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DTCON – Portable Device Tree Connector

Open Source Hardware thrives

- Many Linux based embedded boards are available to the community.
- Raspberry PI(s)
- Beaglebone and variants
- Linaro's 96 boards
- C.H.I.P.
- Orange PI (*)
- Minnowboard
- And a ton of others

What do people do with them

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- Just tinker about with embedded Linux!
- Learn about how hardware works and how it interfaces with Linux
- Make cool stuff with them.
  - 3D printers (Replicape)
  - Fly drones
  - Water their lawns
  - Make expansion boards to sell them.

Expansion boards

- Expansion boards are plugged into a physical connector
- Single row, or double row.
- Single connector, or multi connector
- Provides power ground and electrical signals
- Direct connection to the pads of the SoC package
- Modern SoCs are **complicated**

What it takes to make a new expansion board work?

- You connect wires!
- One set of wires is your UART, another is your I2C bus, a couple of others is your GPIO lines etc.
- You need to describe those connections and peripheral configuration in a manner than Linux understands.
- Many ways to describe hardware to Linux, we'll talk about how you do it using Device Tree.

Device Tree and devices

```
/ {
    foo0: foo@0 {
      compatible = “barcorp,foo”;
      status = “okay”;
      baz = <12>;
      interrupts = <12>;
      ….
    };
};
```

Exactly the same as a device soldered on the board

- No difference than when having the expansion board soldered on the main board.
- One needs to be intimately aware of the minutiae of each board and as a consequence of the SoC Linux port.
- You need to get everything right. Maybe there's a device example configured similar to your own and you can copy.
- If not, you have to figure out everything.

Intermission: Beaglebone example

1. Read the schematic of expansion board. Write down pinout, and jot down the configuration of each pin and pin-number.
2. Lookup the connector chapter reference manual of the Beaglebone and figure out which mode the processor pad that's connected to the connector pin must be set to.
3. Look in the hardware reference manual of the SoC which pad is configured by which pinmux register.
4. Look in the technical reference manual of the SoC which value to set in the hardware pinmux register looked up before.
5. Fill in the pinmux configuration in the correct format and add in the device tree.
6. Fill in any other special configuration parameters to the device tree nodes controlling the devices present on the expansion board.

