Linaro Connect
MADRID 2024 | MAY 14-17 2024

Open source support for Arm's Mali-C55 ISP

Daniel Scally
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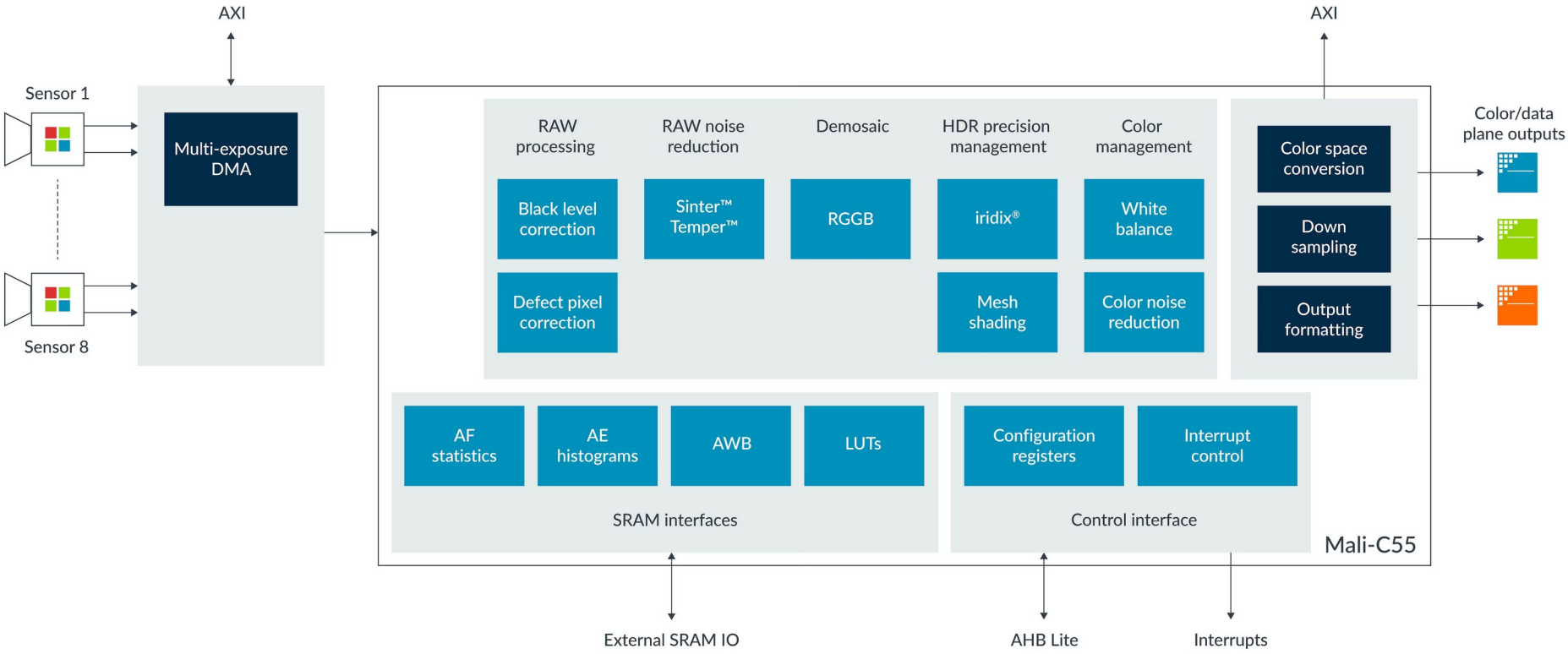
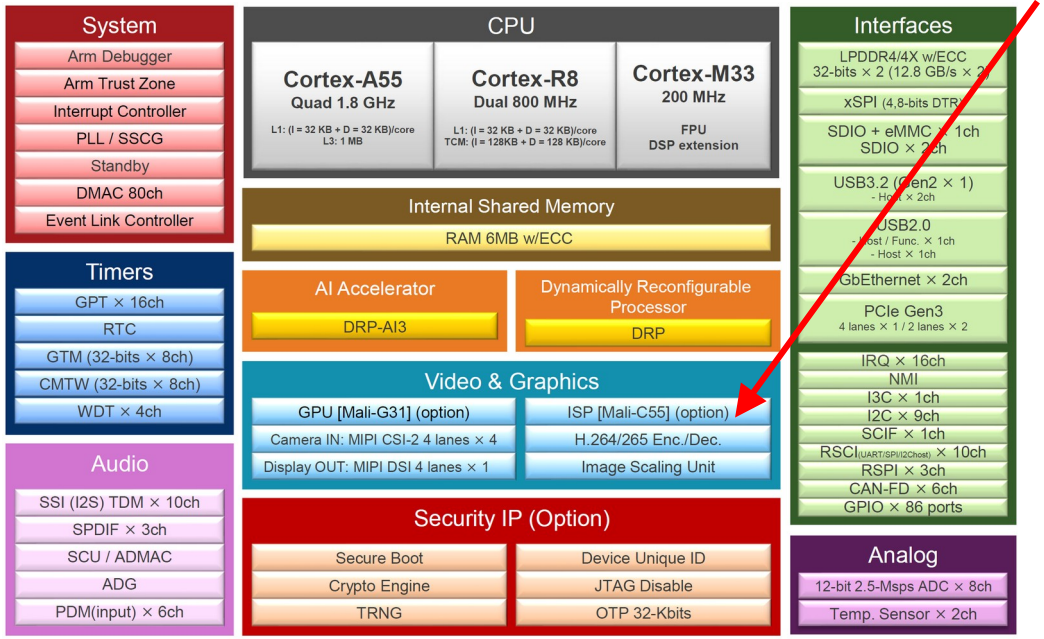
- Introduction
- The hardware
- The kernel
- libcamera
- Future challenges
- How can you use what we’ve done?
- Any questions?

Hi, I’m Dan

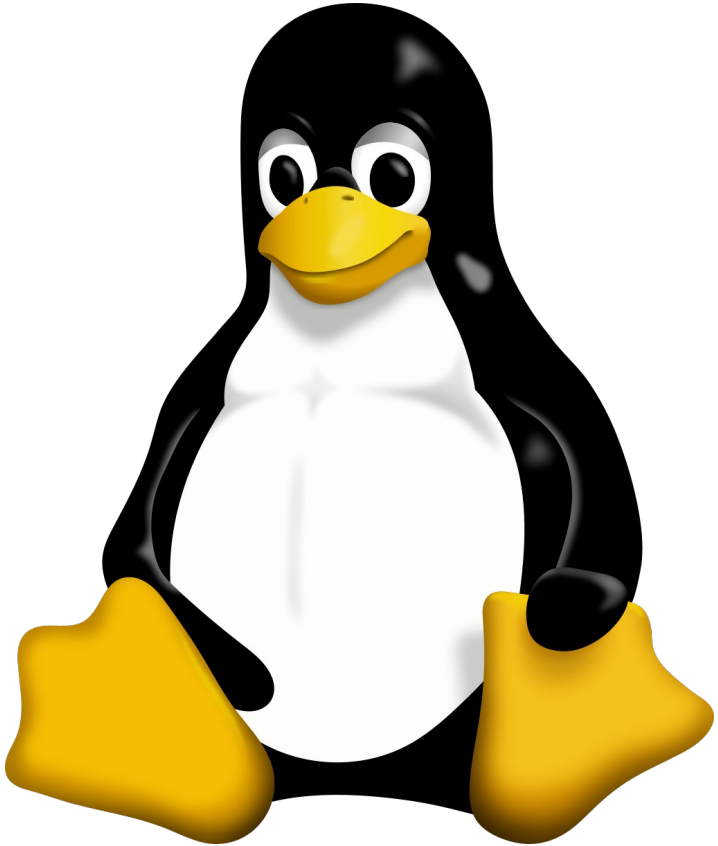
Arm’s Mali-C55 ISP

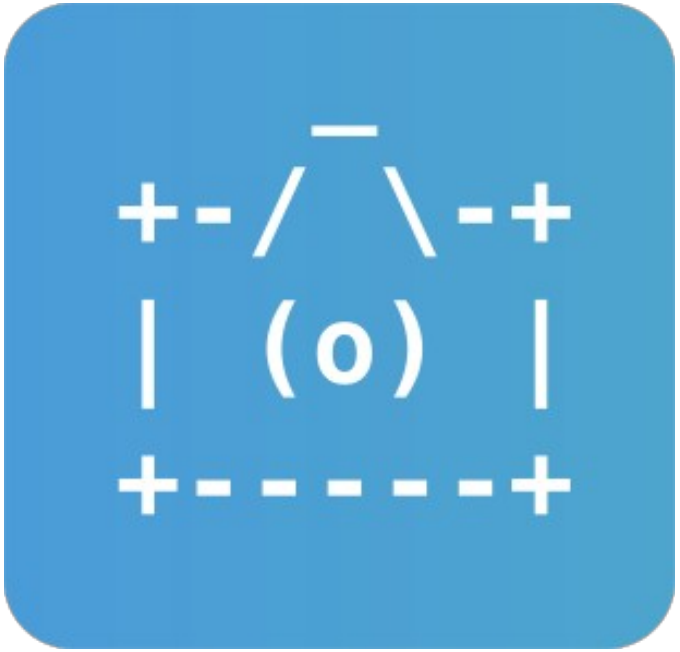


Where can I get one?



- Renesas RZ/V2H is the SoC you want (but it's an option, so be careful)
- RZ/V2H-EVK has it
- IMDT has a V2H SOM and SBC
- Kakip might have one with a form factor like Rpi in the future

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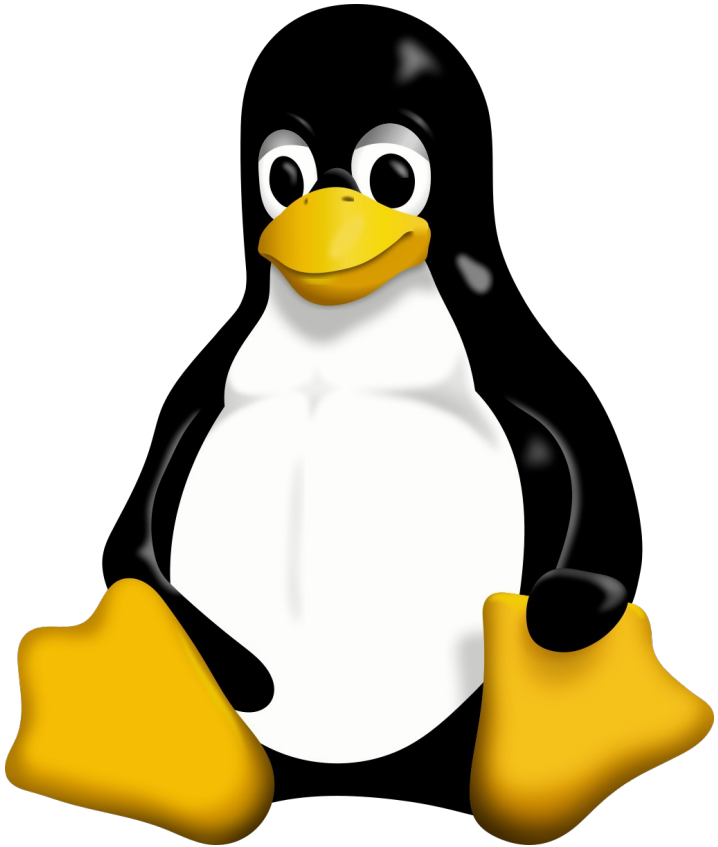

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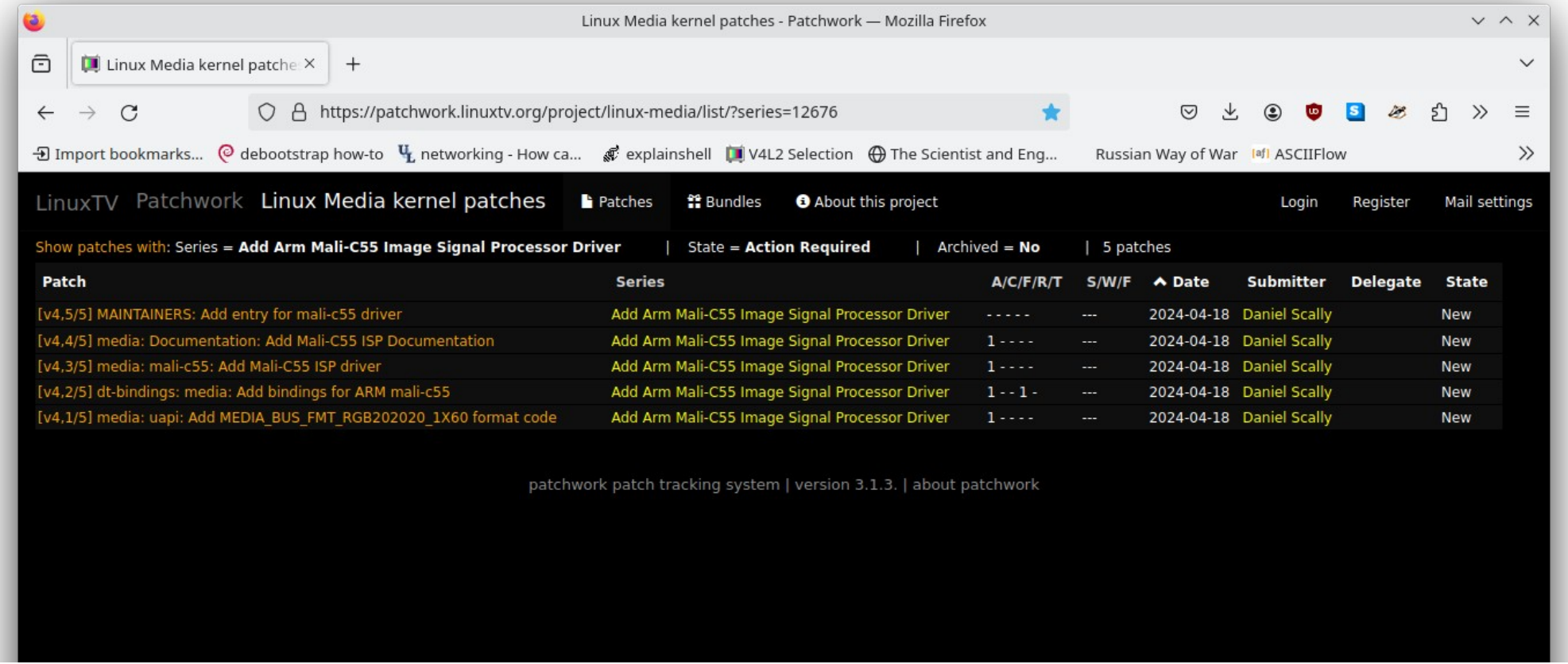
Linux Media kernel patches - Patchwork — Mozilla Firefox
Linux Media kernel patche
https://patchwork.linuxtv.org/project/linux-media/list/?series=12676
Import bookmarks...
debootstrap how-to
networking - How ca...
explainshell
V4L2 Selection
The Scientist and Eng...
Russian Way of War
ASCIIFlow
LinuxTV Patchwork Linux Media kernel patches
Patches
Bundles
About this project
Login
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Show patches with: Series = Add Arm Mali-C55 Image Signal Processor Driver | State = Action Required | Archived = No | 5 patches
Patch
Series
A/C/F/R/T
S/W/F
Date
Submitter
Delegate
State
[v4,5/5] MAINTAINERS: Add entry for mali-c55 driver
Add Arm Mali-C55 Image Signal Processor Driver
- - - - -

