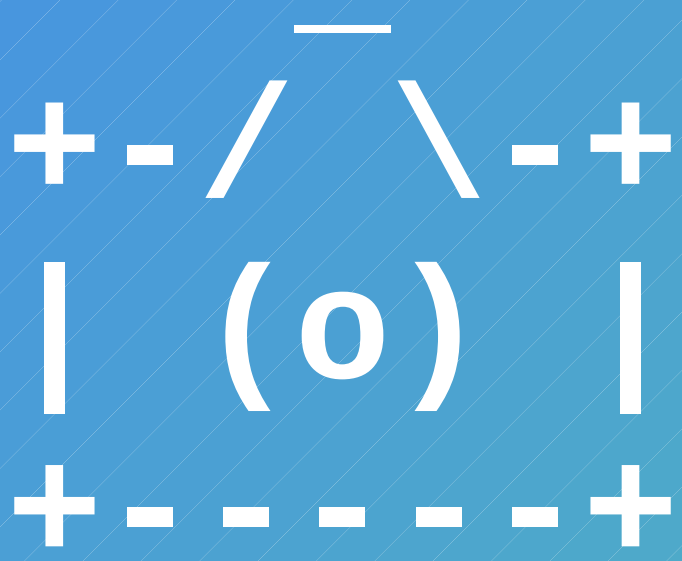


Giving Linux a Camera Stack: libcamera's 3 Years Journey and Exciting Future

Embedded Linux Conference 2021
Seattle, 2021-09-28

Laurent Pinchart
laurent.pinchart@ideasonboard.com

IDEAS ON BOARD

Once Upon A Time

Panasonic MC20 + Pinnacle Miro DC10

In the beginning...

Logitech Quickcam Express

IDEAS ON BOARD

... were simple devices

A monolithic API for TV grabbers and webcams alike.

High-level controls, the TV signal provides a good image already.

Enables development of universal applications.

Logitech Quickcam Express For Notebooks

IDEAS ON BOARD

Early UVC Camera

From: Laurent Pinchart <laurent.pinchart@skynet.be>
To: linux-usb@vger.kernel.org, video4linux-list@redhat.com
Subject: [PATCH] USB Video Class driver
Date: Wed, 23 Apr 2008 01:37:11 +0200

Hi everybody,

after more than two years of development the Linux UVC driver is mostly ready
to jump the fence and get included in the mainline kernel.

This driver aims to support video input devices compliant with the USB Video
Class specification. This means lots of currently manufactured webcams, and
probably most of the future ones.

I plan to submit the driver through the V4L subsystem, but I'd like it to get
a proper review on both the linux-usb and video4linux mailing lists first.

Given the size of the patch I'm open to any suggestion that would make the
review process easier.

Laurent Pinchart

(my humble 25 August 1991 moment)

USB Video Class

Palm Treo 650 (PXA270, 0.3MP Camera)

