Using DT overlays to support the C.H.I.P.'s capes

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Context

Overview

The 1-wire bus

Introduction to Device Tree Overlays

- Example: the base tree
- Example: the overlay
- phandle resolution

Applying a Device Tree Overlay

The cape manager

Current status

What is this talk about?

- Giving an overview of how to handle capes in the kernel, and describing the requirements.
- Describing the solution we went for.
- Digging into the different parts of our solution.

Context

Context

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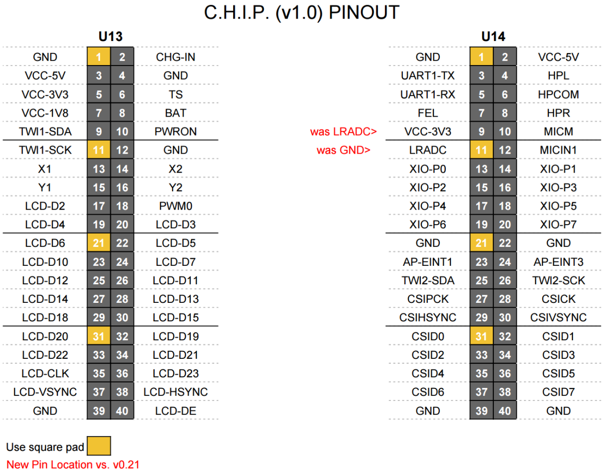
Context: the CHIP, the capes and us

- The **CHIP**: a 9$ board by **NextThing Co.** built around the Allwinner R8 SoC (Cortex-A8).
- Funded thanks to a Kickstarter campaign in 2015.
- **Free Electrons** working on the CHIP kernel support.
- Was designed from the beginning to have adapters:
  - VGA adapter.
  - HDMI adapter.
  - Pocket CHIP.

The CHIP expander



C.H.I.P. (v1.0) PINOUT

U13

GND	1	2	CHG-IN
VCC-5V	3	4	GND
VCC-3V3	5	6	TS
VCC-1V8	7	8	BAT
TWI1-SDA	9	10	PWRON
TWI1-SCK	11	12	GND
X1	13	14	X2
Y1	15	16	Y2
LCD-D2	17	18	PWM0
LCD-D4	19	20	LCD-D3
LCD-D6	21	22	LCD-D5
LCD-D10	23	24	LCD-D7
LCD-D12	25	26	LCD-D11
LCD-D14	27	28	LCD-D13
LCD-D18	29	30	LCD-D15
LCD-D20	31	32	LCD-D19
LCD-D22	33	34	LCD-D21
LCD-CLK	35	36	LCD-D23
LCD-VSYNC	37	38	LCD-HSYNC
GND	39	40	LCD-DE

U14

	GND	1	2	VCC-5V
	UART1-TX	3	4	HPL
	UART1-RX	5	6	HPCOM
	FEL	7	8	HPR
was LRADC>	VCC-3V3	9	10	MICM
was GND>	LRADC	11	12	MICIN1
	XIO-P0	13	14	XIO-P1
	XIO-P2	15	16	XIO-P3
	XIO-P4	17	18	XIO-P5
	XIO-P6	19	20	XIO-P7
	GND	21	22	GND
	AP-EINT1	23	24	AP-EINT3
	TWI2-SDA	25	26	TWI2-SCK
	CSIPCK	27	28	CSICK
	CSIHSYNC	29	30	CSIVSYNC
	CSID0	31	32	CSID1
	CSID2	33	34	CSID3
	CSID4	35	36	CSID5
	CSID6	37	38	CSID7
	GND	39	40	GND

Use square pad 🟨

New Pin Location vs. v0.21

Cape definition & benefits

- An adapter to extend board functionalities.
- Some I/Os are muxable: different capes for different usages!
- Prototype development made easy.
- DIY projects.
- Everyone can design and sell his own capes.

Requirements

- Capes can be changed.
- Not a finite set of capes.
    - The capes need to be auto-detected at boot time.
- Capes can be stacked.
    - The auto-detection mechanism should be able to enumerate the capes.
- This should work **without** the user intervention!