2024-04-18
Daniel Scally
New
[v4,4/5] media: Documentation: Add Mali-C55 ISP Documentation
Add Arm Mali-C55 Image Signal Processor Driver
1 - - - -

2024-04-18
Daniel Scally
New
[v4,3/5] media: mali-c55: Add Mali-C55 ISP driver
Add Arm Mali-C55 Image Signal Processor Driver
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2024-04-18
Daniel Scally
New
[v4,2/5] dt-bindings: media: Add bindings for ARM mali-c55
Add Arm Mali-C55 Image Signal Processor Driver
1 - - 1 -

2024-04-18
Daniel Scally
New
[v4,1/5] media: uapi: Add MEDIA_BUS_FMT_RGB202020_1X60 format code
Add Arm Mali-C55 Image Signal Processor Driver
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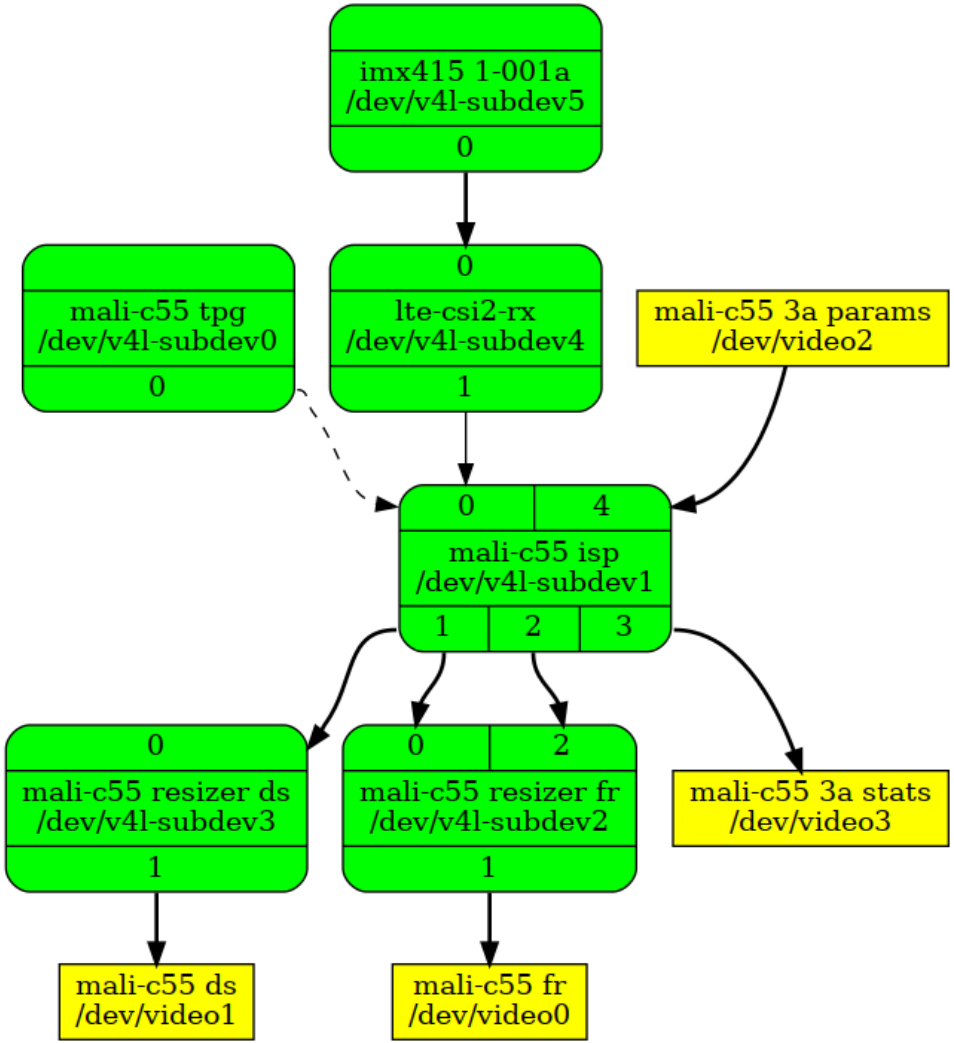
2024-04-18
Daniel Scally
New
patchwork patch tracking system | version 3.1.3. | about patchwork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mali-c55 tpg
/dev/v4l-subdev0
0
0
lte-csi2-rx
/dev/v4l-subdev4
1
mali-c55 3a params
/dev/video2
0
4
mali-c55 isp
/dev/v4l-subdev1
1
2
3
0
mali-c55 resizer ds
/dev/v4l-subdev3
1
0
2
mali-c55 resizer fr
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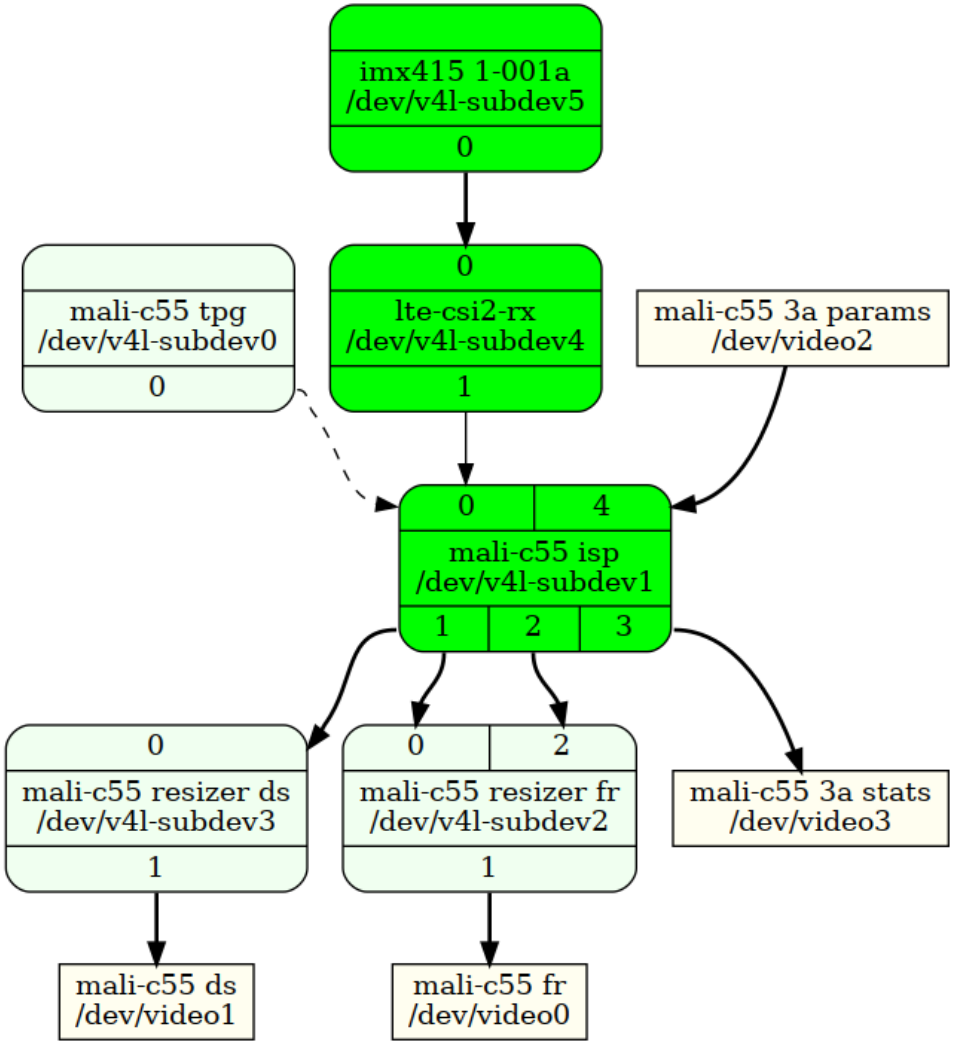
mali-c55 3a stats
/dev/video3
mali-c55 ds
/dev/video1
mali-c55 fr
/dev/video0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/dev/v4l-subdev4
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mali-c55 tpg
/dev/v4l-subdev0
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mali-c55 3a params
/dev/video2
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mali-c55 isp
/dev/v4l-subdev1
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mali-c55 resizer ds
/dev/v4l-subdev3
1
0
2
mali-c55 resizer fr
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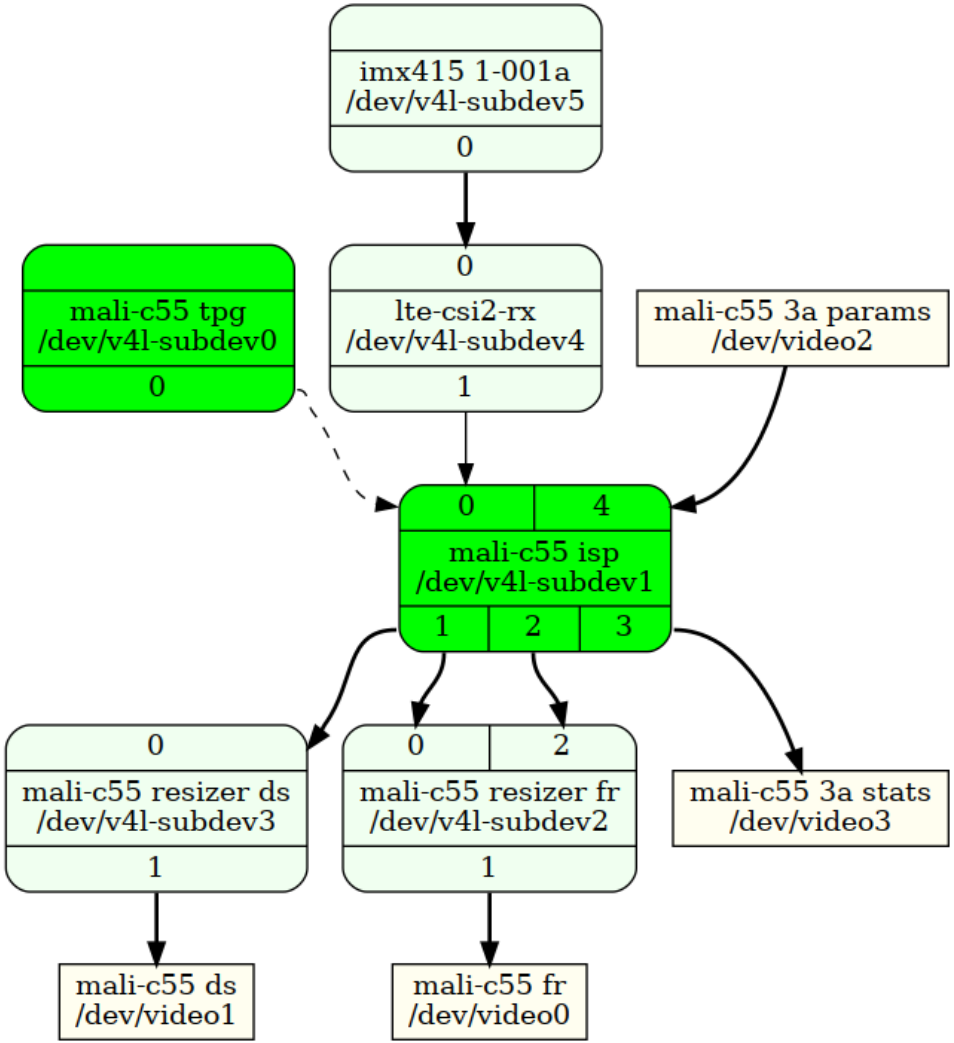
/dev/video3
mali-c55 ds
/dev/video1
mali-c55 fr
/dev/video0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/dev/v4l-subdev4
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mali-c55 tpg
/dev/v4l-subdev0
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mali-c55 3a params
/dev/video2
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mali-c55 isp
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mali-c55 resizer ds
/dev/v4l-subdev3
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2
mali-c55 resizer fr
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mali-c55 3a stats
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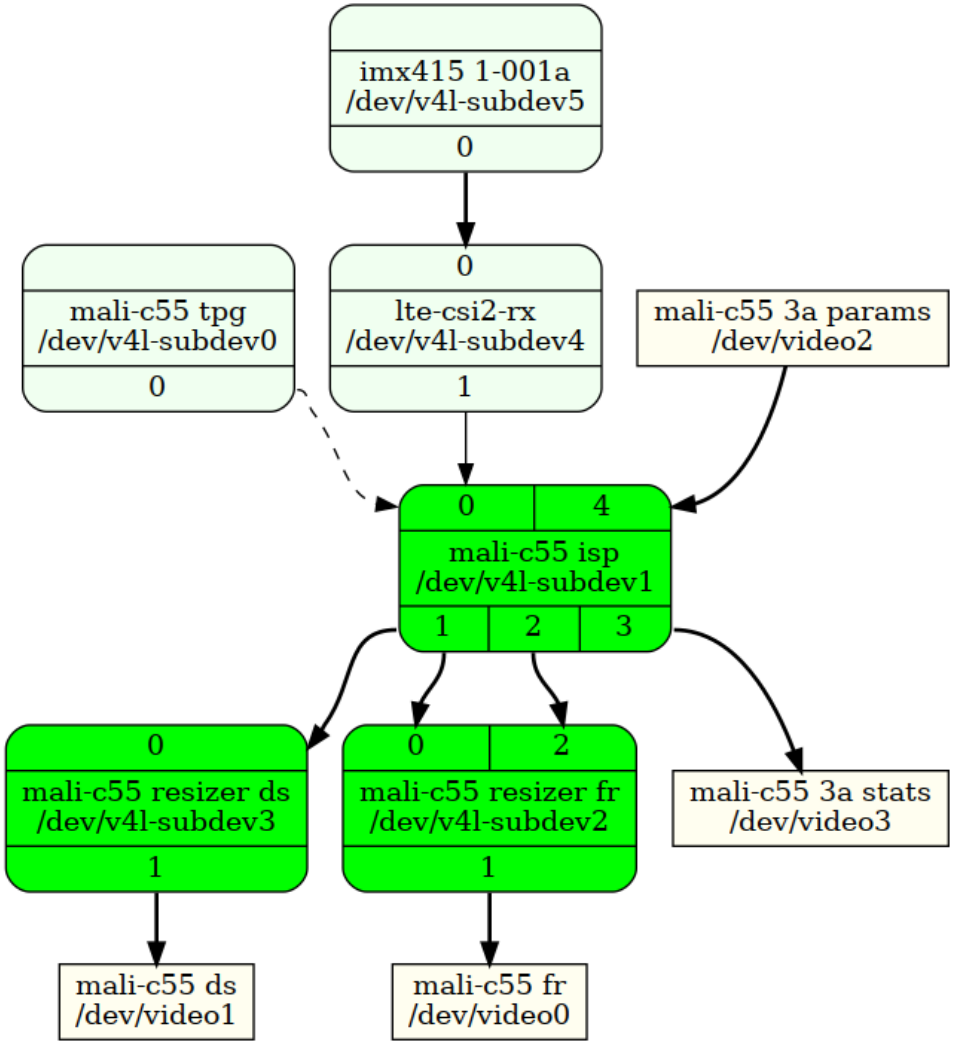
/dev/video1
mali-c55 fr
/dev/video0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mali-c55 resizer fr
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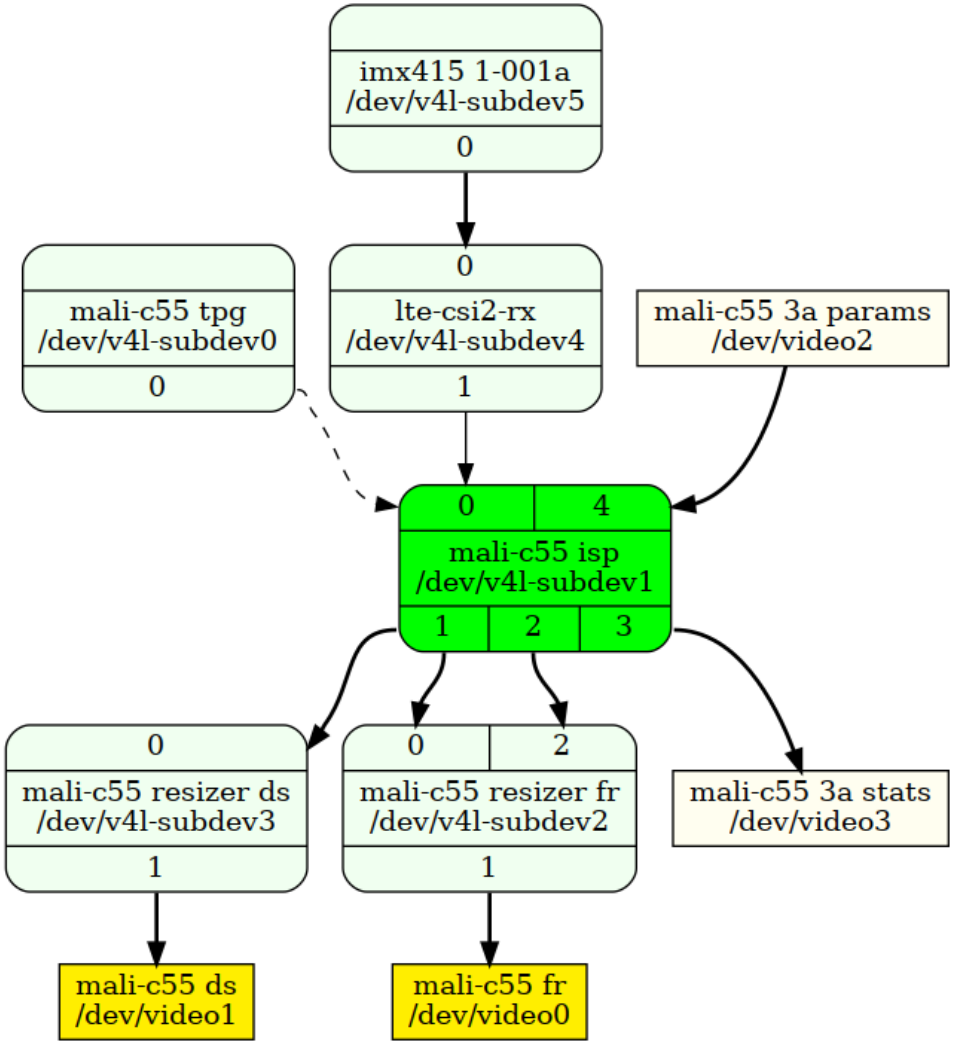
/dev/video1
mali-c55 fr
/dev/video0