Configuration is SoC specific

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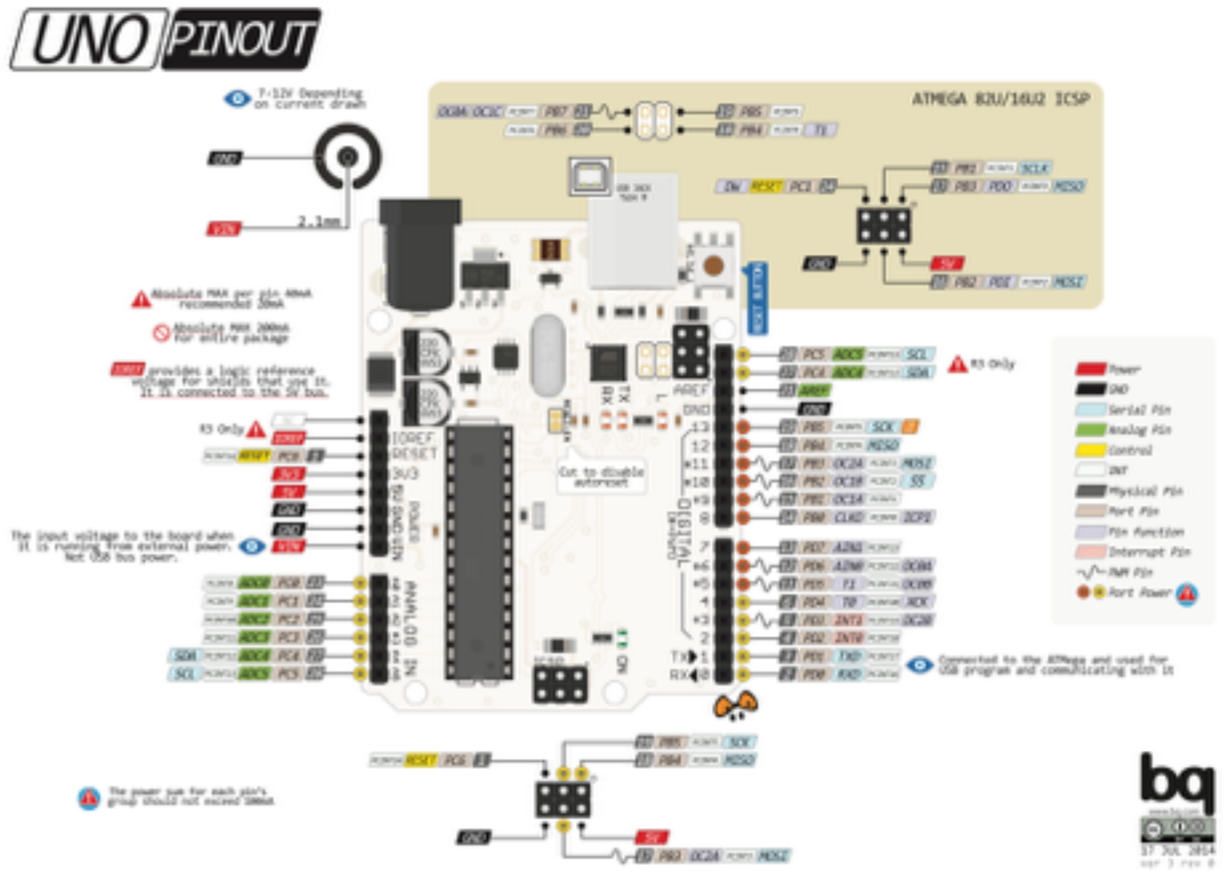
- The configuration is SoC specific.
- Figuring out the configuration is hard.
- Getting it wrong is frustrating (not easy to debug)
- Many community boards have compatible expansion connectors.
  - Arduino Compatible
  - RPI Compatible
  - Grove
  - 96 boards