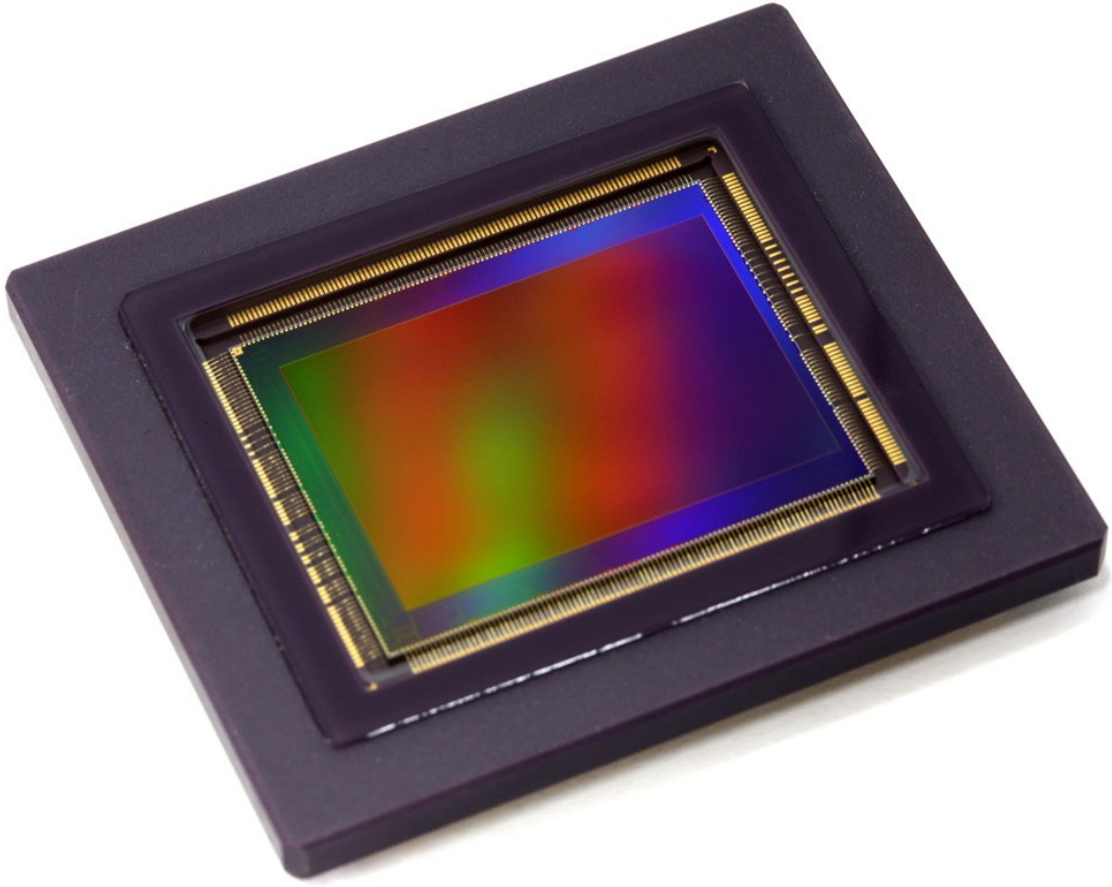
IDEAS ON BOARD

Embedded Cameras

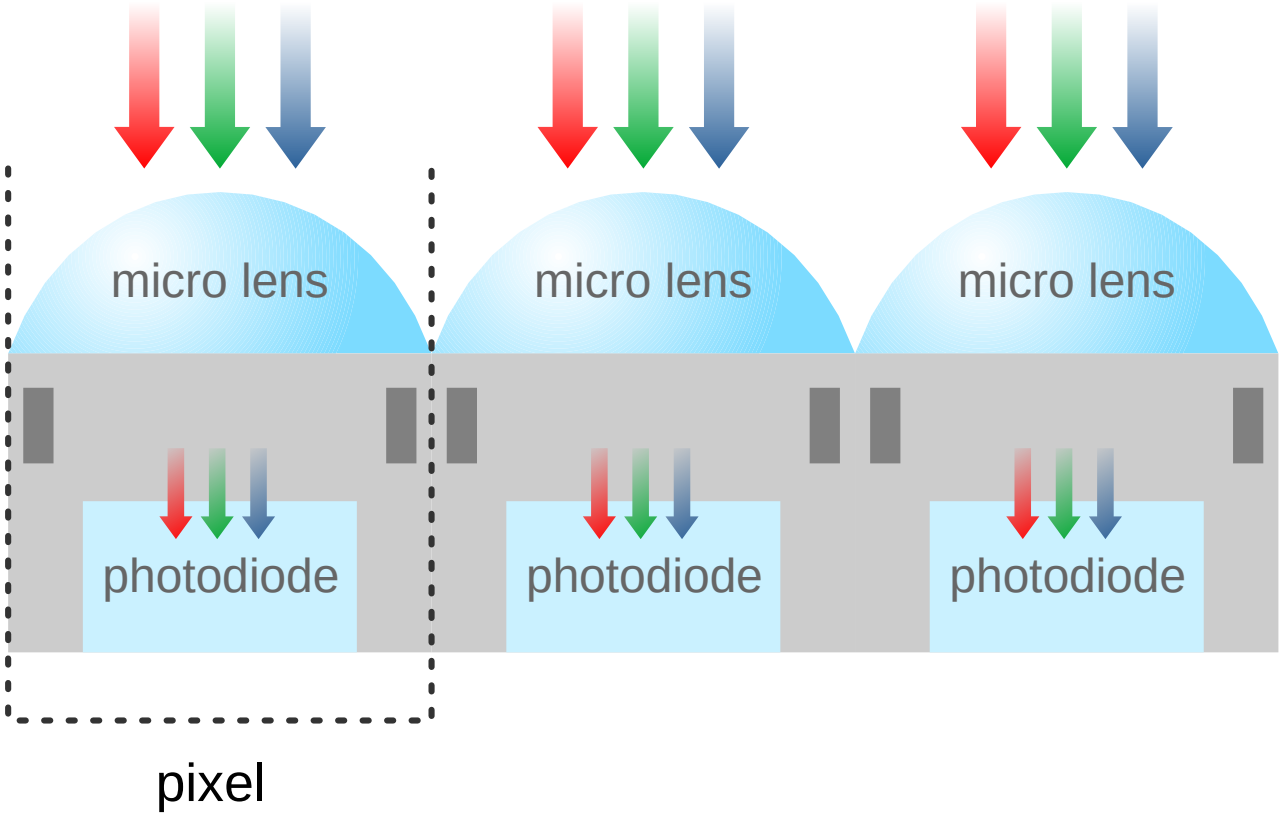
```
From: Guennadi Liakhovetski <g.liakhovetski@pengutronix.de>
To: video4linux-list@redhat.com
Subject: [PATCH 1/6] soc_camera V4L2 driver for directly-connected
    SoC-based cameras
Date: Tue, 5 Feb 2008 18:46:13 +0100 (CET)

This driver provides an interface between platform-specific camera
busses and camera devices. It should be used if the camera is connected
not over a "proper" bus like PCI or USB, but over a special bus, like,
for example, the Quick Capture interface on PXA270 SoCs. Later it should
also be used for i.MX31 SoCs from Freescale.  It can handle multiple
cameras and / or multiple busses, which can be used, e.g., in
stereo-vision applications.

Signed-off-by: Guennadi Liakhovetski <g.liakhovetski@pengutronix.de>
```