imx415 1-001a
/dev/v4l-subdev5
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mali-c55 tpg
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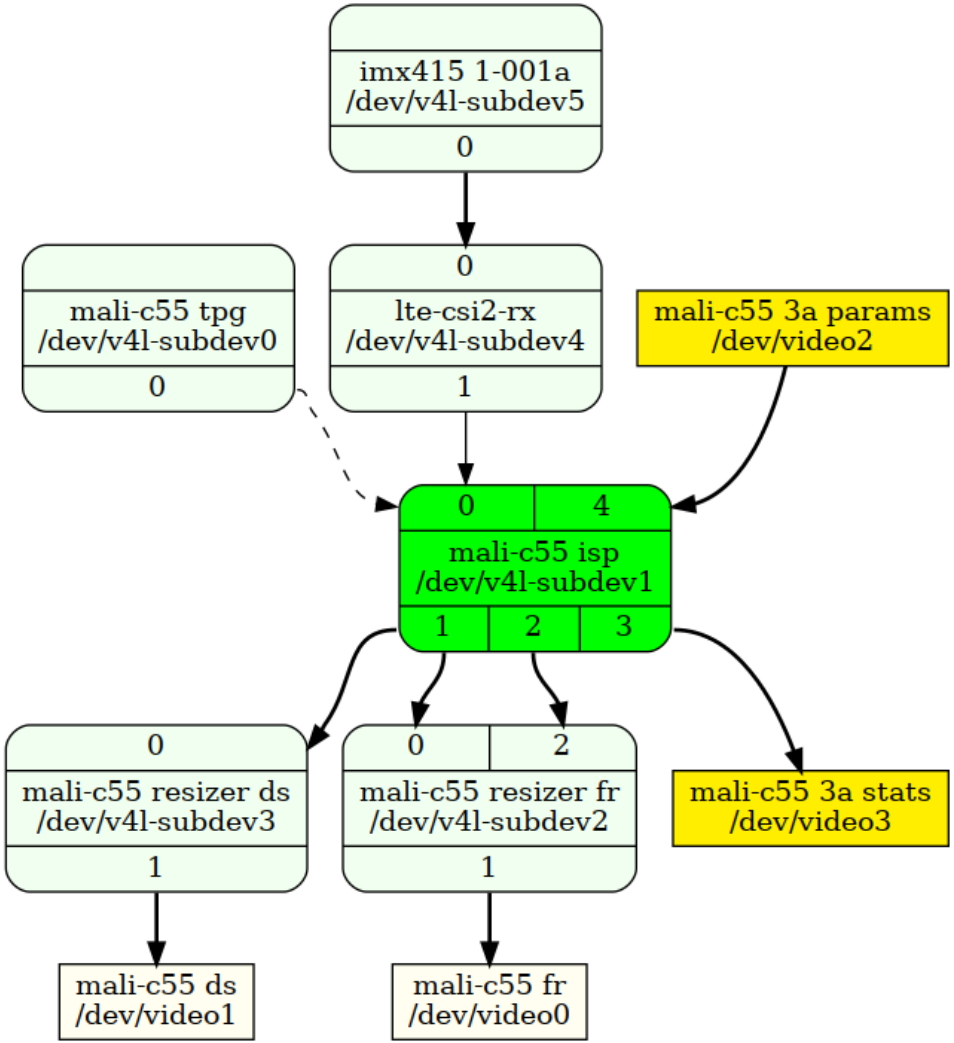
/dev/video1
mali-c55 fr
/dev/video0


imx415 1-001a
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mali-c55 tpg
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mali-c55 3a params
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mali-c55 resizer fr
/dev/v4l-subdev2
1
mali-c55 3a stats
/dev/video3
mali-c55 ds
/dev/video1
mali-c55 fr
/dev/video0

Usually parameters are monolithic

```
struct mali_c55_params_buffer {
        struct {
                __u32 chan00;
                __u32 chan01;
                __u32 chan10;
                __u32 chan11;
                _u8 field_flags;
        } sensor_off_preshading;
        struct {
                __u8 skip_x;
                __u8 offset_x;
                __u8 skip_y;
                __u8 offset_y;
                __u8 scale_bottom;
                __u8 scale_top;
                __u8 plane_mode;
                __u8 tap_point;
                __u8 field_flags;
        } aexp_hist;

        // Plus lots more sub-structs...

        __u8 block_flags
};
```

We've gone for a common header...

```
struct mali_c55_params_block_header {
        enum mali_c55_param_block_type type;
        bool enabled;
        size_t size;
};
```

```
enum mali_c55_param_block_type {
    MALI_C55_PARAM_BLOCK_SENSOR_OFFS,
    MALI_C55_PARAM_BLOCK_AEXP_HIST,
    MALI_C55_PARAM_BLOCK_AEXP_IHIST,
    MALI_C55_PARAM_BLOCK_AEXP_HIST_WEIGHT,
    MALI_C55_PARAM_BLOCK_AEXP_IHIST_WEIGHTS,
    MALI_C55_PARAM_BLOCK_DIGITAL_GAIN,
    MALI_C55_PARAM_BLOCK_AWB_GAINS,
    MALI_C55_PARAM_BLOCK_AWB_CONFIG,
    MALI_C55_PARAM_BLOCK_AWB_GAINS_AEXP,
    MALI_C55_PARAM_MESH_SHADING_CONFIG,
    MALI_C55_PARAM_MESH_SHADING_SELECTION,
    MALI_C55_PARAM_BLOCK_SENTINEL,
};
```

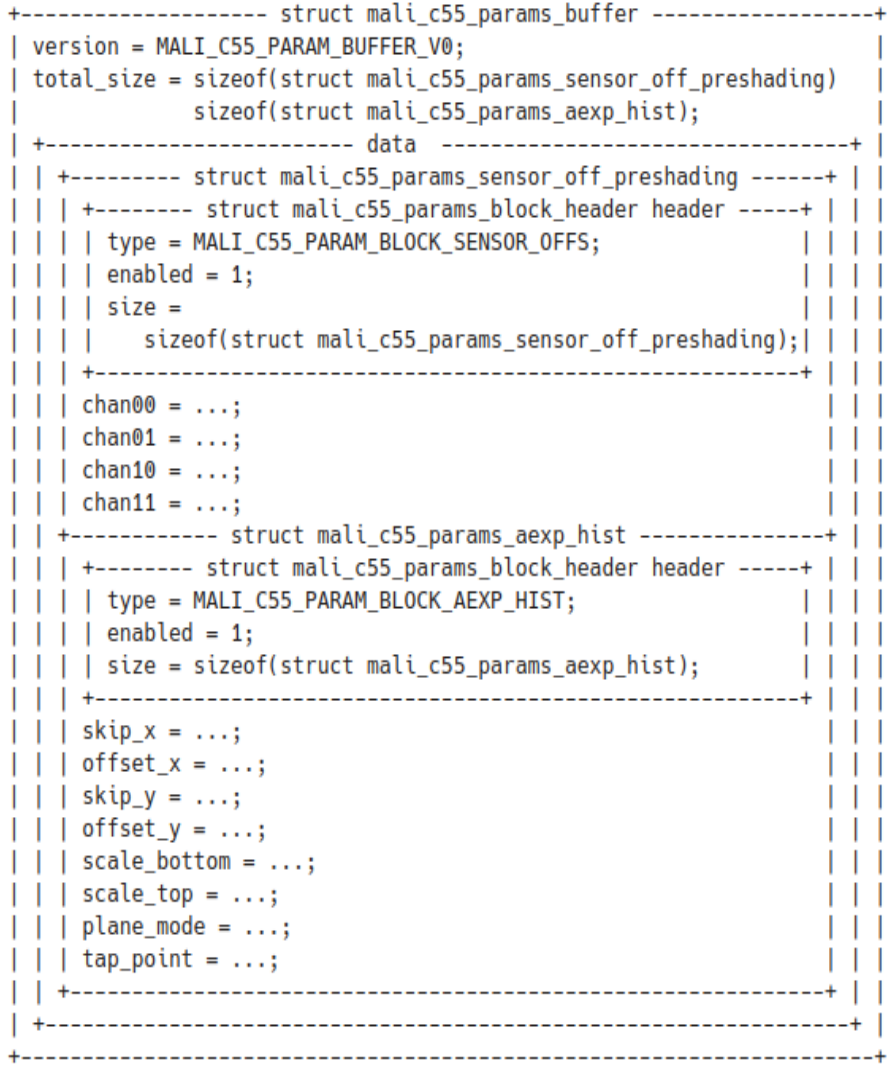
...embedded into structs for each block...

```
struct mali_c55_params_sensor_off_preshading {
    struct mali_c55_params_block_header header;
    __u32 chan00;
    __u32 chan01;
    __u32 chan10;
    __u32 chan11;
};
```

```
struct mali_c55_params_aexp_hist {
    struct mali_c55_params_block_header header;
    __u8 skip_x;
    __u8 offset_x;
    __u8 skip_y;
    __u8 offset_y;
    __u8 scale_bottom;
    __u8 scale_top;
    __u8 plane_mode;
    __u8 tap_point;
};
```

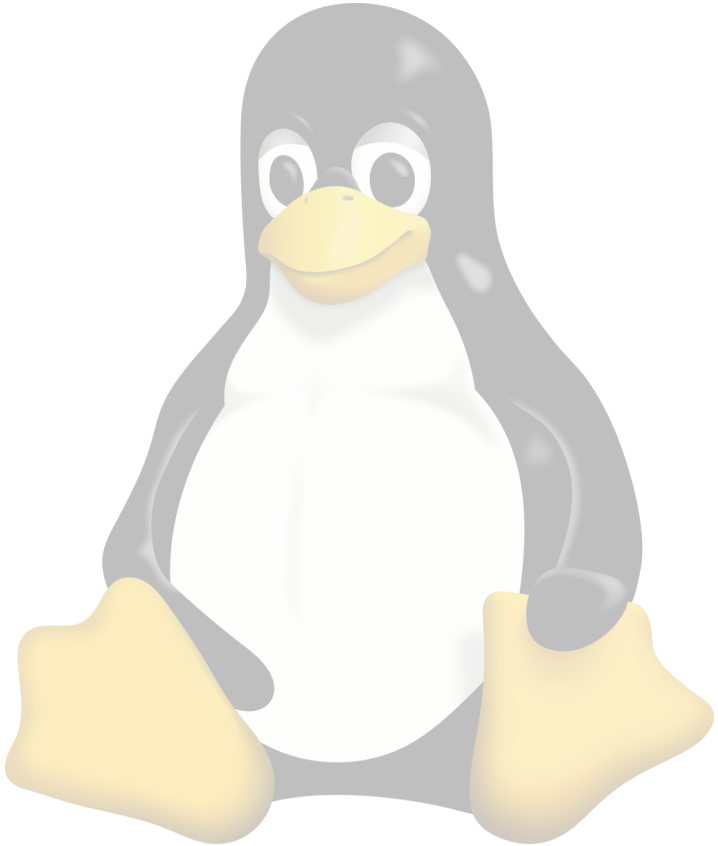
...and then those are packed into .data[]...

