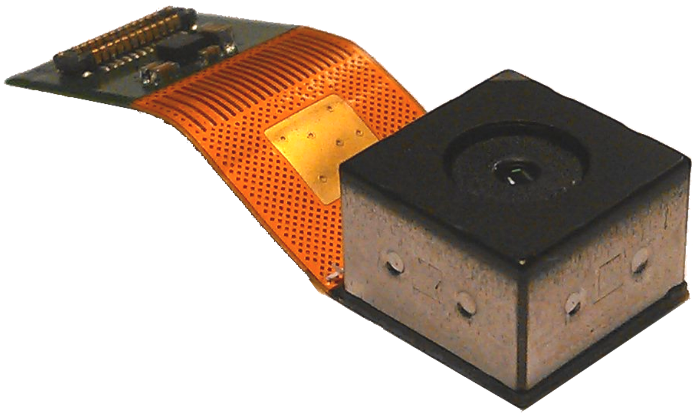
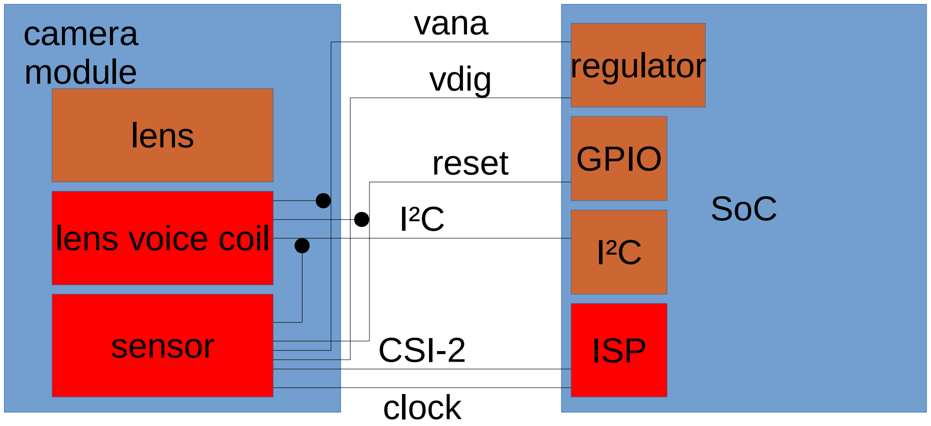
Cameras in embedded systems: Device tree and ACPI view

Sakari Ailus - Intel

A typical embedded system with a camera

- Image Signal Processor
- Raw camera sensor
- Lens voice coil





Raw sensors

- Raw sensors have little processing logic in the sensor itself
  - Analogue and digital gain but not much more