What is a camera?

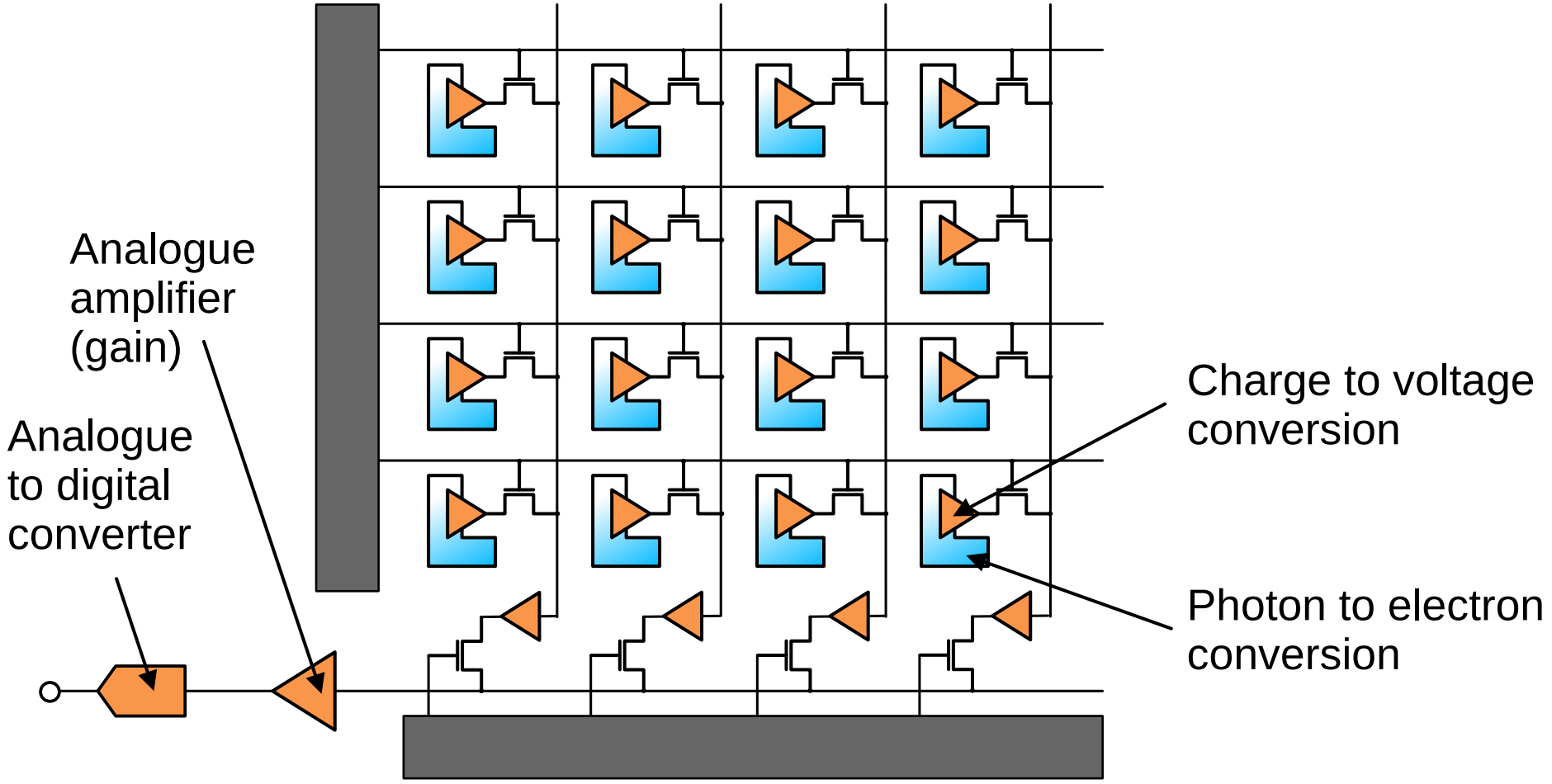
IDEAS ON BOARD



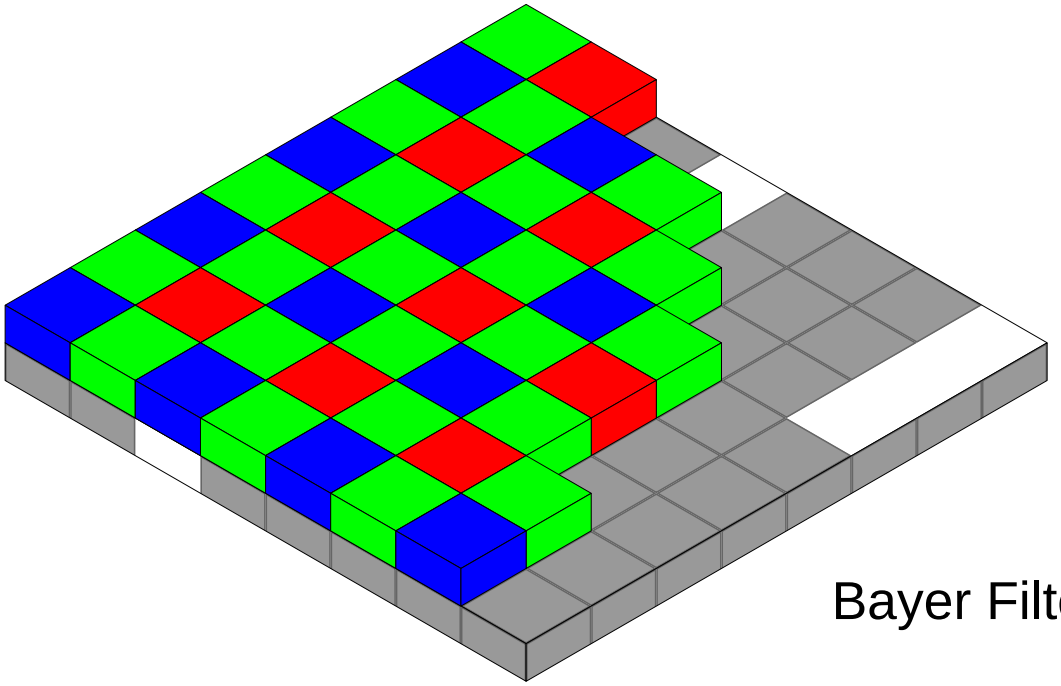
CMOS Sensor


micro lens
micro lens
micro lens
photodiode
photodiode
photodiode
pixel

CMOS Sensor


Analogue amplifier (gain)
Analogue to digital converter
Charge to voltage conversion
Photon to electron conversion

CMOS Sensor



Bayer Filter

Colour Filter Array