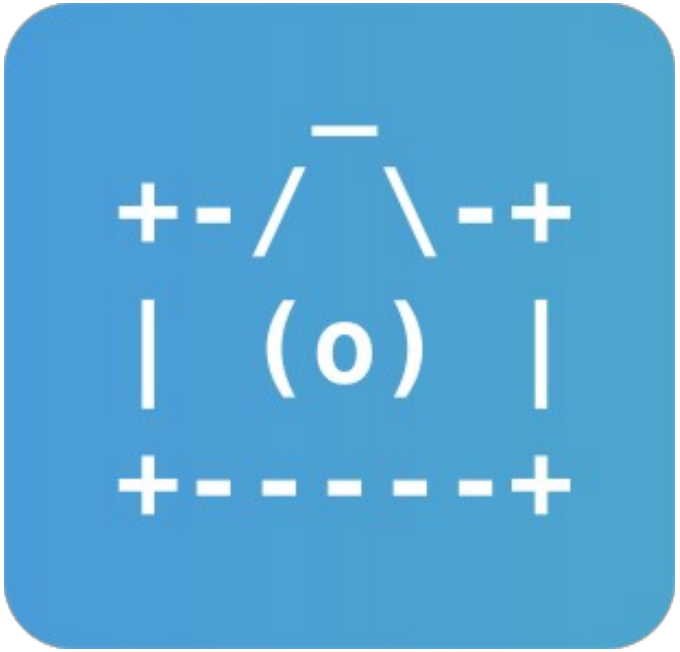
```
struct mali_c55_params_buffer {
        enum mali_c55_param_buffer_version version;
        size_t total_size;
        __u8 data[MALI_C55_PARAMS_MAX_SIZE];
};
```



Then we can handle them in the driver with some type punning

```
struct mali_c55_params_buffer *config = vb2_plane_addr(...);
size_t block_offset = 0;

while (block_offset < config->total_size) {
    struct mali_c55_params_block_header *block;

    block = (struct mali_c55_params_block_header *)
            &config->data[block_offset];

    switch (block->type) {
    case MALI_C55_PARAM_BLOCK_SENSOR_OFFS:
            struct mali_c55_params_sensor_off_preshading *sensor_offs =
                    (struct mali_c55_params_sensor_off_preshading *)block;

            handle_sensor_offs(sensor_offs);
            break;
    ...
    }

    block_offset += block_size
}
```

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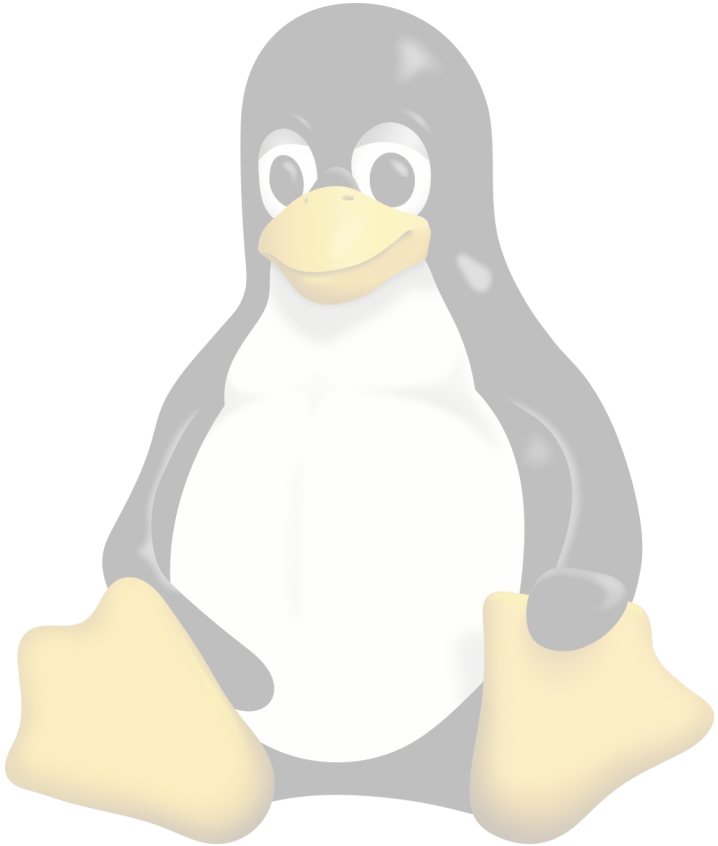
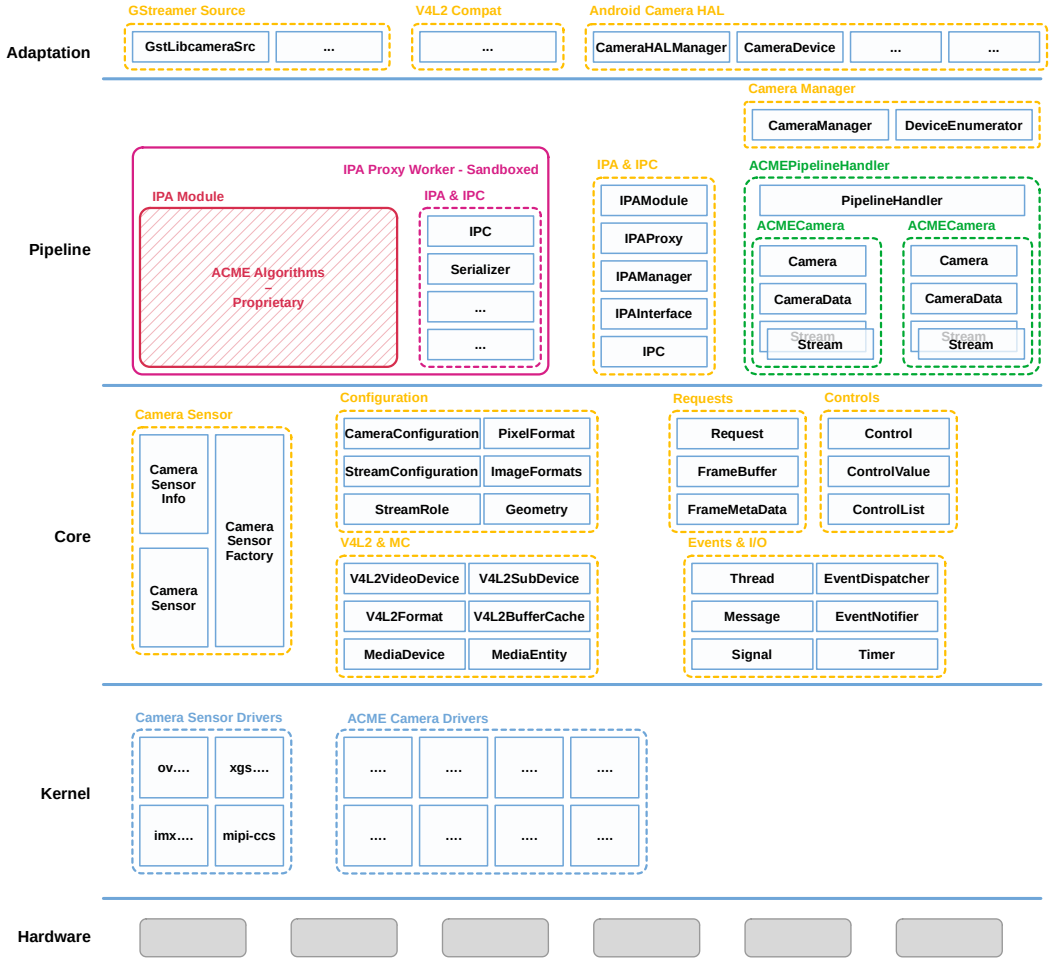
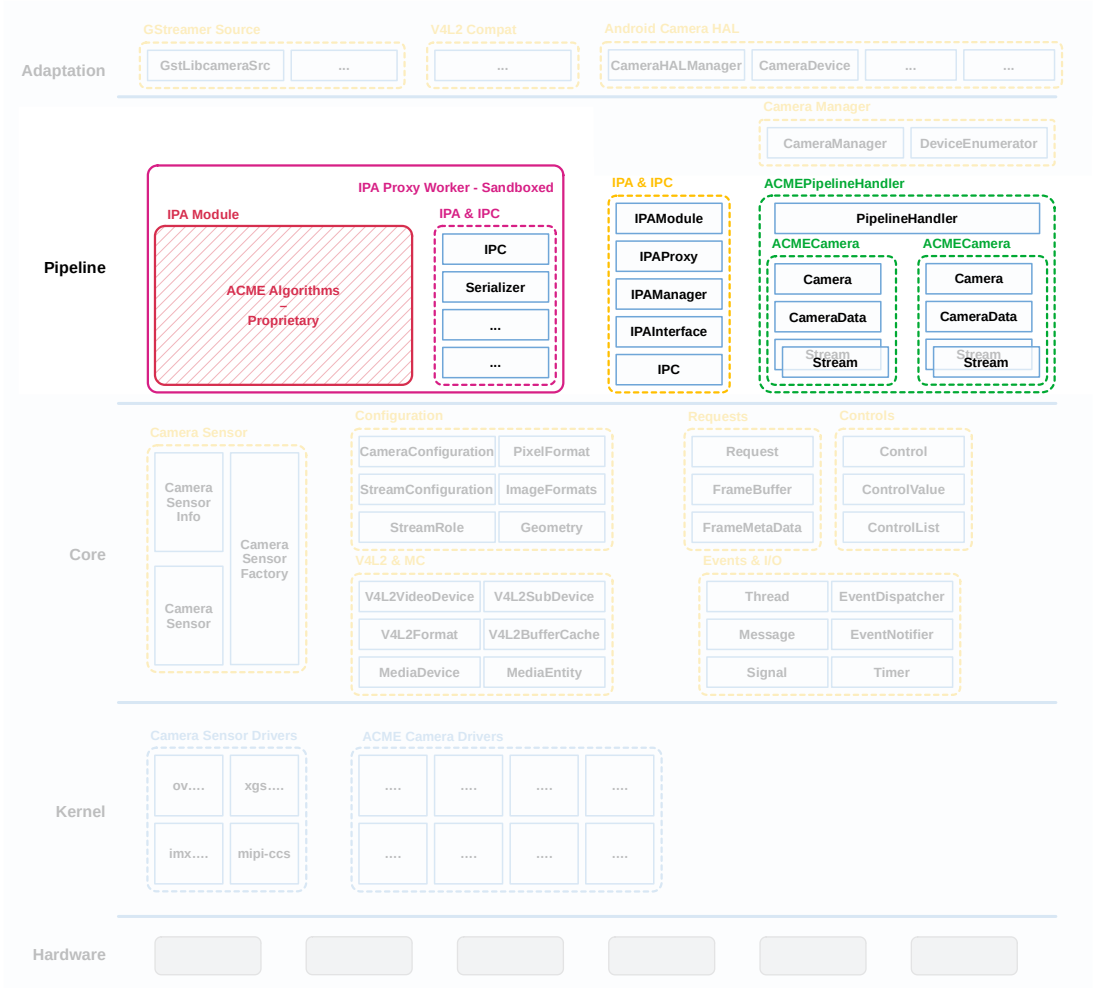




The Camera Stack



The Pipeline

Learn How to Support Your SoC and ISP in Libcamera - Laurent Pinchart, Ideas on Board

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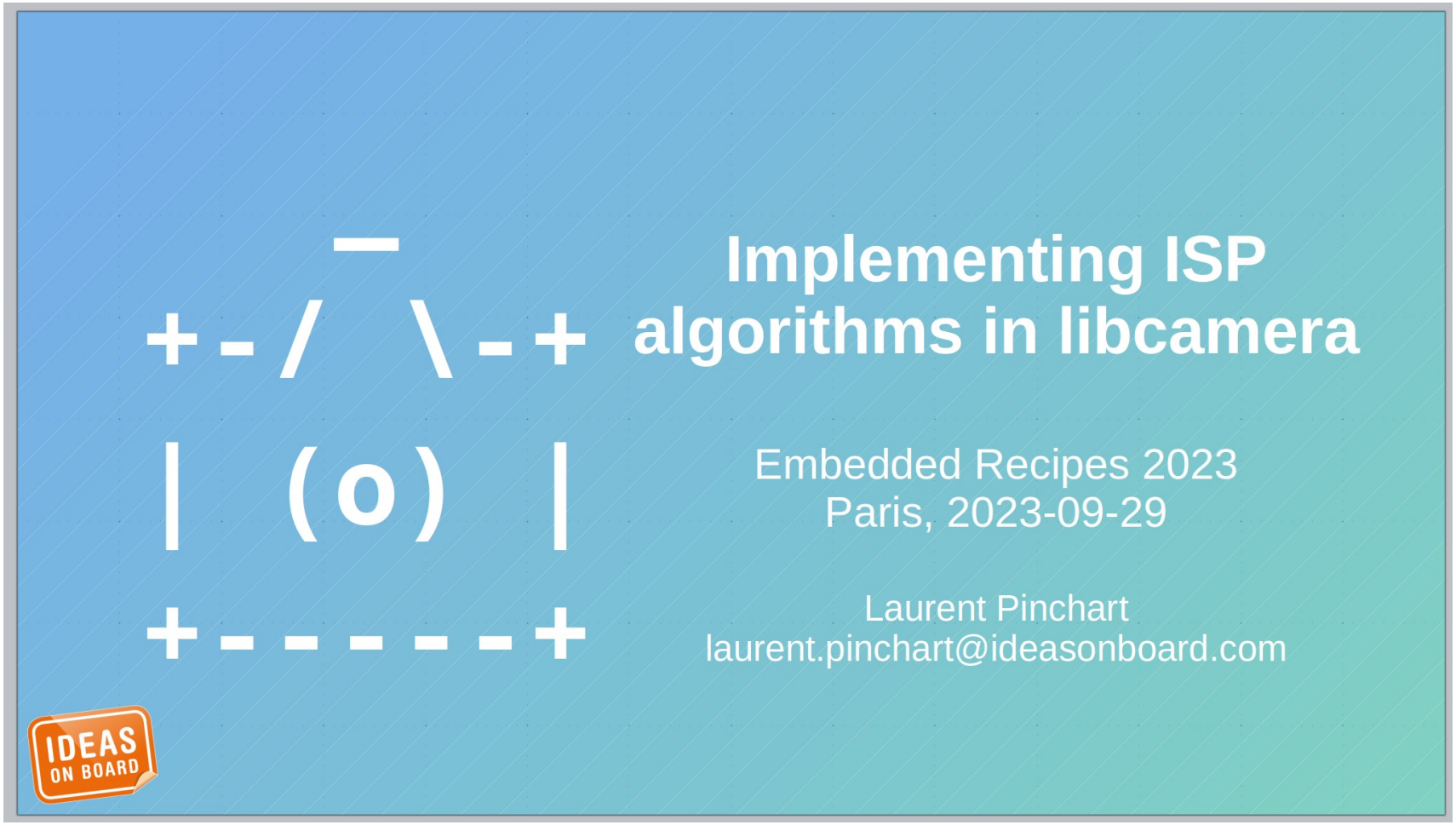
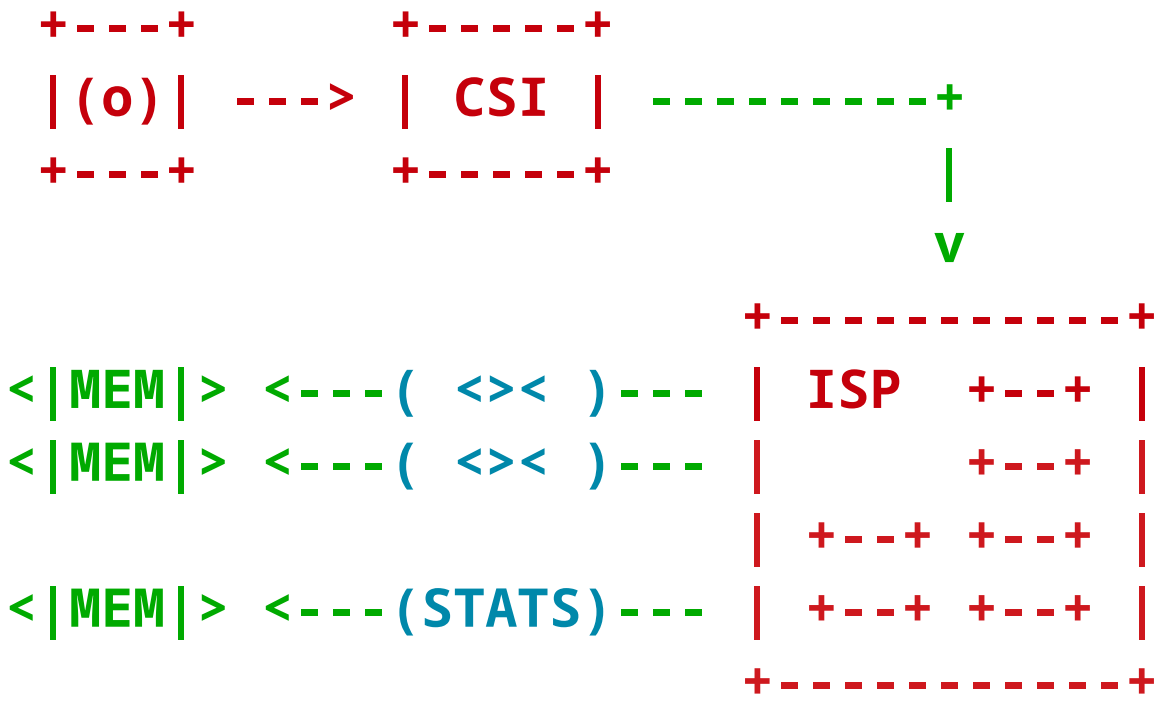
IDEAS ON BOARD