This is how white looks like! -->

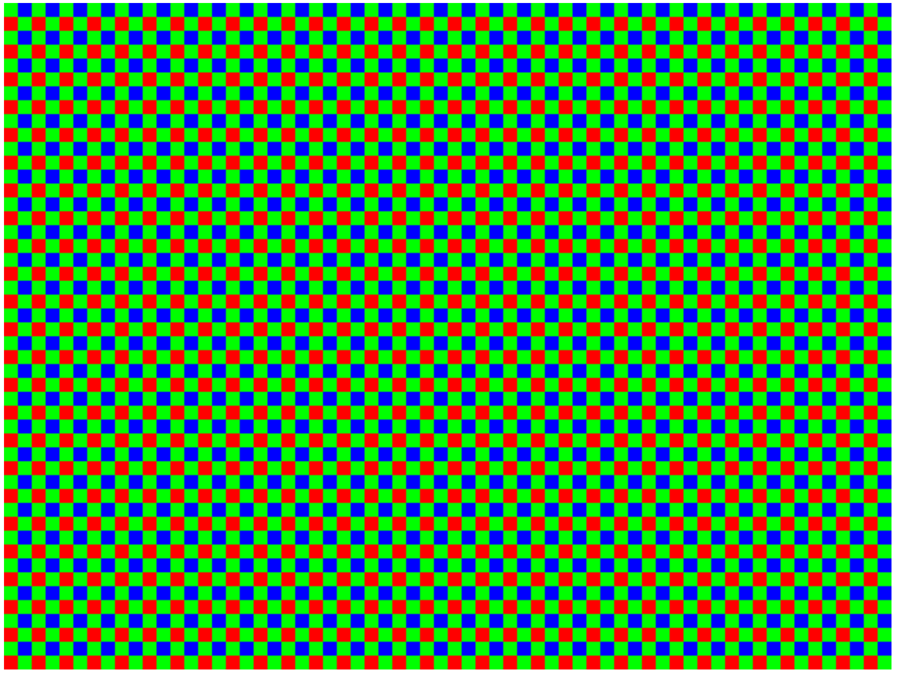


Image signal processors

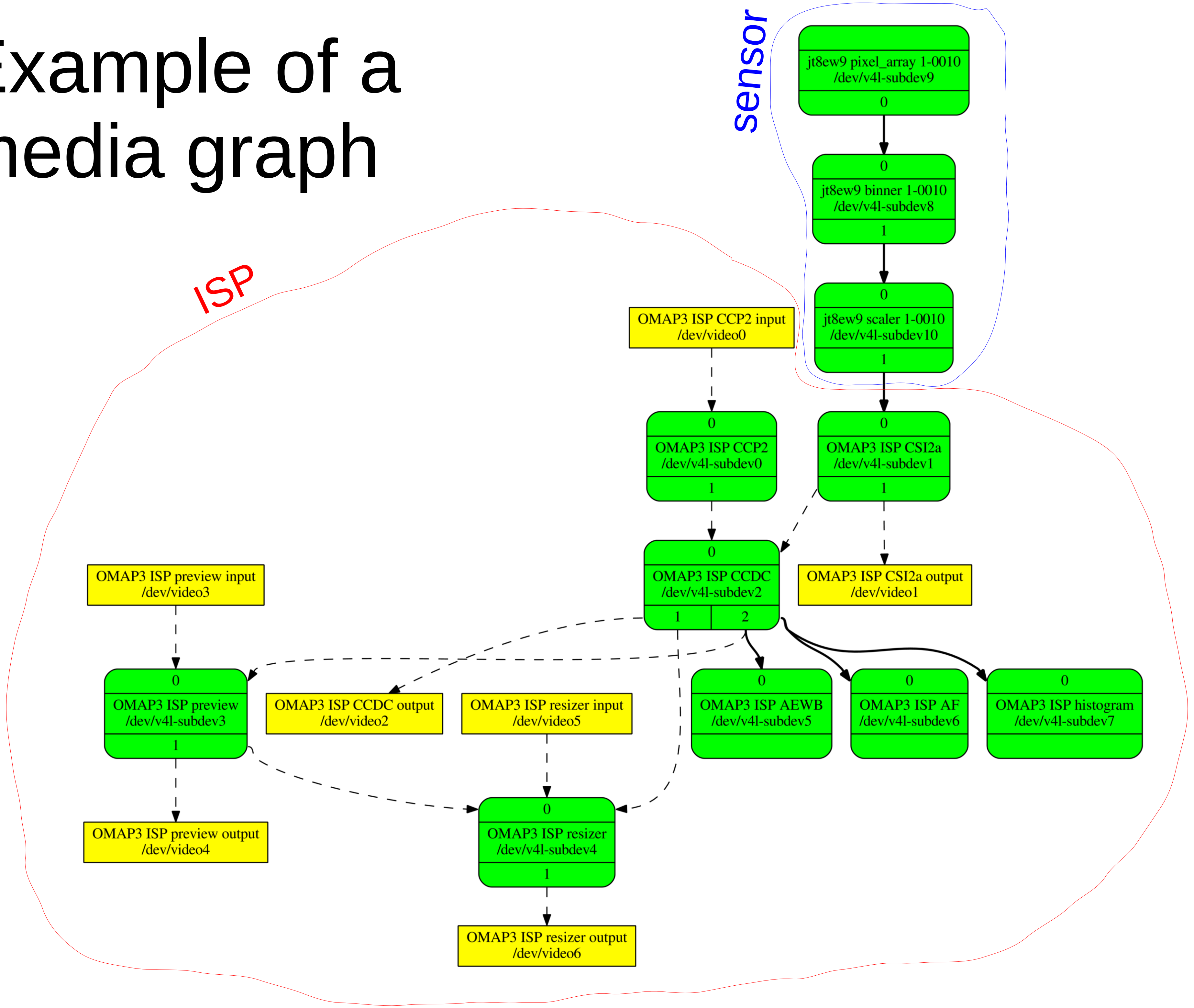
- Process the image for viewing

After ISP processing white looks like this --->

Video4Linux and Media controller

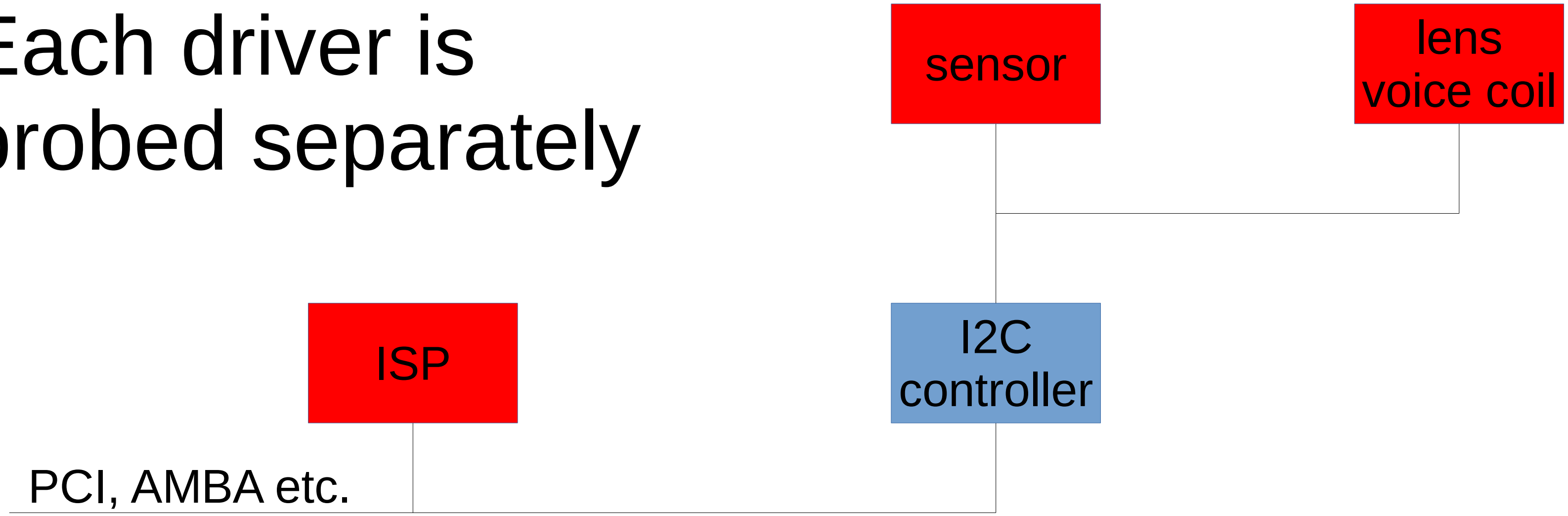
- Video4Linux (V4L2) is the Linux API for capturing images
  - Video capture cards
  - USB webcams
  - Cameras in embedded devices
- Media controller is a control interface for complex media devices
  - Image pipeline discovery and configuration
  - Device discovery

Example of a media graph



Probing

- Each driver is probed separately



- How to tell drivers they all are part of the same media device?