Overview

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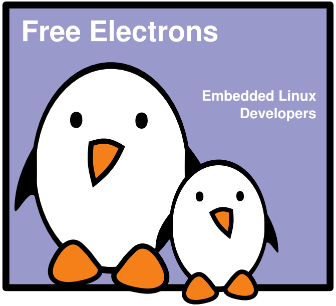

The header

- Used to organize the cape's description.
- Needs a magic value to differentiate it from random data.
- Capes can have different versions or revisions.
- Allows each cape to store specific data.
- This header is stored in an onboard EEPROM.
    - Easy to read from / write to.
    - Cheap.

The header format

```
struct cape_chip_header {
        u32     magic;     /* must be 0x43484950 "CHIP" */
        u8      version;   /* spec version */
        u32     vendor_id;
        u16     product_id;
        u8      product_version;
        char    vendor_name[32];
        char    product_name[32];
        u8      rsvd[36];  /* rsvd for future versions */
        u8      data[16];  /* per-cape specific */
} __packed;
```

Cape identification

- Each pin used to communicate to the EEPROM cannot be reused:
  - We wanted a bus with the lowest number of lines.
- We did not need a high speed bus:
  - Only used to read the cape's header.
- The bus must support enumeration, to connect more than one cape.
- We chose the 1-wire bus.

Kernel hardware description

- The CHIP is based on an ARM Cortex-A8.
- The hardware description is now done with Device Trees in the upstream kernel, for ARM based boards.
- Describe the SoC IPs, and which ones to enable (and configure) for a given board.
- The proper solution would be to modify this device tree.
  - This can be done with device tree overlays!

The 1-wire bus

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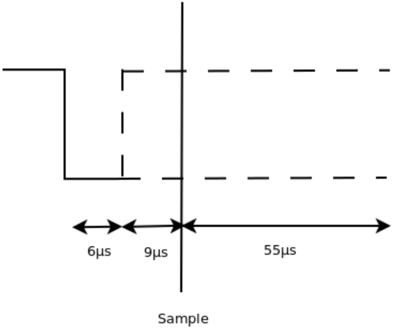
Overview

- Single signal.
- Low-speed data and signaling.
- Only two wires needed:
  - Data.
  - Ground.
- Uses a capacitor to store charge and power the device when the data line is active.
  - The capacitor needs to be charged!
  - We had weird side effects because of this in U-Boot → the line needs to be pulled long enough firstly.
- Two speed modes: normal and overdrive (speed x10).
- Four operations: `read`, `write 0`, `write 1` and `reset`.
- Can be used over a GPIO.
  - `drivers/w1/master/w1-gpio.c`

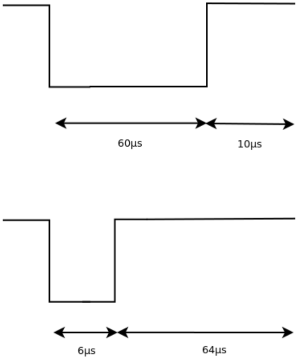
Read operation

1. Drive the bus low.
2. Wait 6µs.
3. Release the bus.
4. Wait 9µs.
5. Sample the bus to read the bit send by the slave.
6. Wait 55µs.



Write operation

- To write 0:
  1. Drive the bus low.
  2. Wait 60µs.
  3. Release the bus.
  4. Wait 10µs.
- To write 1:
  1. Drive the bus low.
  2. Wait 6µs.
  3. Release the bus.
  4. Wait 64µs.



Reset operation

Reset the bus slave devices and ready them for a command.

1. Drive the bus low.
2. Wait 480µs.
3. Release the bus.
4. Wait for 70µs.
5. Sample the bus:
    - 0: one or more slave devices present.
    - 1: no slave device present.

Slave devices numeration

- Each devices have a 64-bit unique identifier.
- Used to address them individually by the master.
- Binary tree search.

Kernel support

- `drivers/w1`
- Not actively maintained.
- No interface to the 1-wire framework.
  - Slave drivers should be in `drivers/w1/slaves`
  - Difficult to use the bus from outside the subsystem.