source: https://en.wikipedia.org/wiki/Bayer_filter

Original

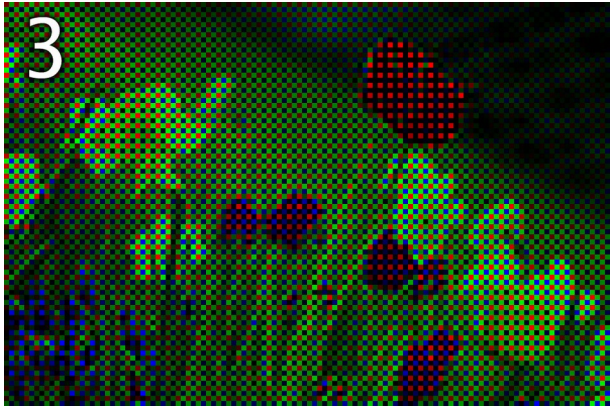
120x80 Bayer image

CFA Interpolation

source: https://en.wikipedia.org/wiki/Bayer_filter

Original

120x80 Bayer image



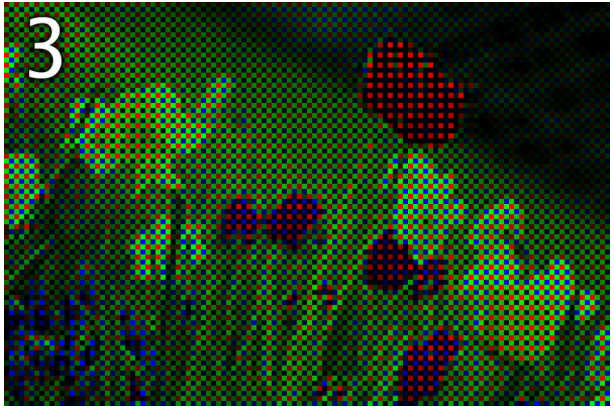
Colour-coded

CFA Interpolation

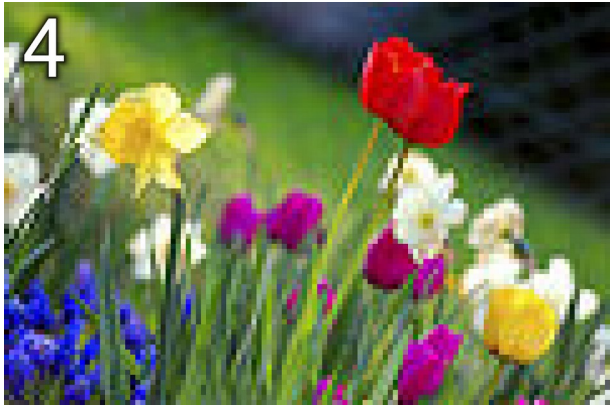
source: https://en.wikipedia.org/wiki/Bayer_filter