Media device setup

Media device driver

sensor driver

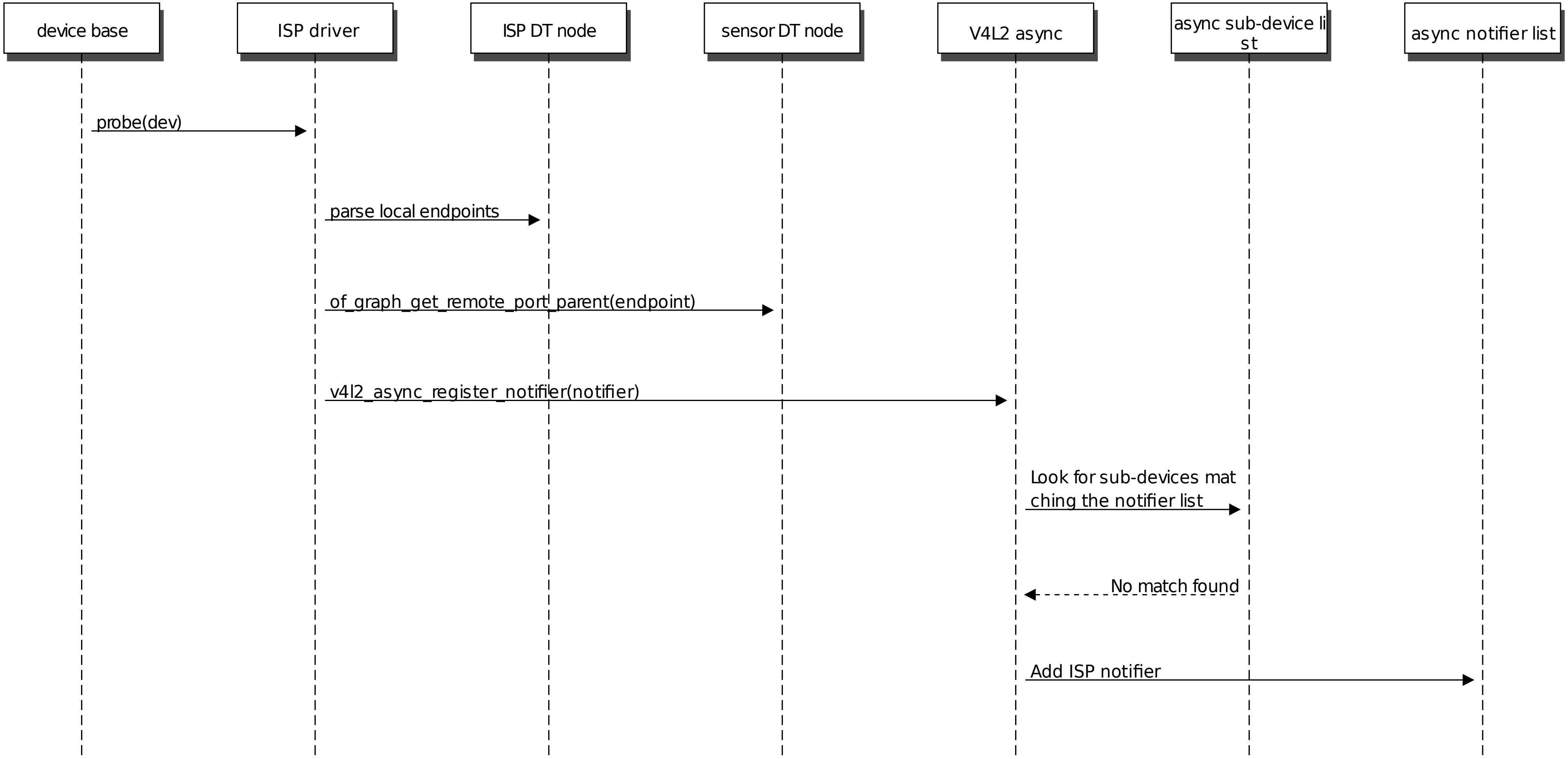
1. media_device_init()
2. v4l2_device_register()
3. video_register_device()
4. v4l2_device_register_subdev(sensor)
5. v4l2_device_register_subdev(isp)
6. v4l2_register_subdev_nodes()
7. media_device_register()