https://www.youtube.com/watch?v=x9ndjdvXPl0

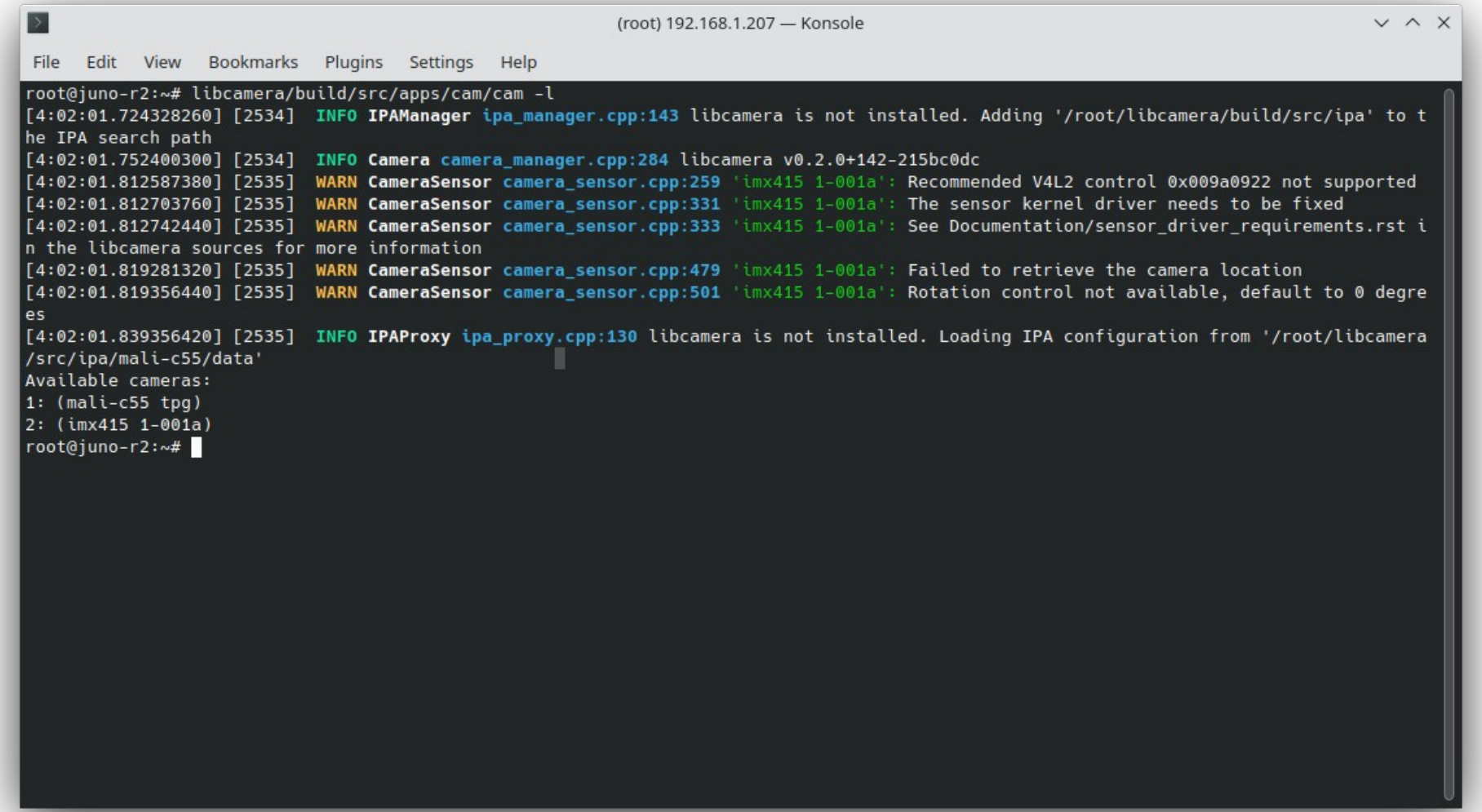


https://www.youtube.com/watch?v=RrHcgBa2f0U

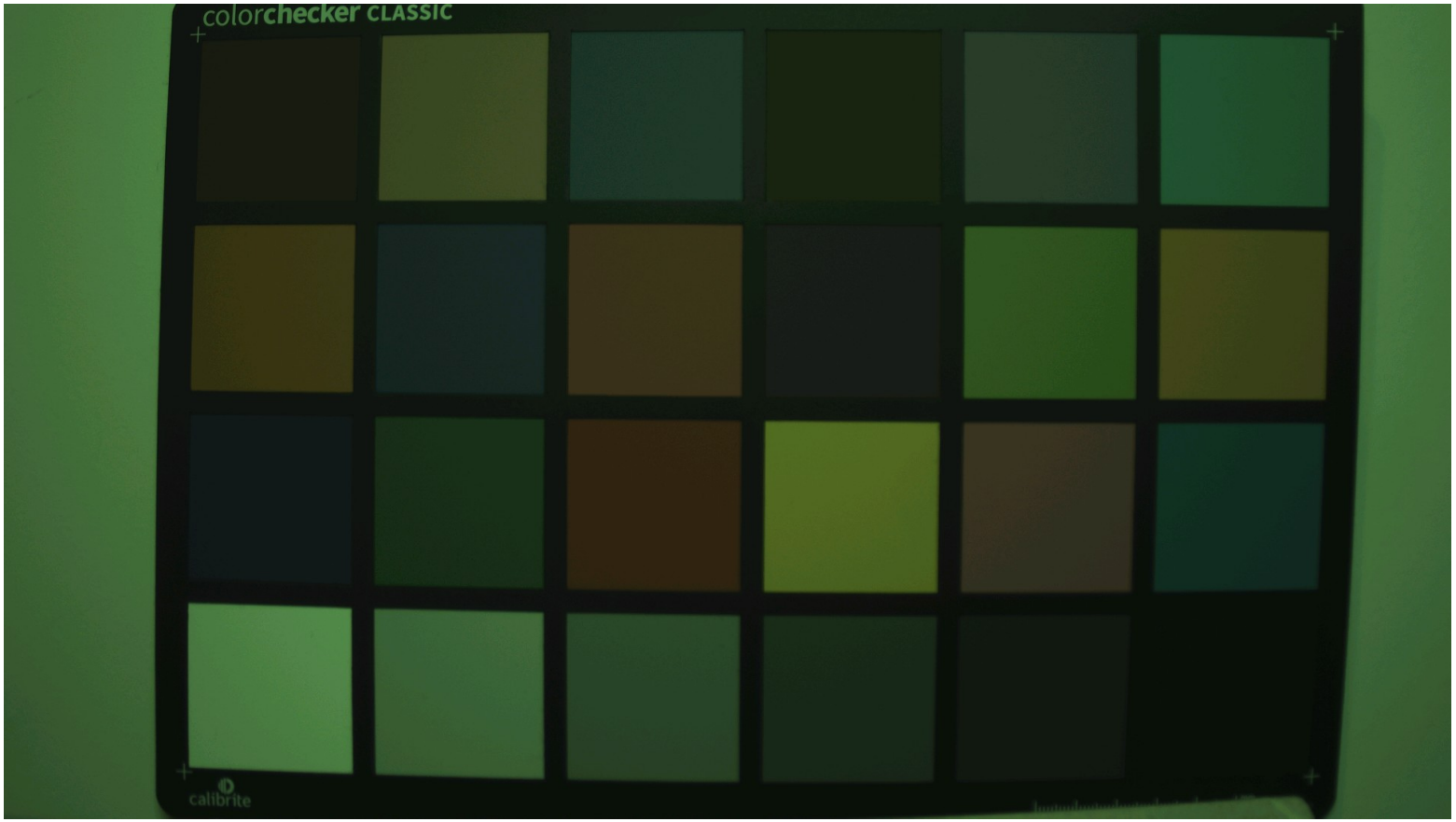


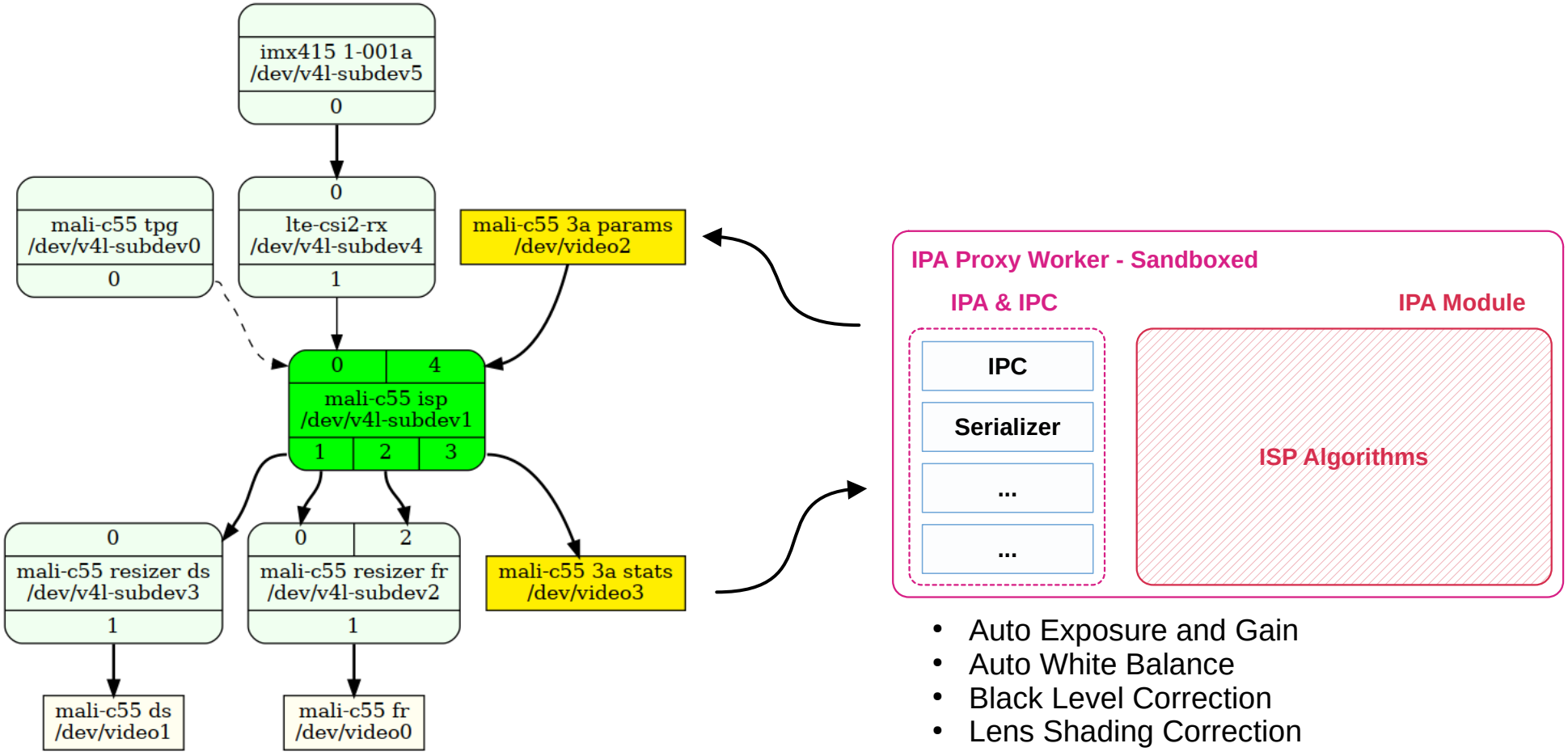
The pipeline handler interfaces with all kernel devices. It abstracts them and exposes video streams to upper layers.