Introduction to Device Tree Overlays

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Overview

- The device tree is a data structure.
- It's organized as a tree: there are nodes.
- Not aimed to be generated dynamically.
- Loaded at boot time by the bootloader, or embedded in the kernel image.
- Nice for describing a SoC or a board... but not suitable for hot-pluggable stuff.

Device Tree Overlays

- Allows modification of the device tree at runtime:
  - To add a node.
  - To modify a property.
- Not persistent across reboots.
- Examples:
  - Turn on or off an hardware block by updating a node `status` property.
  - Modifying the pinmux.
  - Adding a hardware controller description.

Upstream status

- In-kernel support: `CONFIG_OF_DYNAMIC`.
- No U-Boot support (at the time of writing)... but patches sent while in the plane on our way to ELC :-)
- DTC (device tree compiler) needs a patch to enable dynamic phandle resolution.
  - Required to use device tree overlays.
  - Still not available upstream.
  - This means the one used by the kernel build system cannot handle overlays!

Overlay example: adding a new node

```
/dts-v1/;
/plugin/;

/ {
        compatible = "nextthing,chip","allwinner,sun5i-r8";

        fragment@0 {
                target-path = "/soc@01c00000";

                __overlay__ {
                        leds {
                                compatible = "gpio-leds";
                                pinctrl-names = "default";
                                pinctrl-0 = <&chip_test_led>;

                                led0 {
                                        label = "Test led";
                                        gpios = <&pio 3 4 0>; /* PD4 */
                                        default-state = "on";
                                };
                        };
                };
        };
};
```

Overlay example: modifying a property

```
/dts-v1/;
/plugin/;

/ {
        compatible = "nextthing,chip","allwinner,sun5i-r8";

        fragment@0 {
                target = <&mmc0>;
                __overlay__ {
                        status = "okay";
                };
        };
};
```

Targets

- To be applied a device tree overlay fragment needs a target.
- Describes where to apply the changes.
- Two possibilities:
  - `target-path`: the argument is a path.
  - `target`: the argument is a phandle.
- When using `target`, the phandle resolution should be dynamic.

Compiling

- `dtc -O dtb -o foo.dtb -@ foo.dts`
- The `-@` option comes from an out-of-tree patch.
- It will generates extra nodes under the root node:
  - `__symbols__` in the base tree.
  - `__symbols__`, `__fixups__` and `__local_fixups__` in the overlay.
  - Contains metadata used for symbol resolution.
- `/plugin/` marks device tree overlay.

Example: the base tree

Base tree

```
/dts-v1/;

/ {
        compatible = "example";
        foo = <&bar>;

        bar: bar@0 {
                compatible = "example,bar";
        };
};
```

Device Tree object without dynamic symbols

```
/dts-v1/;

/ {
    compatible = "example";
    foo = <0x00000001>;

    bar@0 {
        compatible = "example,bar";
        linux,phandle = <0x00000001>;
        phandle = <0x00000001>;
    };
};
```

Device Tree object with dynamic symbols

```
/dts-v1/;
/ {
    compatible = "example";
    foo = <0x00000001>;
    bar@0 {
        compatible = "example,bar";
        linux,phandle = <0x00000001>;
        phandle = <0x00000001>;
    };

    __symbols__ {
        bar = "/bar@0";
    };
};
```

Example: the overlay

Device Tree Overlay

```
/dts-v1/;
/plugin/;
/ {
        compatible = "example";
        fragment@0 {
                target-path = "/";

                __overlay__ {
                        quux = <&qux>;

                        qux: qux@0 {
                                property = <&foo>;
                        };
                };
        };
};
```

Device Tree Overlay Object

```
/dts-v1/;
/ {
    compatible = "example";
    fragment@0 {
        target-path = "/";
        __overlay__ {
            quux = <0x00000001>;
            qux@0 {
                property = <0xdeadbeef>;
                linux,phandle = <0x00000001>;
                phandle = <0x00000001>;
            };
        };
    };
    __symbols__ {
        qux = "/fragment@0/__overlay__/qux@0";
    };
    __local_fixups__ {
        fragment@0 {
            __overlay__ {
                quux = <0x00000000>;
            };
        };
    };
    __fixups__ {
        foo = "/fragment@0/__overlay__/qux@0:property:0";
    };
};
```

phandle resolution

phandle resolution

1. Get the max base tree phandle value, and add `1`.
2. Ajdust the overlay phandle values, then use the `__local_fixups__` node to fix local references.
3. Use the `__fixups__` node to resolve the overlay phandles referencing objects in the base tree.
4. Update these references.