V4L2 async

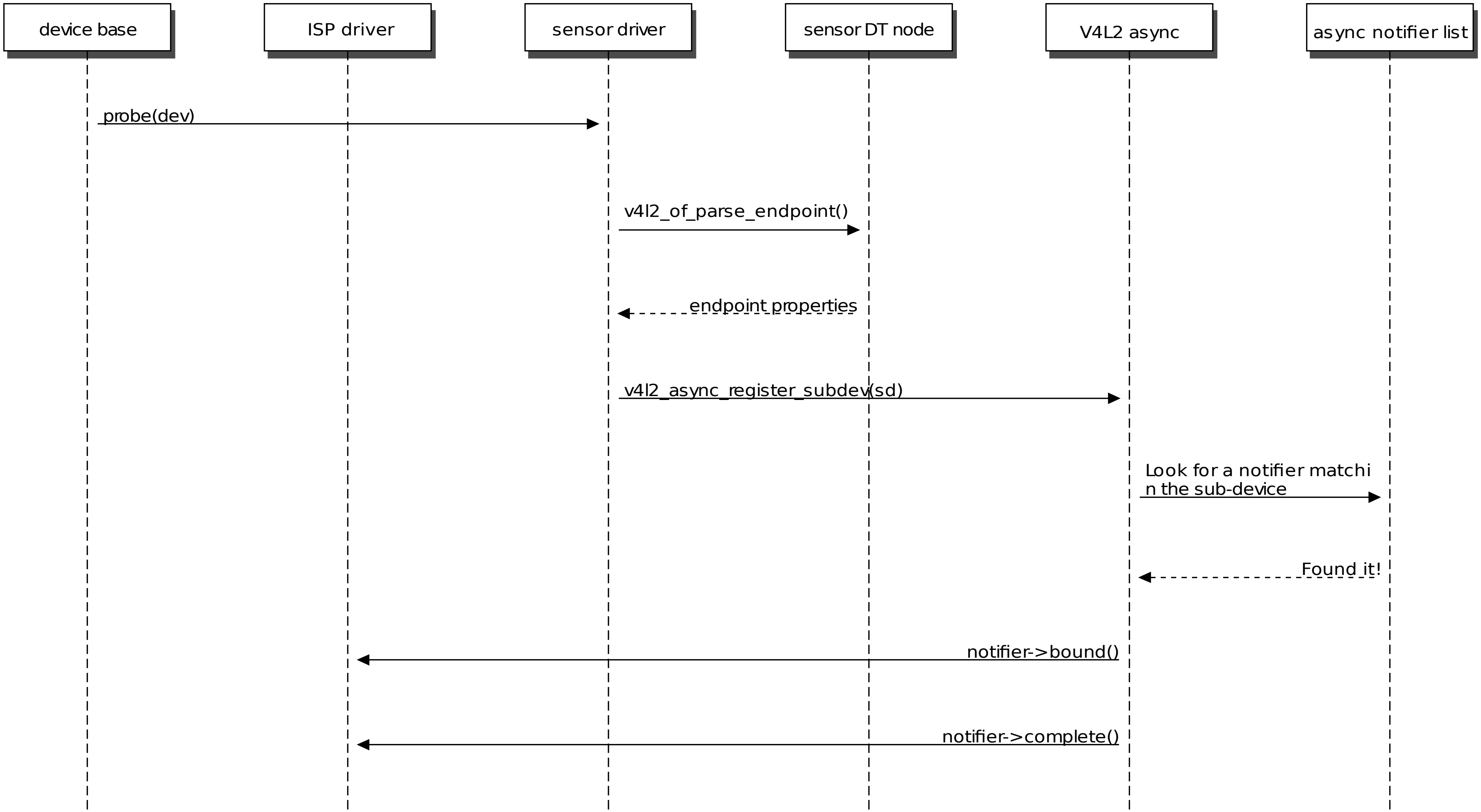
V4L2 async

- The V4L2 async framework facilitates sub-device registration
- V4L2 sub-device device node creation and media device registration postponed after probe
- To do its job, the V4L2 async framework makes use of firmware provided information

V4L2 async example (ISP)



V4L2 async (sensor)



Device tree

Device tree

- System hardware description in a human readable format
- Originates from Sparc / Open Firmware
- Primarily used on embedded systems
  - ARM
  - Also PowerPC, Sparc and x86
- Tree structure
  - Nodes
  - Properties
- Source code compiled into binary before use

Device Tree standard and bindings

- Device Tree specification maintained by devicetree.org
  - Syntax and some semantics
- Bindings define the interface between the firmware and the software
  - Bindings are Operating System specific
  - Linux Device tree binding documentation part of the Linux kernel source
  - FreeBSD developers appear to be converging towards using Linux DT bindings

Device tree graphs

- **phandle** properties can be used to refer to other nodes in the tree
- Port is an interface in a device (as in an IP block)
- Endpoint describes one end of a connection to a port [7]