The Pipeline Handler


(root) 192.168.1.207 — Konsole
File Edit View Bookmarks Plugins Settings Help
root@juno-r2:~# libcamera/build/src/apps/cam/cam -l
[4:02:01.724328260] [2534] INFO IPAManager ipa_manager.cpp:143 libcamera is not installed. Adding '/root/libcamera/build/src/ipa' to the IPA search path
[4:02:01.752400300] [2534] INFO Camera camera_manager.cpp:284 libcamera v0.2.0+142-215bc0dc
[4:02:01.812587380] [2535] WARN CameraSensor camera_sensor.cpp:259 'imx415 1-001a': Recommended V4L2 control 0x009a0922 not supported
[4:02:01.812703760] [2535] WARN CameraSensor camera_sensor.cpp:331 'imx415 1-001a': The sensor kernel driver needs to be fixed
[4:02:01.812742440] [2535] WARN CameraSensor camera_sensor.cpp:333 'imx415 1-001a': See Documentation/sensor_driver_requirements.rst in the libcamera sources for more information
[4:02:01.819281320] [2535] WARN CameraSensor camera_sensor.cpp:479 'imx415 1-001a': Failed to retrieve the camera location
[4:02:01.819356440] [2535] WARN CameraSensor camera_sensor.cpp:501 'imx415 1-001a': Rotation control not available, default to 0 degrees
[4:02:01.839356420] [2535] INFO IPAProxy ipa_proxy.cpp:130 libcamera is not installed. Loading IPA configuration from '/root/libcamera/src/ipa/mali-c55/data'
Available cameras:
1: (mali-c55 tpg)
2: (imx415 1-001a)
root@juno-r2:~#

Hurray – you can take a picture

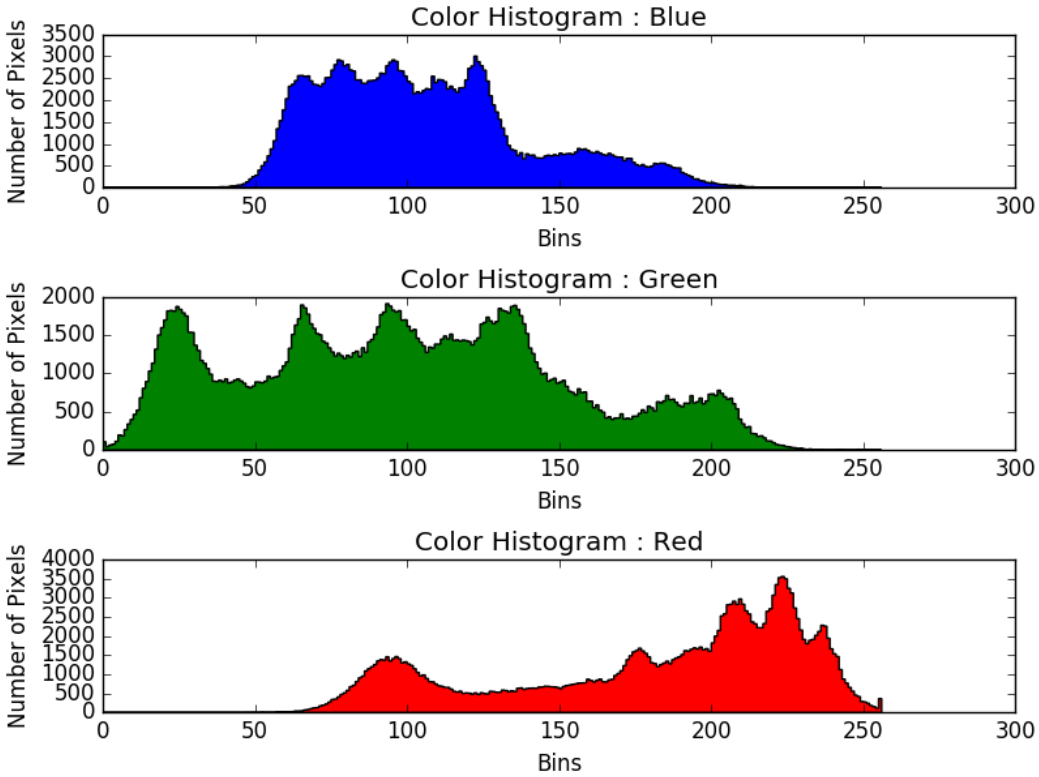




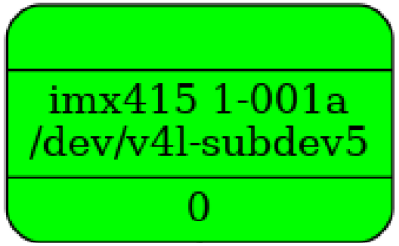
- Auto Exposure and Gain
- Auto White Balance
- Black Level Correction
- Lens Shading Correction

The IPA Interface

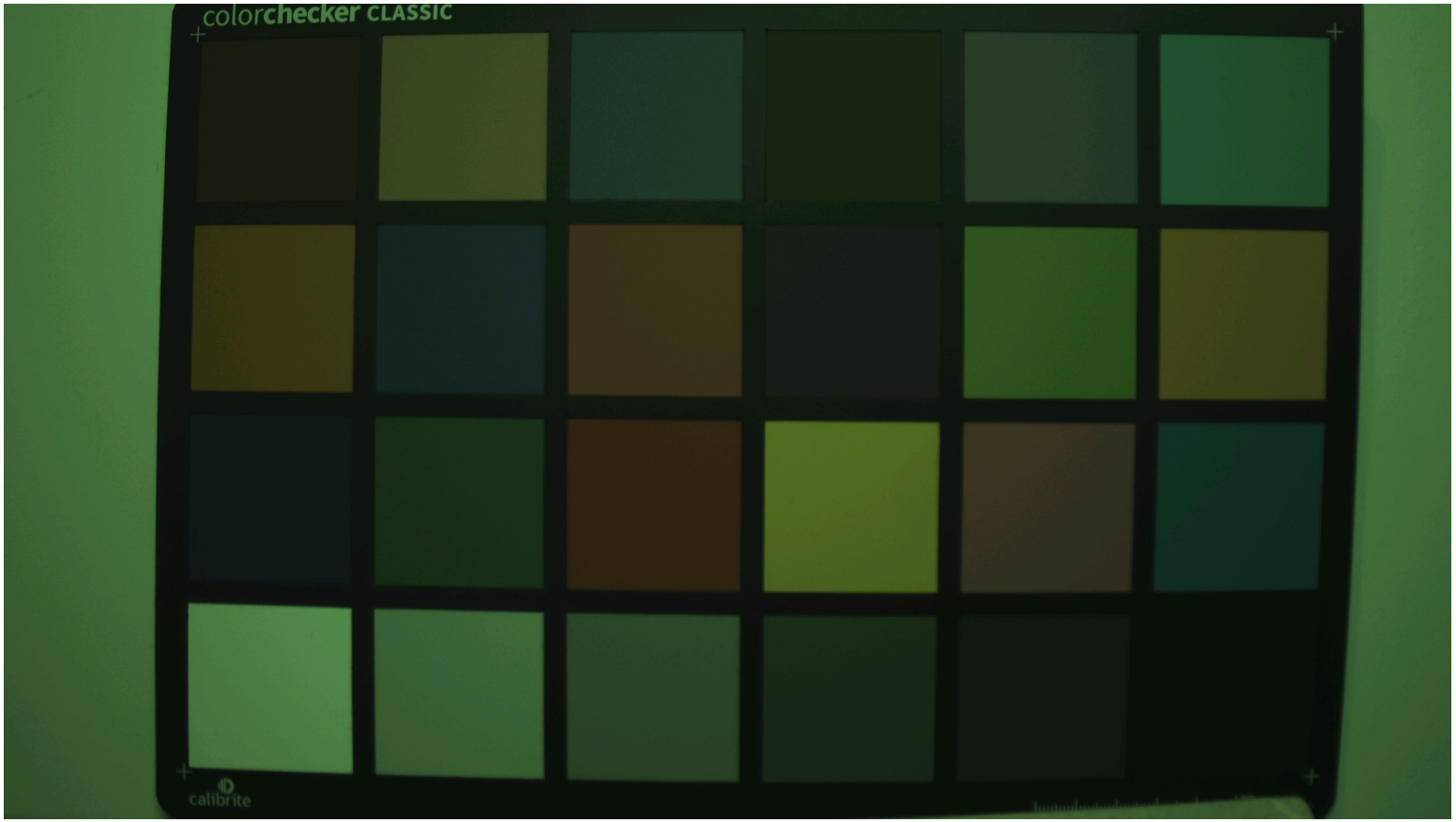
AEGC Histograms



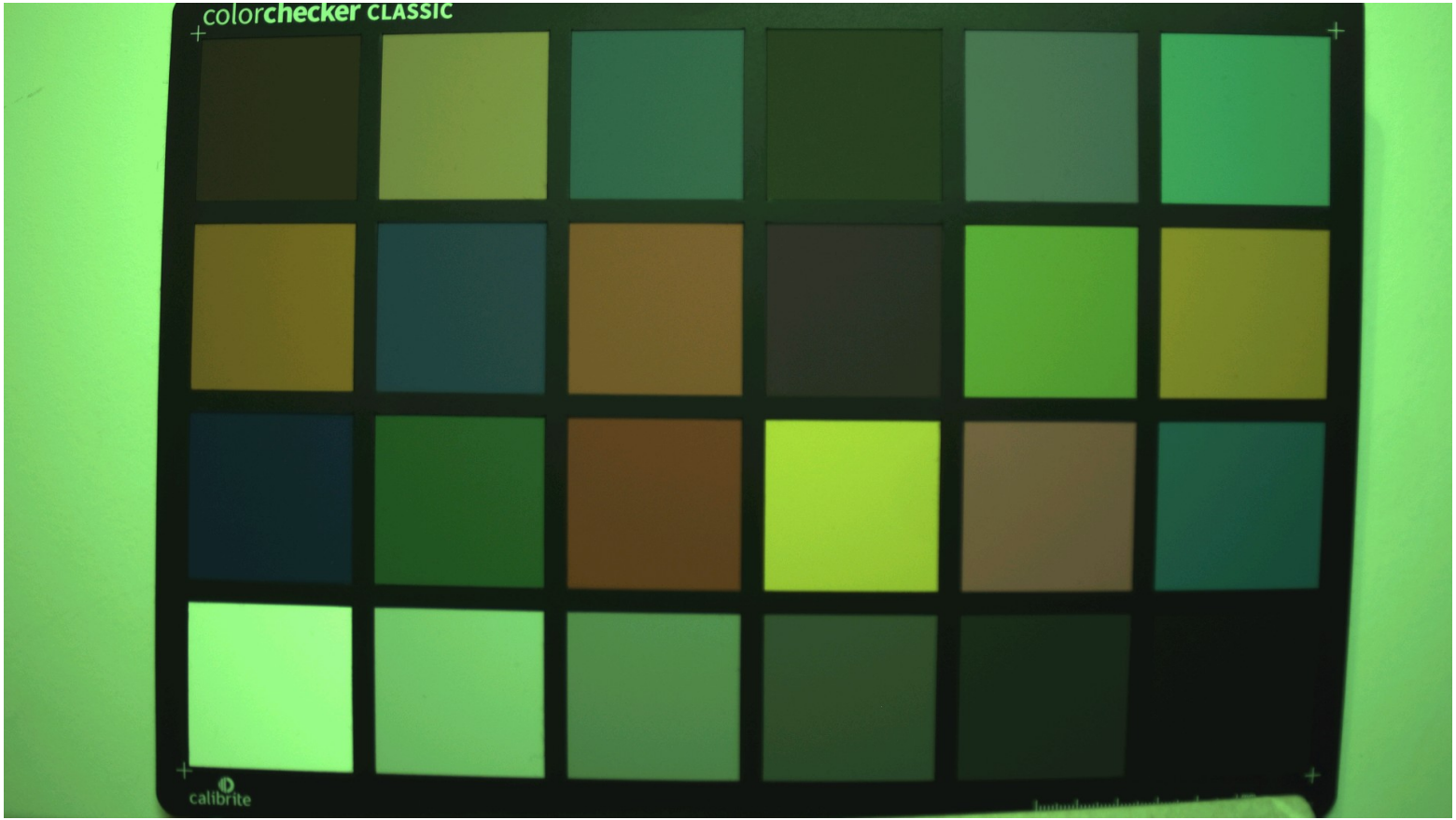

```
double yAvg = (rAvg *.299) + (gAvg * .587) + (bAvg * .114);

Duration effectiveExposure = thisFramesExposure * thisFramesGain;
Duration targetExposure = effectiveExposure * (yTgt / yAvg);

newExposure, newGain = splitUpExposure(targetExposure);
```



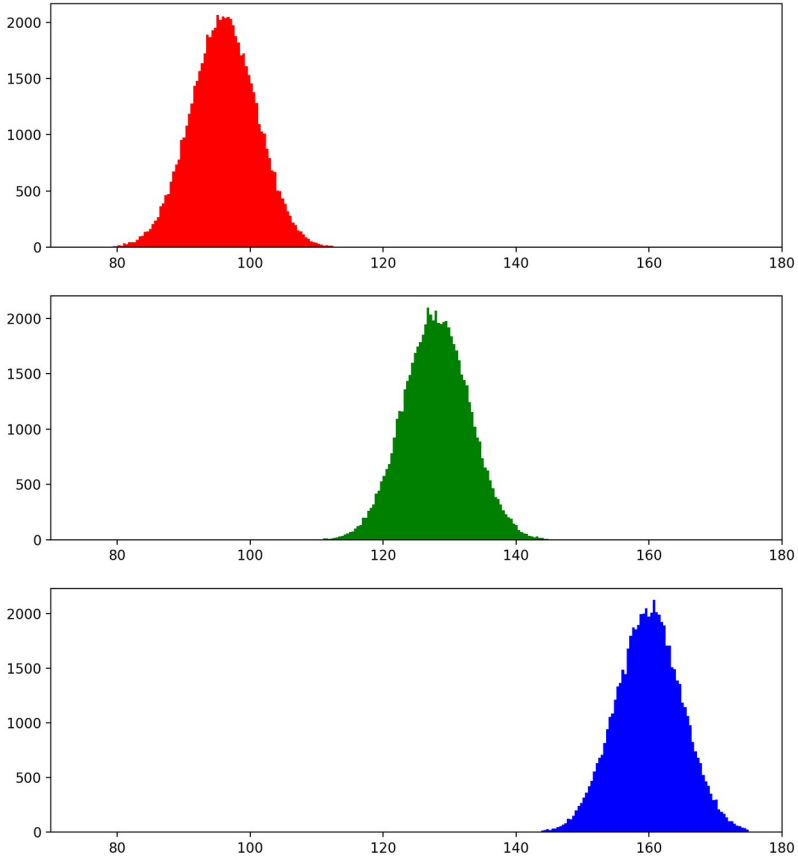
We go from a dim image



To a brighter one



We aim to achieve a “grey world”