Original

120x80 Bayer image



Colour-coded

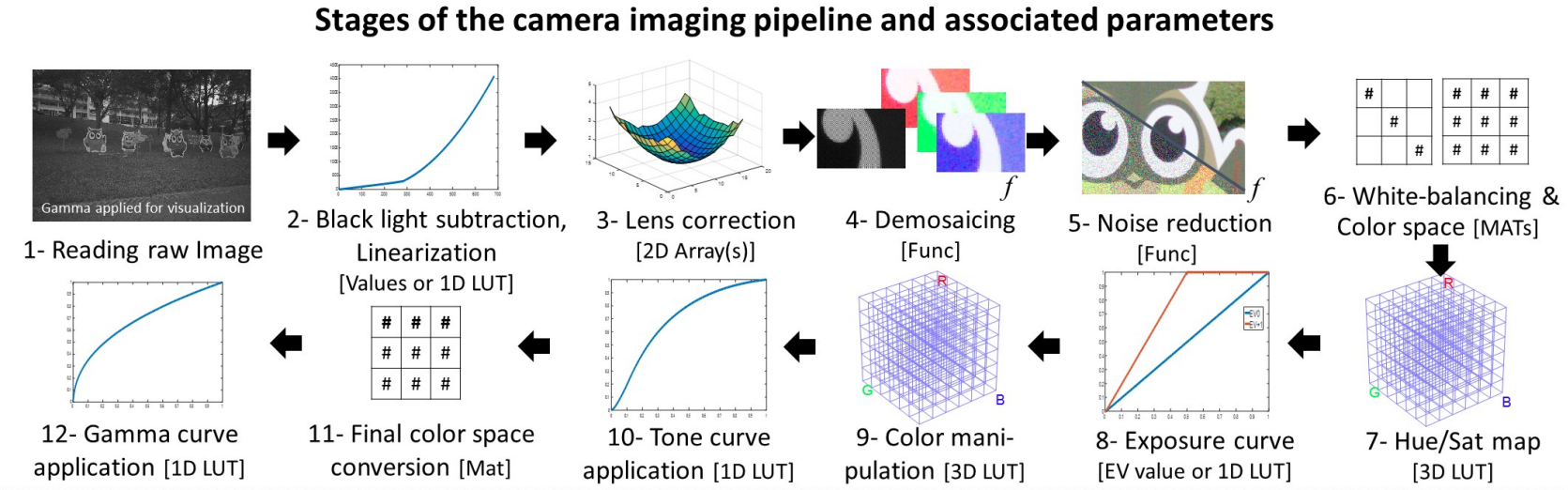


Colour interpolation

CFA Interpolation

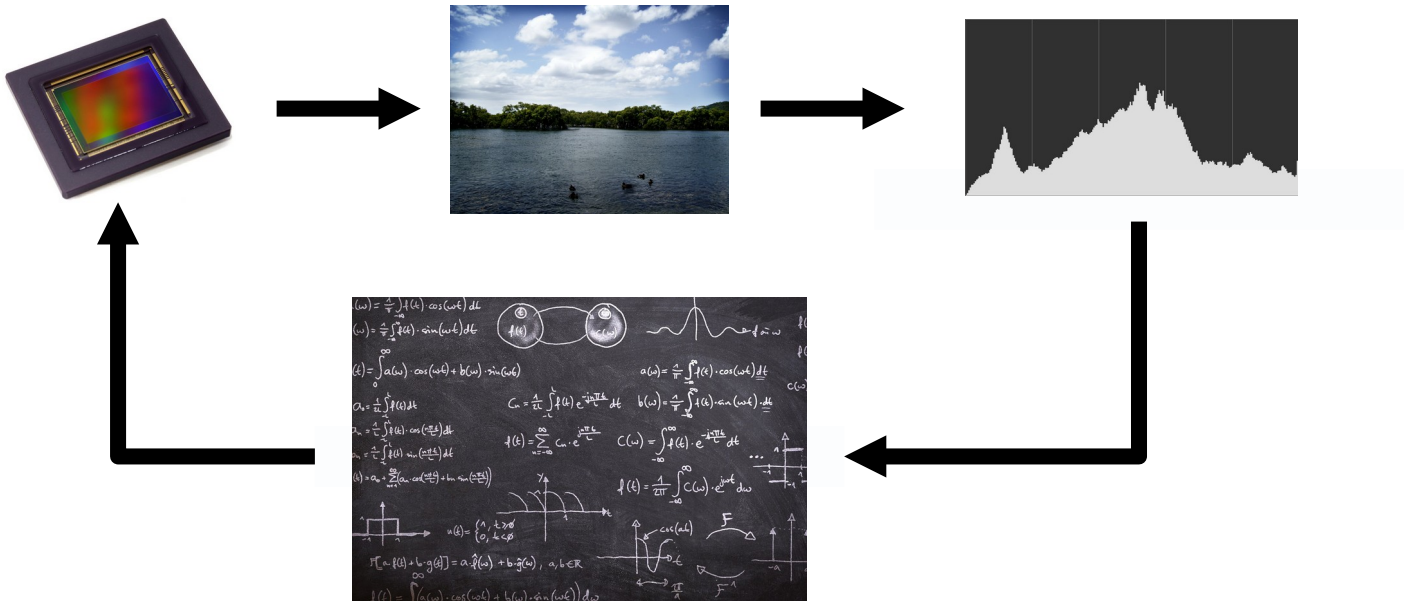
source: https://en.wikipedia.org/wiki/Bayer_filter