Sensor node

```
&i2c2 {
	smia_1: camera@10 {
		compatible = "nokia,smia";
		reg = <0x10>;
		/* No reset gpio */
		vana-supply = <&vaux3>;
		clocks = <&isp 0>;
		clock-frequency = <9600000>;
		nokia,nvm-size = <(16 * 64)>;
		port {
			smia_1_1: endpoint {
				link-frequencies = /bits/ 64 <199200000 210000000 499200000>;
				clock-lanes = <0>;
				data-lanes = <1 2>;
				remote-endpoint = <&csi2a_ep>;
			};
		};
	};
};
```

source: arch/arm/boot/dts/omap3-n9.dts

ISP node board specific part

```
&isp {
	vdd-csiphy1-supply = <&vaux2>;
	vdd-csiphy2-supply = <&vaux2>;
	ports {
		port@2 {
			reg = <2>;
			csi2a_ep: endpoint {
				remote-endpoint = <&smia_1_1>;
				clock-lanes = <2>;
				data-lanes = <1 3>;
				crc = <1>;
				lane-polarities = <1 1 1>;
			};
		};
	};
};
```

source: arch/arm/boot/dts/omap3-n9.dts

OF graph API

- Parse port and endpoint nodes under device nodes
- Enumerate over endpoints
- Obtain remote endpoint
  - Based on the phandle value

ACPI

ACPI

- Advanced Configuration and Power Interface
- Operating system independent
- Origins in x86 and PC
  - Increasingly used in embedded systems
- Device discovery and enumeration
- **Power management**
- ACPI methods
  - Runnable code
  - ACPI virtual machine

ACPI

- ACPI specifications developed by UEFI Forum
  - Roughly one specification per year
- What do you do if you need to add a new kind of a device?
  - A new ACPI specification?

ACPI Device Specific Data

- _DSD object type part of ACPI 5.1 and later
  - Key-value pairs (property extension) and
  - Tree structures (hierarchical data extension)
- Together property and data extension could be used to implement very similar functionality to Devicetree
- _DSD property registry [6]
  - Light-weight approach for registering _DSD properties

fwnode property API

- Access properties independently of underlying firmware implementation
  - Device Tree
  - ACPI
- Makes use of ACPI _DSD property extension [2]

Future work

Fwnode graph API

- Functionally the same as the OF graph API
  - But is firmware independent
- Device tree implementation is used on Device tree
- Makes use of the _DSD hierarchical data extension [3] on ACPI
- Implementation at RFC level [4]

V4L2 fwnode API

- ”V4L2 ACPI support”
  - Embedded systems with I²C components
  - Requires both fwnode graph API and V4L2 fwnode API
- Same functionality as V4L2 OF API
- V4L2 fwnode and V4L2 OF fully interoperable
  - Sub-device driver using V4L2 fwnode works with a media device driver using V4L2 OF
  - and vice versa!
- RFC implementation available [5]

Flash

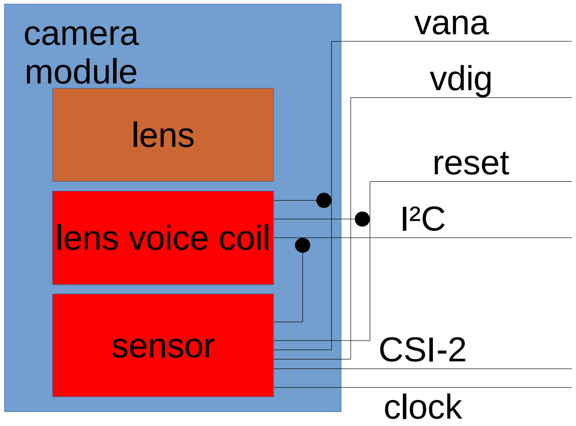
- LED flash devices supported
- But the kernel has no knowedge which sensor they're related to
  - This is rather important if there are multiple cameras in the system, such as most mobile phones nowadays
- Standardise phandle property for this?

Camera module

- Currently there's no ”camera module” concept in the kernel (nor DT or ACPI)
- Camera module construction is important for the user space
  - Which sensor and lens are related?
  - What kind of lens is there?
  - What's the voice coil spring constant?
  - Is there an infra red filter? What kind of filter is it?
  - What's the aperture size?