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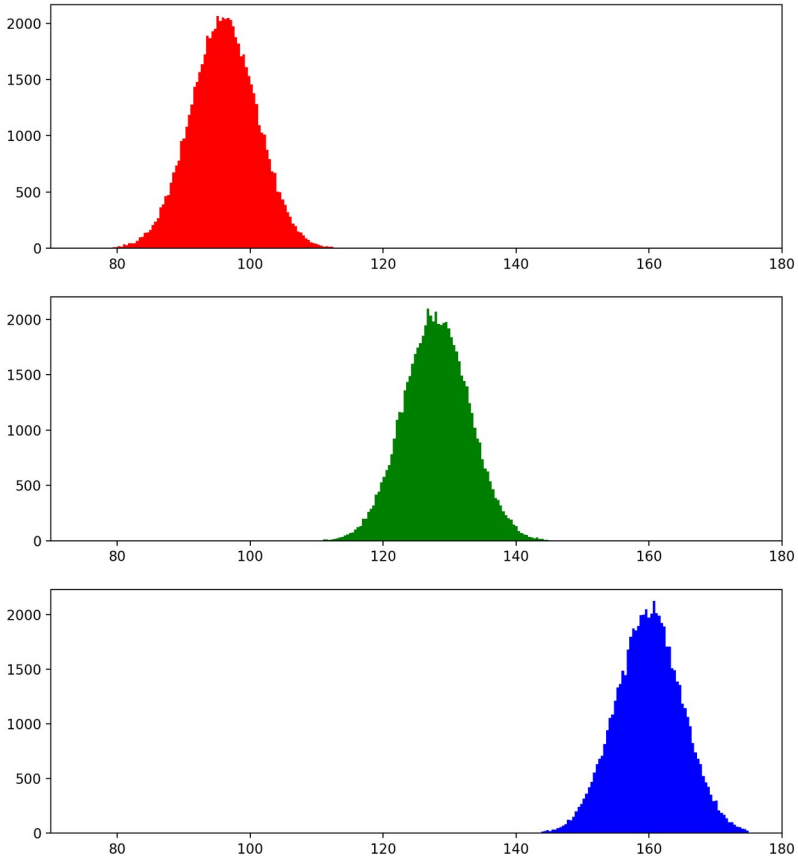
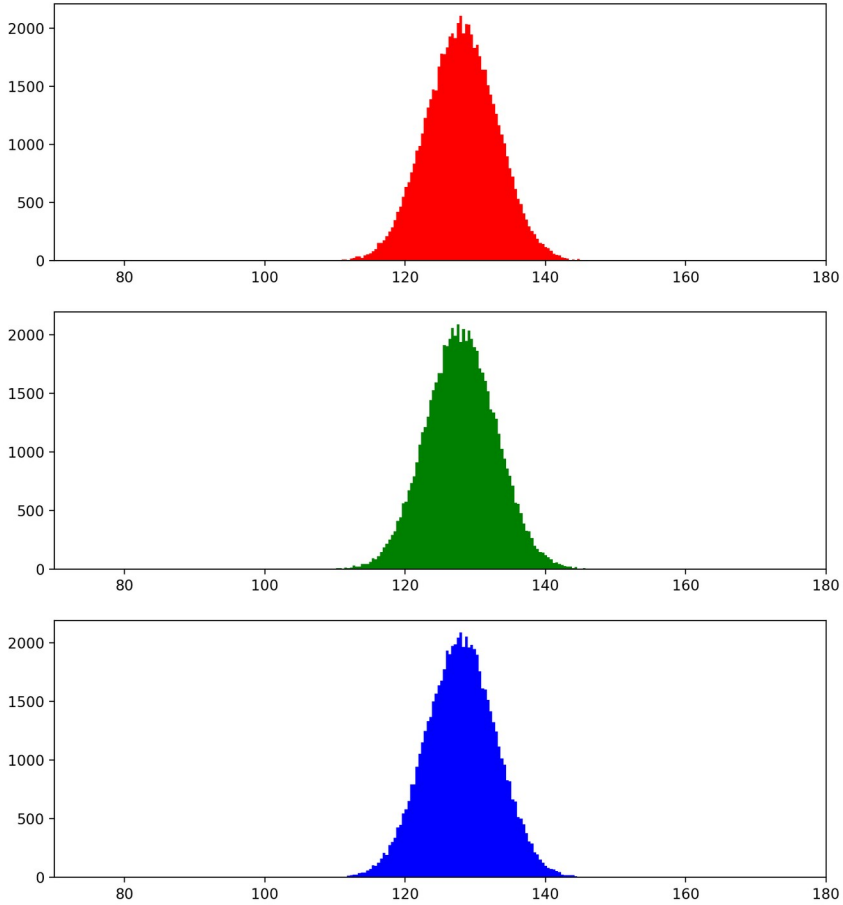




And the ISP makes it easy

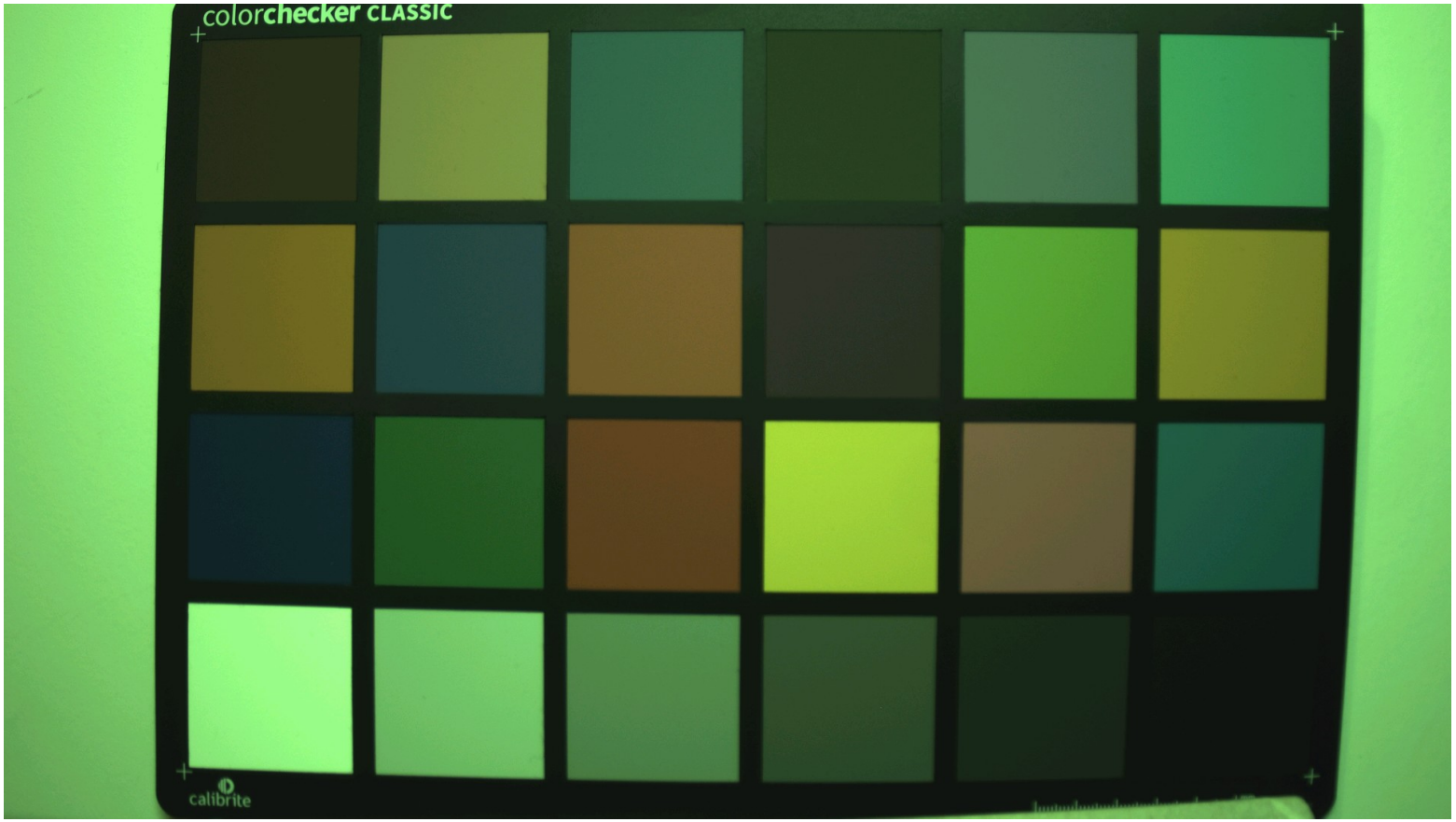
```
struct mali_c55_awb_average_ratios {
        __u16 avg_rg_gr;
        __u16 avg_bg_br;
        __u32 num_pixels;
}


/*
 *      gain00 = R
 *      gain01 = Gr
 *      gain10 = Gb
 *      gain11 = B
 */

struct mali_c55_params_awb_gains {
        struct mali_c55_params_block_header header;
        __u16 gain00;
        __u16 gain01;
        __u16 gain10;
        __u16 gain11;
};
```

And the ISP makes it easy

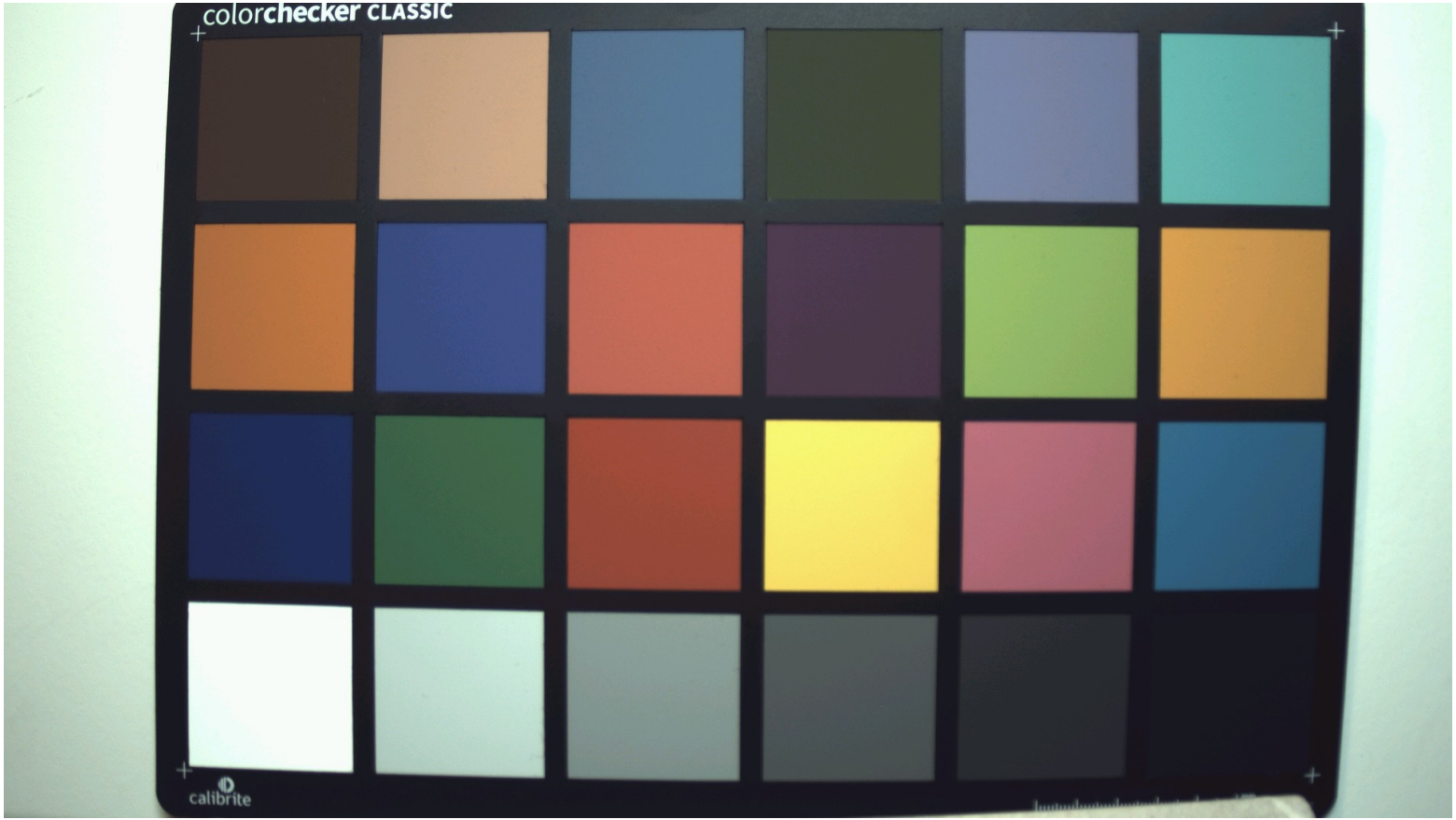
```
struct mali_c55_awb_average_ratios {
        __u16 avg_rg_gr;
        __u16 avg_bg_br;
        __u32 num_pixels;
}


/*
 *      gain00 = R
 *      gain01 = Gr
 *      gain10 = Gb
 *      gain11 = B
 */

struct mali_c55_params_awb_gains {
        struct mali_c55_params_block_header header;
        __u16 gain00;
        __u16 gain01;
        __u16 gain10;
        __u16 gain11;
};
```

```
void MaliC55Awb::process(...)
{

    ...

    params->gain00 = 1 / stats->avg_rg_gr;
    params->gain01 = 1;
    params->gain10 = 1;
    params->gain11 = 1 / stats->avg_bg_gr;

    ...

}
```