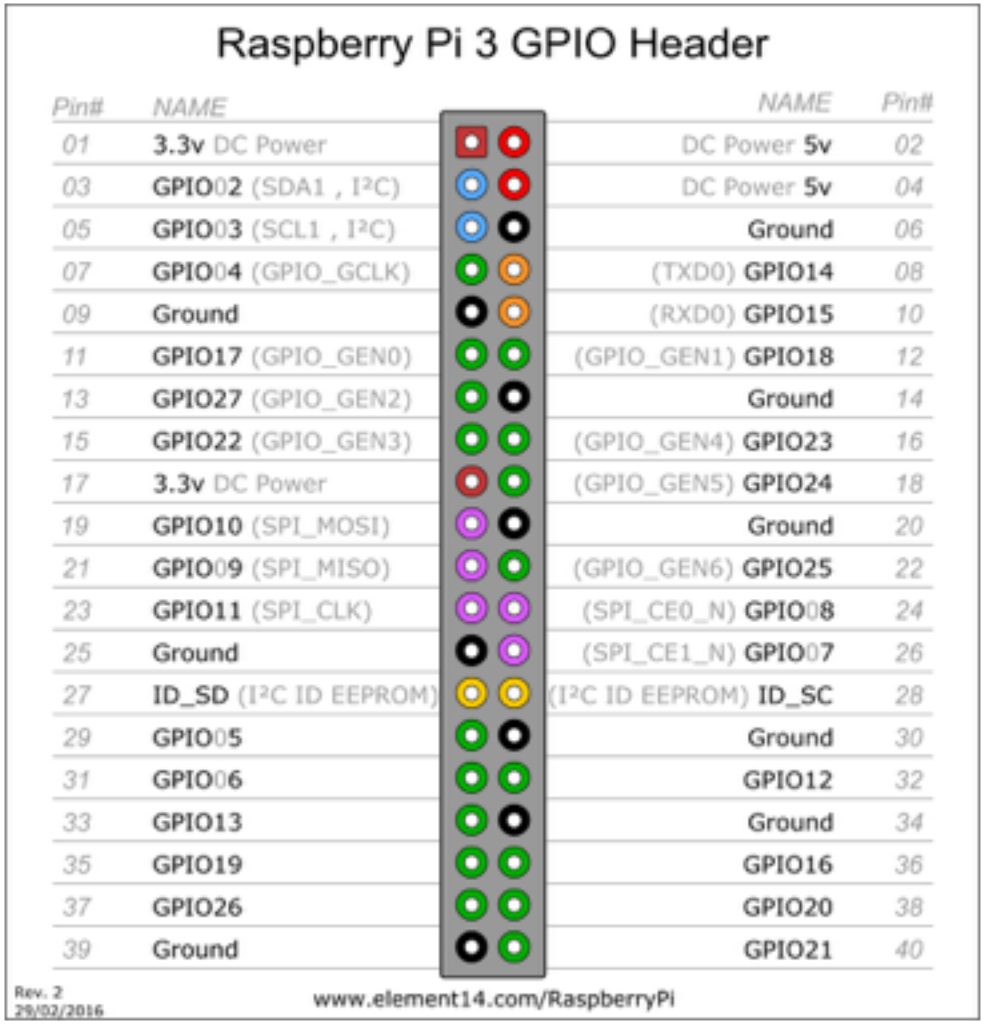
Mission: Portable Expansion Boards

- Make expansion boards work in every board that has a compatible expansion connector
- Simplify the expansion board definition
- Remove all SoC specific configuration from the expansion board definition

The ubiquitous Arduino Connector



The RPi Connector



Raspberry Pi 3 GPIO Header

Pin#	NAME	NAME	Pin#
01	3.3v DC Power	DC Power 5v	02
03	GPIO02 (SDA1 , I²C)	DC Power 5v	04
05	GPIO03 (SCL1 , I²C)	Ground	06
07	GPIO04 (GPIO_GCLK)	(TXD0) GPIO14	08
09	Ground	(RXD0) GPIO15	10
11	GPIO17 (GPIO_GEN0)	(GPIO_GEN1) GPIO18	12
13	GPIO27 (GPIO_GEN2)	Ground	14
15	GPIO22 (GPIO_GEN3)	(GPIO_GEN4) GPIO23	16
17	3.3v DC Power	(GPIO_GEN5) GPIO24	18
19	GPIO10 (SPI_MOSI)	Ground	20
21	GPIO09 (SPI_MISO)	(GPIO_GEN6) GPIO25	22
23	GPIO11 (SPI_CLK)	(SPI_CE0_N) GPIO08	24
25	Ground	(SPI_CE1_N) GPIO07	26
27	ID_SD (I²C ID EEPROM)	(I²C ID EEPROM) ID_SC	28
29	GPIO05	Ground	30
31	GPIO06	GPIO12	32
33	GPIO13	Ground	34
35	GPIO19	GPIO16	36
37	GPIO26	GPIO20	38
39	Ground	GPIO21	40

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www.element14.com/RaspberryPi