Lens Shading



Camera Pipeline

source: https://karaimer.github.io/camera-pipeline/

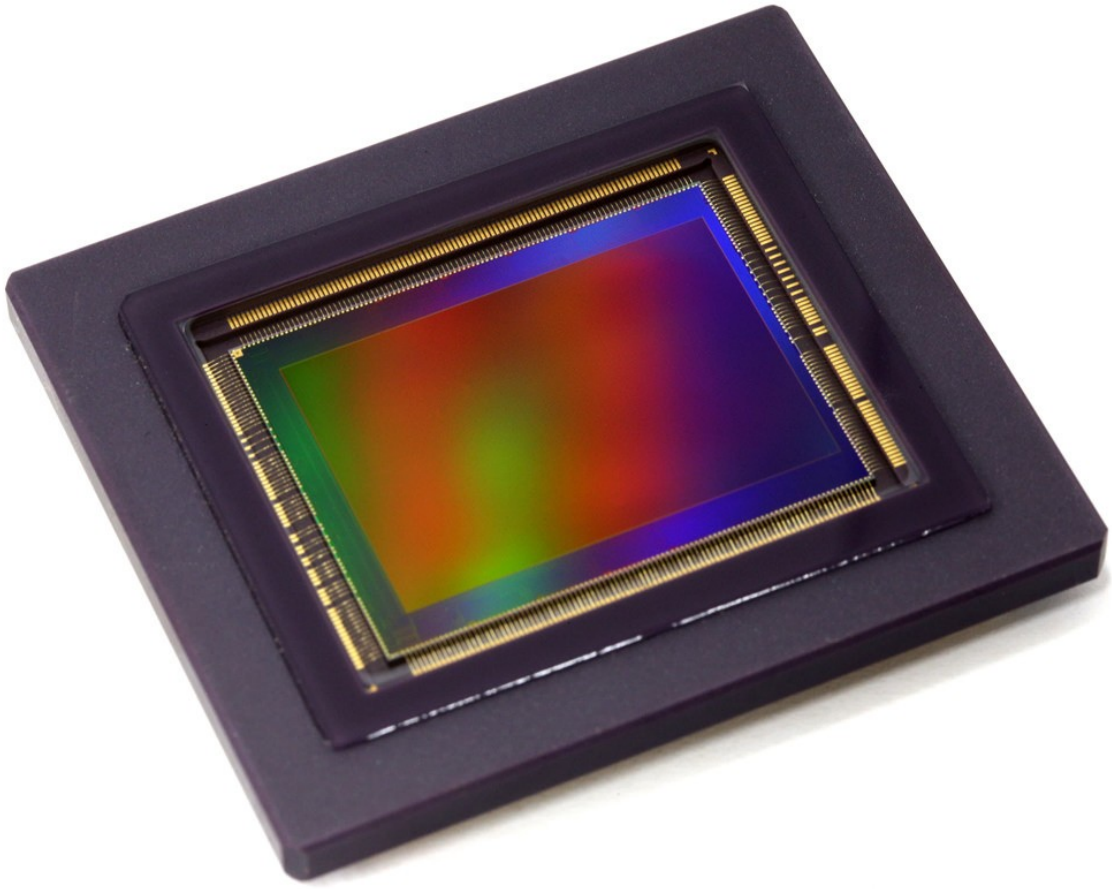


Auto Algorithms (a.k.a. 3A)

