake-polarity = <1>;
    dev-wake-gpio = <&msmgpio 61 0>;
    dev-wake-polarity = <1>;
};

   uart_0: serial@f991d000{
       compatible = "qcom,msm-hsuart-v14";
       reg = <0xf991d000 0x1000>, <0xf9904000 0x19000>;
       reg-names = "core_mem", "bam_mem";
```

In this case seems to refers to the UART below

Or this Wifi example..

- Downstream dmesg is helpful - use grep!
- Registered in board file: `arch/arm/mach-msm/board_wifi_bcm.c`
- Determined “very likely” on: `sdhc_3: sdhci@f9864900`

```
#define WLAN_POWER    35
#define WLAN_HOSTWAKE 46

static unsigned wlan_wakes_msm[] = {
        GPIO_CFG(WLAN_HOSTWAKE, 0, GPIO_CFG_INPUT,
             GPIO_CFG_NO_PULL, GPIO_CFG_2MA) };

/* for wifi power supply */
static unsigned wifi_config_power_on[] = {
    GPIO_CFG(WLAN_POWER, 0, GPIO_CFG_OUTPUT,
         GPIO_CFG_PULL_UP, GPIO_CFG_2MA)
};
```

Getting more components supported

- Structured todo list might be useful
    - e.g. Kanban board
- Look through downstream dts what you might be missing
    - For non user facing components, like prng
    - Ignore SoC debug things - you probably cannot use or test them anyways
- Compared downstream vs. mainline to understand
    - Understand how downstream code gets “transformed” into mainline code
    - e.g. look at downstream MDP, compare with existing mainline MDP
    - Then attempt to add support for your variant

Tips

- Keep notes to reference
- Save your kconfig!
  - You can spend hours debugging what went wrong
  - I like to commit them into the repo (`make savedefconfig`)
- Kernel cmdline too
- There are useful cmdline options for bringup
  - `clk_ignore_unused`: doesn't disable unused clocks
  - `pd_ignore_unused`: doesn't disable unused power domains
- Know that i2c addresses are sometimes given as "8-bit" instead of "7-bit"
  - 8-bit: 0x50 read, 0x51 write => 7-bit: 0x28
- Devices with same SoC tend to be similar
  - Qualcomm provides a referenced design to OEMs
  - Some manufacturers diverge more than others
- Downstream binding documentation often exists
  - To understand obscure properties

Handy hardware utilities

- USB meter
  - Draining or charging the battery?
  - Or even fast charging?
- Multiplexed UARTs
  - USB-A breakout board
  - Headphone jack

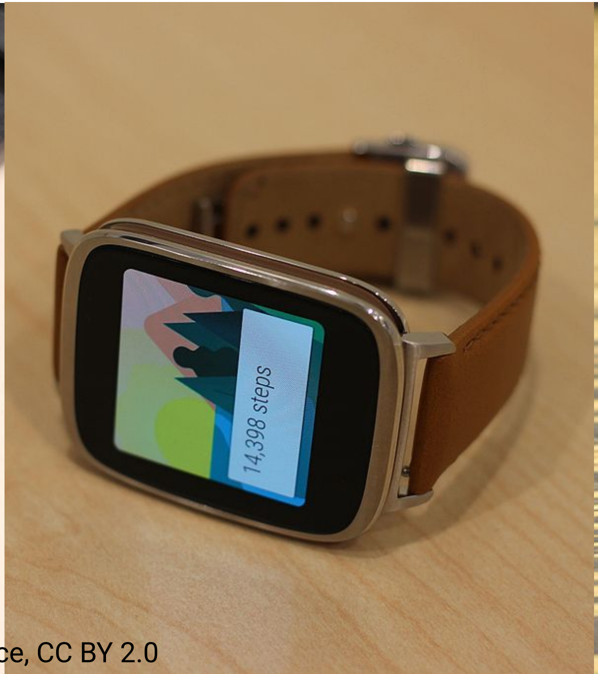
Jacek Rużyczka, CC BY-SA 4.0
https://commons.wikimedia.org/wiki/File:USB_Multime

SparkFun Electronics, CC BY 2.0

Smartwatches!

Not just phones, some older watches use Snapdragon 400!

Some newer ones use “Snapdragon Wear” SoCs



Conclusion

- Mainlining is neither **simple** nor **fast**
- Takes a lot of time and dedication
  - Understand these concepts is difficult
  - I’m still missing knowledge in some important areas
    - Interconnect
    - Audio
    - Cameras
    - IOMMU
- Reward: knowing you brought up mainline on some hardware!
  - And of course the eternal fame of your name in Linux git history

Further resources

- wiki.postmarketos.org - many pages with useful information
- #mainline:postmarketos.org - lots of helpful people
- Other SoC-specific Matrix/IRC channels

Thank you for watching!