The Beaglebone Connector

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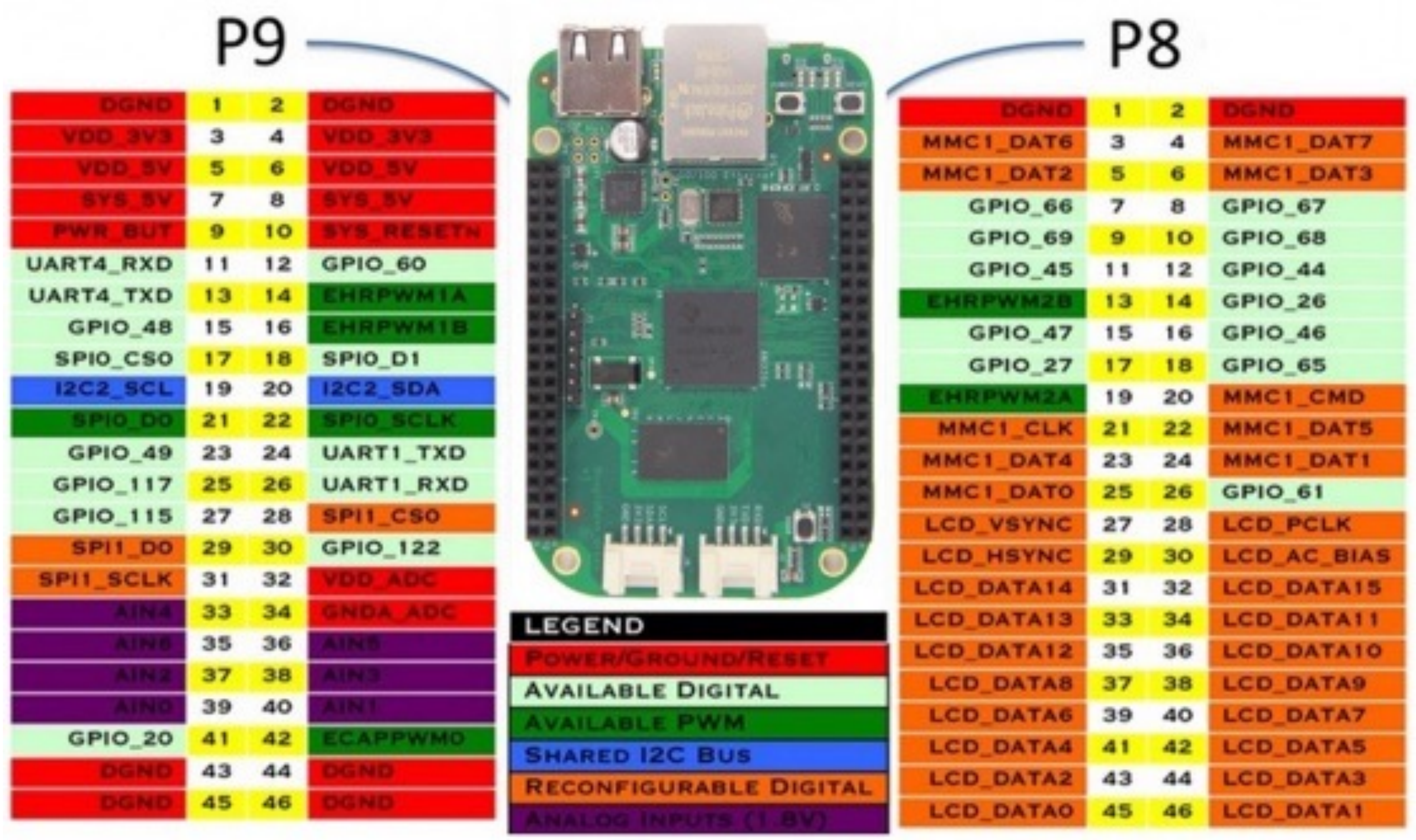

P9

DGND	1	2	DGND
VDD_3V3	3	4	VDD_3V3
VDD_5V	5	6	VDD_5V
SYS_5V	7	8	SYS_5V
PWR_BUT	9	10	SYS_RESETN
UART4_RXD	11	12	GPIO_60
UART4_TXD	13	14	EHRPWM1A
GPIO_48	15	16	EHRPWM1B
SPI0_CS0	17	18	SPI0_D1
I2C2_SCL	19	20	I2C2_SDA
SPI0_D0	21	22	SPI0_SCLK
GPIO_49	23	24	UART1_TXD
GPIO_117	25	26	UART1_RXD
GPIO_115	27	28	SPI1_CS0
SPI1_D0	29	30	GPIO_122
SPI1_SCLK	31	32	VDD_ADC
AIN4	33	34	GNDA_ADC
AIN6	35	36	AIN5
AIN2	37	38	AIN3
AIN0	39	40	AIN1
GPIO_20	41	42	ECAPPWM0
DGND	43	44	DGND
DGND	45	46	DGND