IQ Tuning

source: https://www.flickr.com/photos/davedugdale/15043975135

Back To V4L2

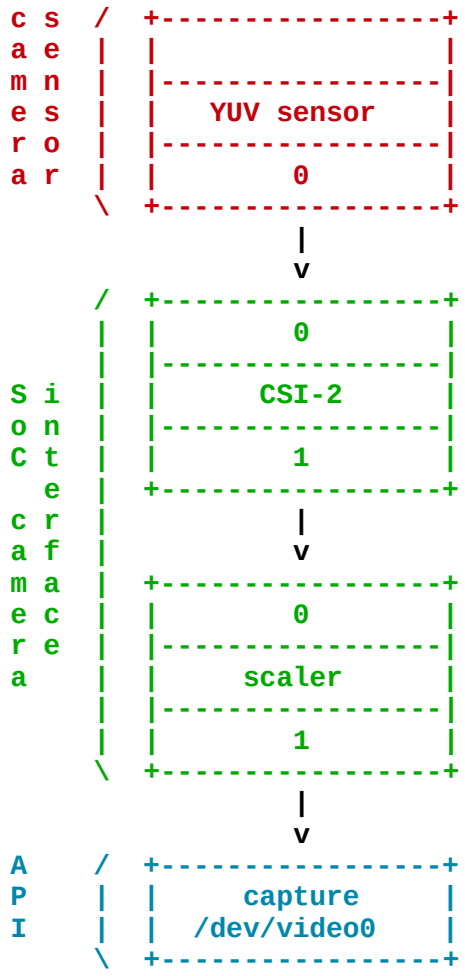


Smart Sensor (a.k.a. YUV Sensor)

Logitech Quickcam Express For Notebooks

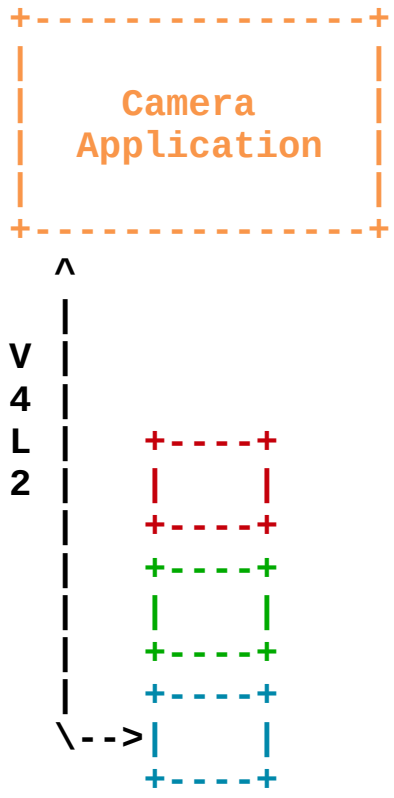
IDEAS ON BOARD

So Small, Yet So Smart



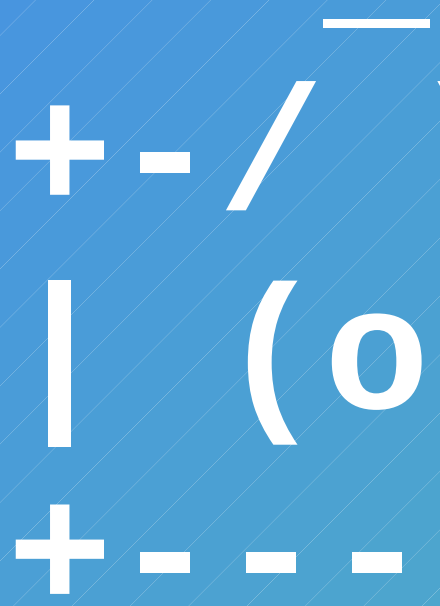
In the beginning were simple pipelines...

… and they were simple to control, with a single API.