Applying a Device Tree Overlay

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Applying Device Tree Overlays 1/4

- `request_firmware()`
- Load a firmware into memory.
- The firmware is actually a Device Tree Overlay blob, stored in `/lib/firmware/`.
- Takes the name of the firmware as an argument.
  - It should be guessed from the cape's header.
  - `dip-<vendor_id>-<product_id>-<product_version>.dtbo`
  - If not found, fallback to: `dip-<vendor_id>-<product_id>.dtbo`

Applying Device Tree Overlays 2/4

- `of_fdt_unflatten_tree()`
  - Unflatten the overlay loaded previously.
  - Create a tree of device nodes from a blob: the live tree format.
- `of_resolv_phandles()`
  - Resolves the phandles against the live tree.
  - Dynamic resolution, using nodes added thanks to `dtc`'s `-@` option.

Applying Device Tree Overlays 3/4

- At this point, we can use the `of_*` helpers.
- Time to make some checks!
- Is the overlay compatible with the machine used?

Applying Device Tree Overlays 4/4

- `of_overlay_create()`
- Creates and applies an overlay.
- Keeps track of the overlay applied.
- Can be reverted with `of_overlay_destroy()`
  - When removing stacked overlays, this needs to be done in reverse order.

The cape manager

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Overview

- Responsible for detecting a cape, identifying it and applying the corresponding overlay.
- Uses all components described before:
  - The 1-wire bus.
  - The EEPROM in which the cape's header is stored.
  - The device tree overlay mechanism.
- Implemented in the kernel space.

The cape manager 1/2

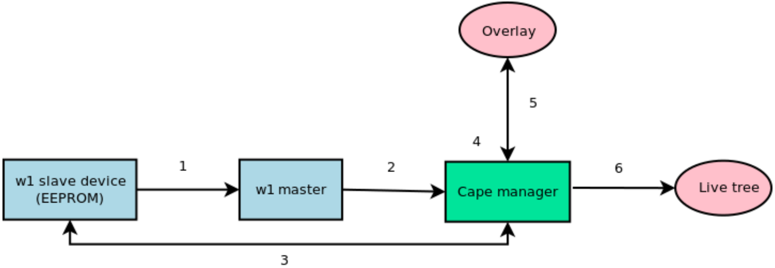
- We patched the 1-wire framework to add callbacks when a new device is detected on the bus.
  - Allows to read the header stored on the cape's EEPROM as soon as the cape is detected.
- The EEPROM driver for the DS2431 was available in `drivers/w1/slaves/`
- Cannot be used outside of the 1-wire framework!
- We redefined its read function in the cape manager.

The cape manager 2/2

- Works fine for most uses.
- Our first test was with a LED and a PWM.
- This can't work when adding / enabling devices handled by subsystems without hotplug support.
  - Like DRM/KMS.
- Quick solution: add the overlay support in the bootloader.
  - Maxime Ripard patched U-Boot.
  - Not yet upstreamed.
- Would be better to patch directly DRM/KMS.

Summary

1. A new salve device is detected on the 1-wire bus.
2. If the new device family is recognized by the cape manager, a callback is called.
3. The cape manager reads the header stored on the EEPROM.
4. The cape manager parses the header and decides which cape to load.
5. A DT overlay is loaded from userspace.
6. The overlay is applied on the live tree.



Current status

Current status

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Status

- Implemented recently.
- Solution not fully upstreamed yet.
- The best thing would be to also support other boards with capes, like the Beaglebone family.
- DTC still needs to be patched.
  - We're not sure what to do.
- We plan to send our patches to the Linux and U-Boot communities.

Thanks! Questions?

free-electrons.com/pub/conferences/2016/elc/tenart-chip-overlays/