P8

DGND	1	2	DGND
MMC1_DAT6	3	4	MMC1_DAT7
MMC1_DAT2	5	6	MMC1_DAT3
GPIO_66	7	8	GPIO_67
GPIO_69	9	10	GPIO_68
GPIO_45	11	12	GPIO_44
EHRPWM2B	13	14	GPIO_26
GPIO_47	15	16	GPIO_46
GPIO_27	17	18	GPIO_65
EHRPWM2A	19	20	MMC1_CMD
MMC1_CLK	21	22	MMC1_DAT5
MMC1_DAT4	23	24	MMC1_DAT1
MMC1_DAT0	25	26	GPIO_61
LCD_VSYNC	27	28	LCD_PCLK
LCD_HSYNC	29	30	LCD_AC_BIAS
LCD_DATA14	31	32	LCD_DATA15
LCD_DATA13	33	34	LCD_DATA11
LCD_DATA12	35	36	LCD_DATA10
LCD_DATA8	37	38	LCD_DATA9
LCD_DATA6	39	40	LCD_DATA7
LCD_DATA4	41	42	LCD_DATA5
LCD_DATA2	43	44	LCD_DATA3
LCD_DATA0	45	46	LCD_DATA1

LEGEND

- 🟥 Power/Ground/Reset
- 🟩 Available Digital
- 🟩 Available PWM
- 🟦 Shared I2C Bus
- 🟧 Reconfigurable Digital
- 🟪 Analog Inputs (1.8V)

Baseboards are commodities

- The base board is a commodity.
- The expansion boards are what's important.
- Choose the right baseboard for my application.
- Base board makers compete in a level playing field.
- Increase the community size by reducing fragmentation.
- (ARM) Multiarch kernels + portable connectors -> Same kernel + root filesystem boots on every board.

dtcon: DT Connector

- An extcon driver
- Defines the core connector constructs.
  - connector
  - functions
  - bridge drivers
  - proxy drivers

connector

- connector/#address-cells -> connector addressing
- Each node contains one or more reg addresses
- reg addresses are pin#
- contain properties unique for each connector pin
- I.e. pad name, textual modes, pinmuxes etc.

functions

- Each pin may be assigned a function.
- Defines set of pins that comprise a function, as well as allowable combination.
- Defines properties that configure a bridge driver (i.e. gpio)
- Defines properties that configure a proxy driver, i.e. parameter names and parameter transformations.

bridge driver

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- Drivers that act a bridge between the connector domain and the base DT domain.
- They are drivers that supply services to other drivers in a way that can’t be expressed using a proxy driver.
- Example of bridge driver is GPIO, controls a set of pins as a single gpio driver and consolidating all pins that can be set to GPIO mode on the connector as a single driver.

proxy driver

- Uses configuration from function it is part of to request pins from the connector and configure them properly for it to work
- It has a device target which is a pointer to the device that's going to be configured and used.
- There is a single proxy driver for all classes of devices that can be supported.
- Proxy drivers deal with devices that provide no services to other drivers. Those need bridge drivers.

Real example
Beaglebone capes

- Beaglebone is a relatively popular board
- Mainline kernel with working cape support
- Extensive pinmuxing options stresses the connector infrastructure.
- A very good selection of peripherals covering corner cases

Real example
Beaglebone & a few capes

- ❑ Beaglebone is a relatively popular board
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proposed driver DT bindings

```
/ {
  dtcon {
    compatible = "extcon,dt-con";
    status = "okay";
    connector { … };
    functions { … };
    plugged { … };
  };
```

connector node DT bindings

```
connector {
  #address-cells = <2>;
  #size-cells = <0>;
  GPIO1_6: GPIO1_6 {
    reg = <8 3>;
    pad = "R9";
    pinmuxes = <&gpmc_ad6>, <&mmc1_dat6>,
                    <&gpio1_6_in &gpio1_6_out>;
    };
   …
 };
```

interrupting.. pinmuxes

```
/* the muxes for the dtcon */
&am33xx_pinmux {
  /* P8.3 GPIO1_6 */
  gpio1_6_in: gpio1_6_in {
    pinctrl-single,pins = <
        AM33XX_IOPAD(0x818,PIN_INPUT_PULLUP | MUX_MODE7)
    >;
  };
  ….
};
```

pinmuxes (cont)

- Connector driver handles all pinmux setting
- The list of enabled pins is used to lookup which pinmux fragments to add to the selected state and enable them.
- Needs a patch to enable runtime pinmux state construction.
- Completely removes the need for a non-board support or SoC developer to set muxes.