We go from a greenish image



To a more balanced one

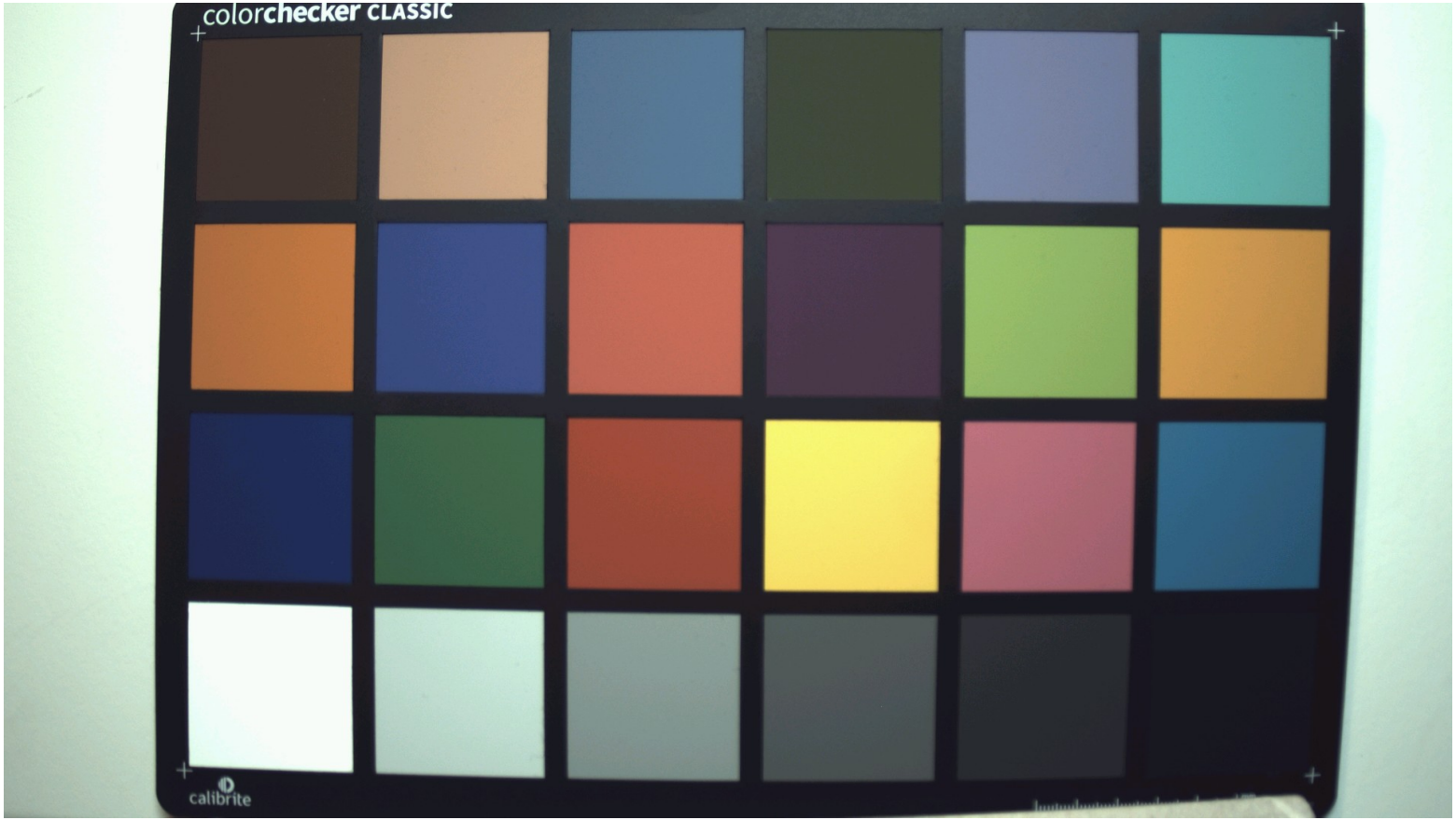


Some values we just parse from tuning files

```yaml
# SPDX-License-Identifier: CC0-1.0
%YAML 1.1
---
version: 1
algorithms:
  - Agc:
  - Awb:
  - BlackLevelCorrection:
      offset00:  51200
      offset01:  51200
      offset10:  51200
      offset11:  51200
...
```

```cpp
int BlackLevelCorrection::init([[maybe_unused]] IPAContext &context,
                               const YamlObject &tuningData)
{
        offset00 = tuningData["offset00"].get<uint32_t>(256);
        offset01 = tuningData["offset01"].get<uint32_t>(256);
        offset10 = tuningData["offset10"].get<uint32_t>(256);
        offset11 = tuningData["offset11"].get<uint32_t>(256);

        if (offset00 > kMaxOffset || offset01 > kMaxOffset ||
            offset10 > kMaxOffset || offset11 > kMaxOffset) {
                LOG(MaliC55Blc, Error) << "Invalid black level offsets";
                return -EINVAL;
        }

        tuningParameters_ = true;

        LOG(MaliC55Blc, Debug)
                << "Black levels: 00 " << offset00 << ", 01 " << offset01
                << ", 10 " << offset10 << ", 11 " << offset11;

        return 0;
}
```

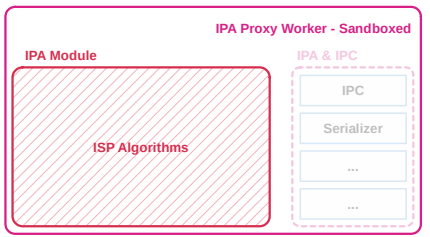
We go from noisy “black”



To well calibrated black

We need to tackle vignetting

```yaml
# SPDX-License-Identifier: CC0-1.0
%YAML 1.1
---
version: 1
algorithms:
  - Agc:
  - Awb:
  - BlackLevelCorrection:
      R:  256
      Gr: 256
      Gb: 256
      B:  256
  - Lsc:
      meshScale: 4
      sets:
        - ct: 2500
          r: [
              21, 20, 19, 17, 15, 14, 12, 11,  9,  9,  9,  9,  8,  8,  9,  9,
               9,  9,  9,  9,  9,  9, 13, 13, 10, 10, 13, 16, 17, 18, 21, 22,
              ...
              ]
          g: [
              19, 18, 17, 15, 13, 12, 10,  9,  8,  8,  7,  7,  7,  7,  7,  7,
               7,  7,  7,  7,  7,  7, 12, 12,  9,  9, 11, 15, 15, 16, 19, 20,
              ...
              ]
...
```



src/ipa/mali-c55/data/imx415.yaml

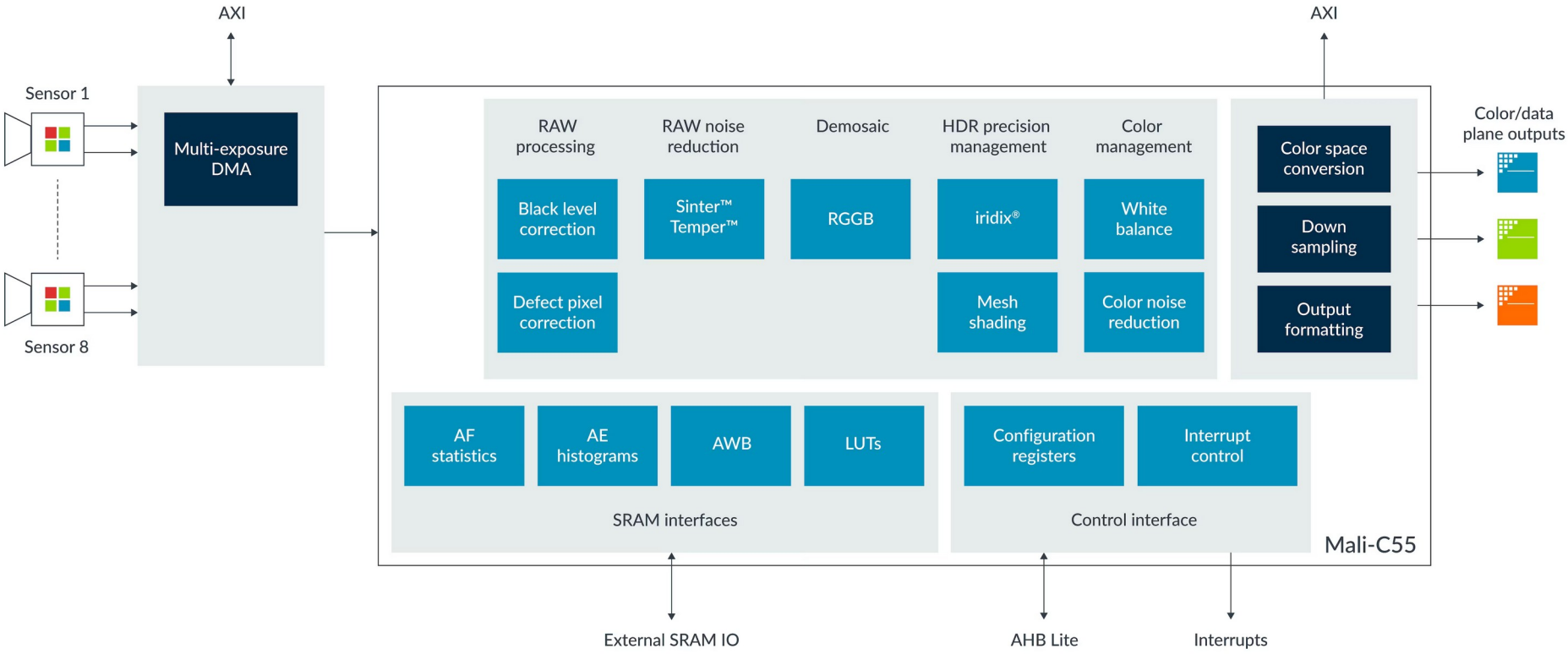
Tuning File

Corrected black levels

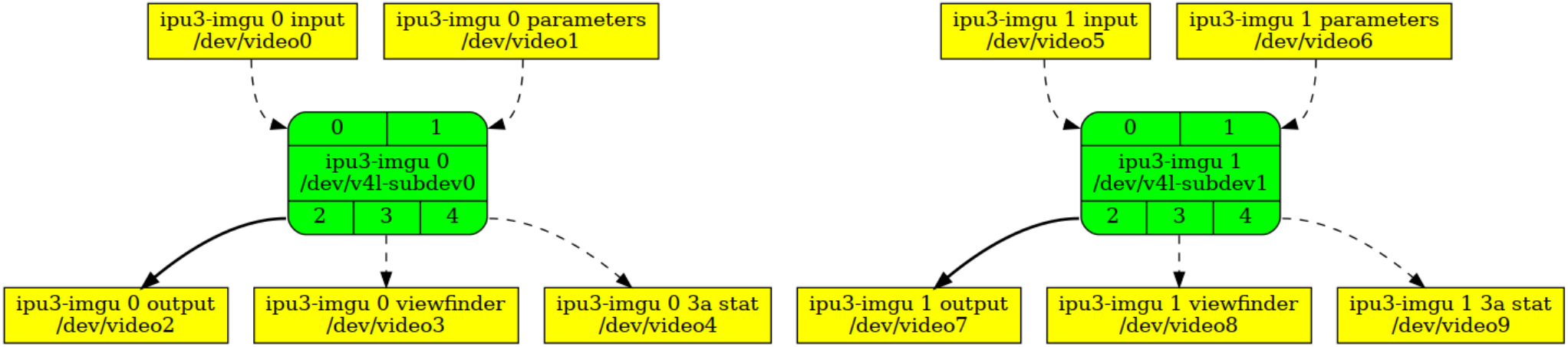
Brightened peripheries

- Introduction
- The hardware
- The kernel
- libcamera
- Future challenges
- How can you use what we've done?
- Any questions?

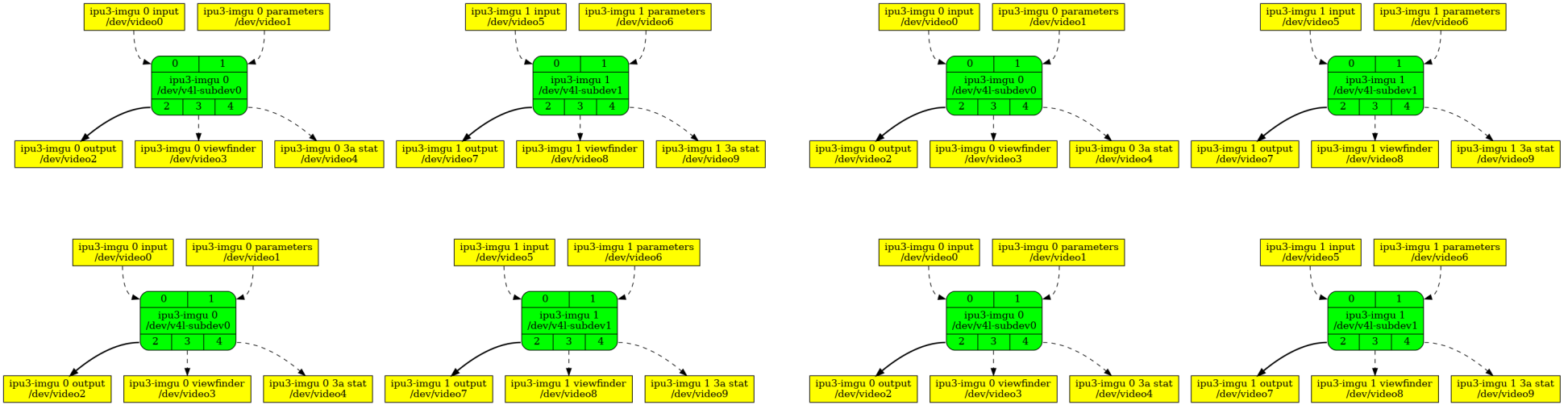
The ISP has other image quality blocks



Multi-context in the kernel today...



...but does it scale?



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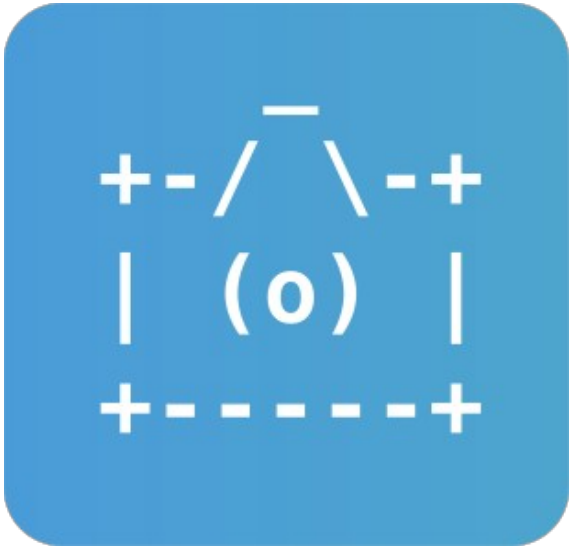
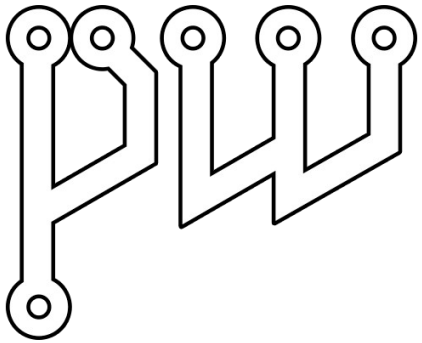
Well, you can use the V4L2 APIs of course...

```
# Set formats on the TPG and ISP
media-ctl -V "'mali-c55 tpg':0[fmt:SRGGB16_1X16/1920x1080]"
media-ctl -V "'mali-c55 isp':0[fmt:SRGGB16_1X16/1920x1080]"
media-ctl -V "'mali-c55 isp':1[fmt:SRGGB16_1X16/1920x1080]"

# Set routing on the FR resizer
media-ctl -R "'mali-c55 resizer fr'[0/0->1/0[1],2/0->1/0[0]]"

# Set format on the resizer, must be done AFTER the routing.
media-ctl -V "'mali-c55 resizer fr':1[fmt:RGB121212_1X36/1920x1080]"

yavta -f RGB565 -s 1920x1080 -c10 /dev/video0
```

But you should just use libcamera





Any questions?

LinaroConnect
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Thank you