Camera module power on and power off sequences

- Regulators, clocks **and / or** GPIOs may be shared between module components
- Power on and power off sequences device component specific
  - Which order and when each resource may be enabled?
  - E.g. regulator and clock are enabled, then after 10 ms the reset GPIO can be lifted and the device is ready for use
- Requirements of both lens and sensor must be considered for module power-up sequence



Questions?

References

[1] http://www.uefi.org/acpi

[2] http://www.uefi.org/sites/default/files/resources/_DSD-device-properties-UUID.pdf

[3] http://www.uefi.org/sites/default/files/resources/_DSD-hierarchical-data-extension-UUID-v1.pdf

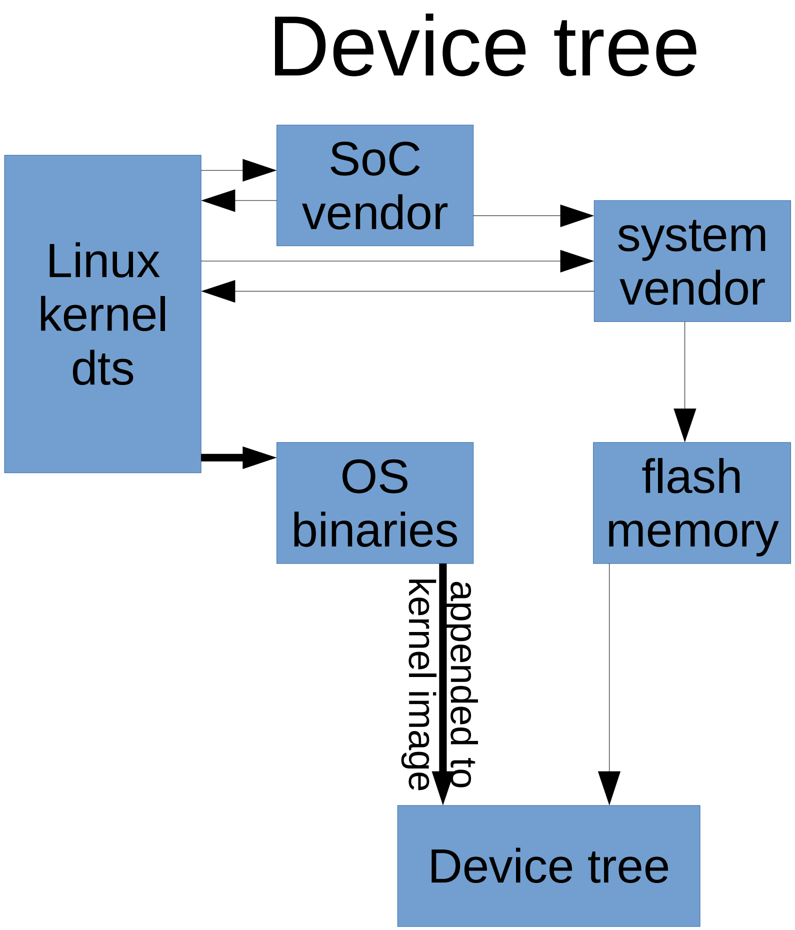
[4] http://www.spinics.net/lists/linux-acpi/msg69547.html