function node DT bindings

- For each function there is a node which contains configuration parameters for the function (not the device instance)
- For the bridge drivers, the contents are completely free-form
- For the proxy drivers, contents follow a general format

```
functions {
  <function-name} { };
};
```

GPIO bridge driver

```
dtcon_gpio: gpio {

  gpio-base = <256>;

  #modes = <2>;

  mode-names = "in", "out";

  gpio = <&gpio0 2 &UART2_RXD &gpio0_2_in &gpio0_2_out>,

         ….

        <&gpio2 11 &GPIO2_11 &gpio2_11_in &gpio2_11_out>,

         ….

  };
```

GPIO bridge driver (cont)

- GPIO cannot be a proxy driver
- GPIO driver provide services to other drivers
  - Interface with the pinctl subsystem.
  - For GPIO controllers that support it they can be an interrupt controller.
  - Many drivers reference a GPIO as part of their operation (i.e. dsr-gpios

Proxy drivers bindings UART

```
uart {

  params {

    rxd = { required; };

    txd = { required; };

    rts-optional { optional; gpio-property = “rts-
    gpios”; gpio-mode = “out”;

  };

};
```

Proxy drivers bindings UART-cont

```
uart {
  uart@2 {
    device = <&uart5>;
    gpio = <&dtcon_gpio>;
    mux@0 {
      txd = <&UART5_TXD &uart5_txd>;
      rxd = <&UART5_RXD &uart5_rxd>,
            <&UART5_CTSN &uart5_rxd_mux1>;
   };
  };
};
```

Proxy drivers bindings
I2C

```
i2c {
  params {
    scl = { required; };
    sda = { required; };
  };
};
```

- And so on… Proxy drivers are generally the same although special behavior can be tackled with the match OF compatible ID table.

Plugged: Just a bus

- compatible = “simple-bus”; actually
- Target for overlays, anything dropped there will be instantiated.
- More secure than vanilla overlays with a security configuration option that disallows any overlays having a target outside of the plugged node.

BB-BONE-UART

```
BB_BONE_UART {
  compatible = “dtcon-uart”;
  status = “okay”;
  txd = <9 21>;
  rxd = <9 22>;
};
```

BB-BONE-UART sequence of events

- A UART compatible proxy driver is instantiated.
- Using the "uart" function node we parse the "parameters" node for connector properties that are representing a connector property.
- We iterate over all children of the uart node for a device target property.
- A match is found when the property points to the connector node that the reg property matches.

BB-BONE-UART
sequence of events (cont)

- The pinmux option that is part of the tuple is enabled
- All properties/child nodes are copied in the target device node.
- Performed using a changeset so that they can be reverted.
- The target device is enabled with 'status="okay"' and it is created.

BB-RELAY-4PORT

```
BB_RELAY_4PORT {
  compatible = "simple-bus";
  status = "okay";
  gpio_relay_4port: gpio_relay_4port@0 {
    compatible = "dtcon-pio";
    status = "okay";
    gpio-controller;
    #gpio-cells = <2>;
    pin-list = <9 15>, <9 23>, <9 12>, <9 27>;
  };
```

BB-RELAY-4PORT (cont)

```
leds@0 {

  compatible = “gpio-leds”;

  status = “okay”;

  jp@1 {

    gpios = <&gpio_relay_4port 0 GPIO_ACTIVE_HIGH>;

    default-state = “keep”;

  }

};
```

BB-RELAY-4PORT sequence of events

- The dtcon-gpio device which is created using the pin-list property to locate the matching connector nodes.
- Note that the numbering of the GPIOs are in the order they are stated in the pin-list property.
- The backend gpiochips are located and kept in a list.
- When the led driver is probed internal API calls are forwarded to the real GPIO drivers present.
- Unfortunately major rewrite of GPIO layer underway, patches do not apply, WIP.

Development status

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- Mostly works for standard devices (UART/I2C/SPI etc).
- GPIO is broken due to GPIO rewrite. Needs a cleaner interface for cascaded GPIO operations.
- Pinmuxing needs patch to build a pinmux state dynamically.
- Bridge drivers for other hardware classes. PWM is next.
- Mainline will take quite a few iterations.

Thank you!

Questions?