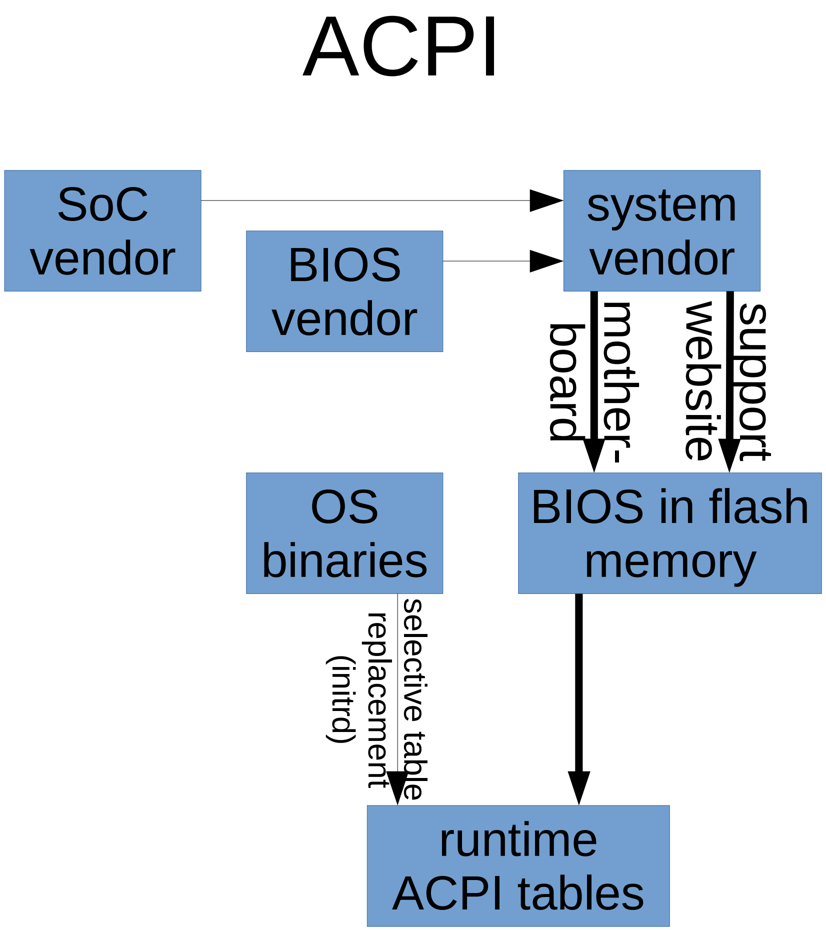
[5] http://www.spinics.net/lists/linux-media/msg106160.html

[6] https://github.com/ahs3/dsd

[7] Documentation/devicetree/bindings/graph.txt

Firmware logistics





ACPI camera example

ACPI camera example

```
Scope (\_SB.PCI0.I2C2)
{
   Device (CAM0)
   {
       Name (_DSD, Package () {
          /* device specific data */
          Package () {
              Package () { "compatible", Package () { "nokia,smia" } },
              Package () { "lanes", 4 },
              Package () { "clock-frequency", 24000000 },
          },
          /* data extension */
          Package () {
              Package () { "ports", "PRTS" },
          }
       })
```

ACPI camera example

```
Name (PRTS, Package() {
   /* data extension */
   Package () {
       Package () { "port@0", "PRT0" },
   }
})
Name (PRT0, Package() {
   /* device specific data */
   Package () {
       Package () { "port", 0 },
   },
   /* data extension */
   Package () {
       Package () { "endpoint@0", "EP0" },
   }
})
```

ACPI camera example

```
        Name (EP0, Package() {
            /* device specific data */
            Package () {
                Package () { "endpoint", 0 },
                Package () { "clock-lanes", 0 },
                Package () { "data-lanes", Package () { 1, 2, 3, 4 } },
                Package () { "link-frequencies",
                        Package () { 209600000, 342000000, 451200000 } },
                Package () { "remote-endpoint", Package() { \_SB.PCI0.ISP, 0, 0, 0 } },
            },
        })
    }
}
```

ACPI ISP example

```
Scope (\_SB.PCI0)
{
  Device (ISP)
  {
     Name (_DSD, Package () {
       /* data extension */
       Package () {
          Package () { "ports", "PRTS" },
       }
     })
     Name (PRTS, Package() {
       /* data extension */
       Package () {
          Package () { "port@4", "PRT4" },
       }
     })
```

ACPI ISP example

```
    Name (PRT4, Package() {
      /* device specific data */
      Package () {
        Package () { "port", 4 }, /* CSI-2 port number */
      },
      /* data extension */
      Package () {
        Package () { "endpoint@0", "EP0" },
      }
    })
    Name (EP0, Package() {
      /* device specific data */
      Package () {
        Package () { "endpoint", 0 },
        Package () { "clock-lanes", 0 },
        Package () { "data-lanes", Package () { 1, 2, 3, 4 } },
        Package () { "remote-endpoint", Package () { \_SB.PCI0.I2C2.CAM0, 0, 0, 0 } },
      },
    })
  }
}
```