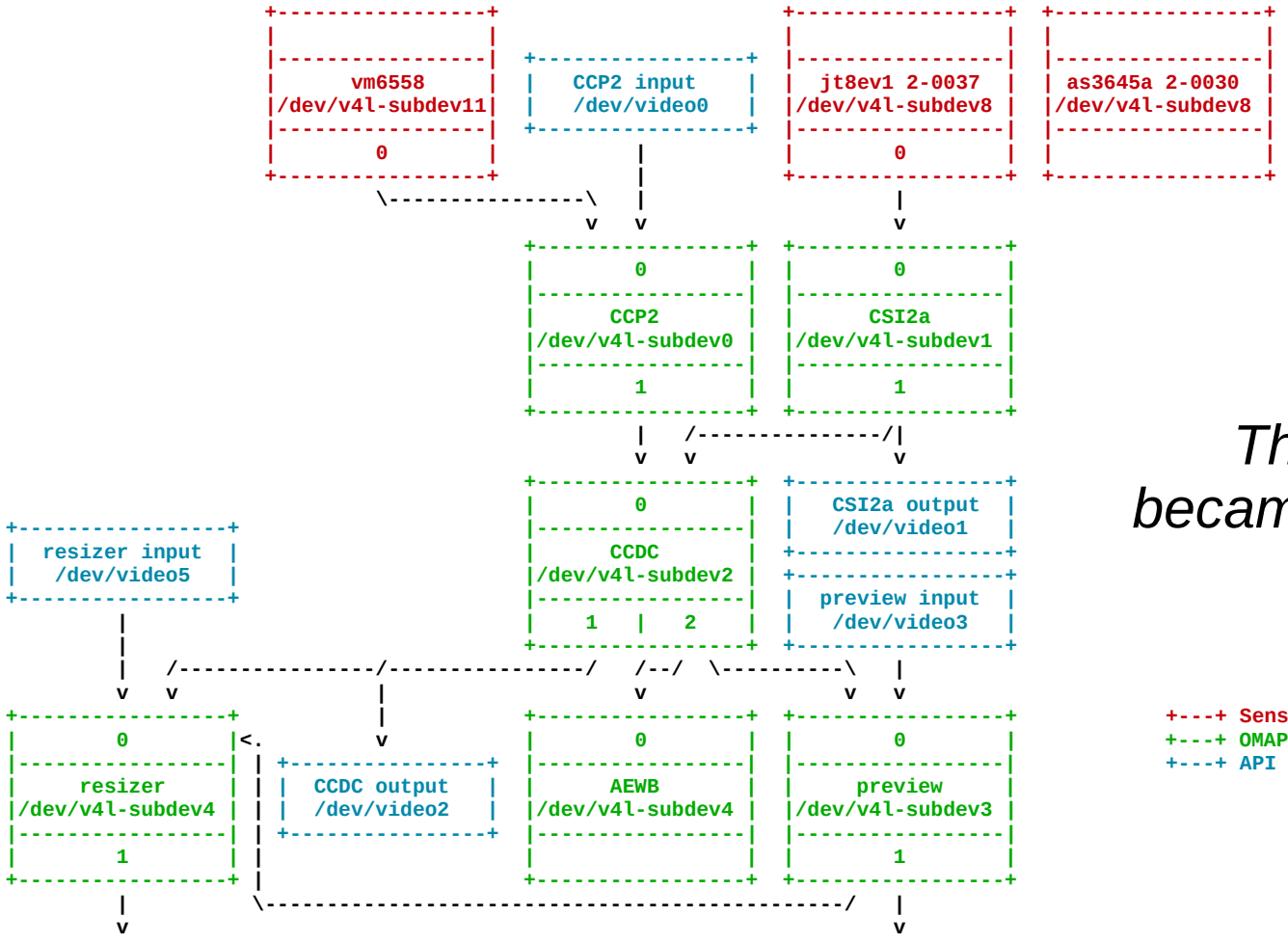
IDEAS ON BOARD

Then the world became complex



The libcamera Journey

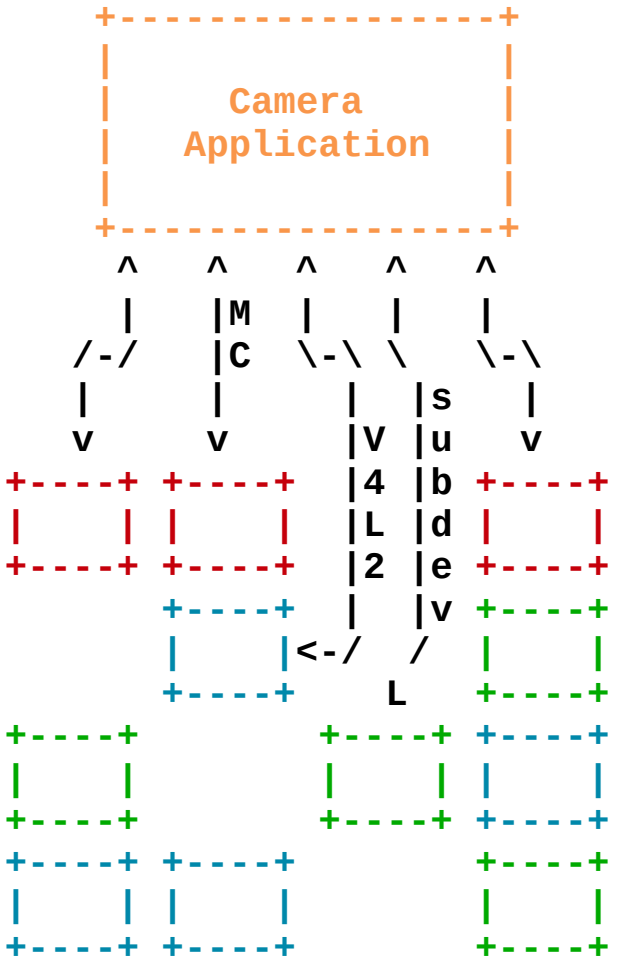
IDEAS ON BOARD



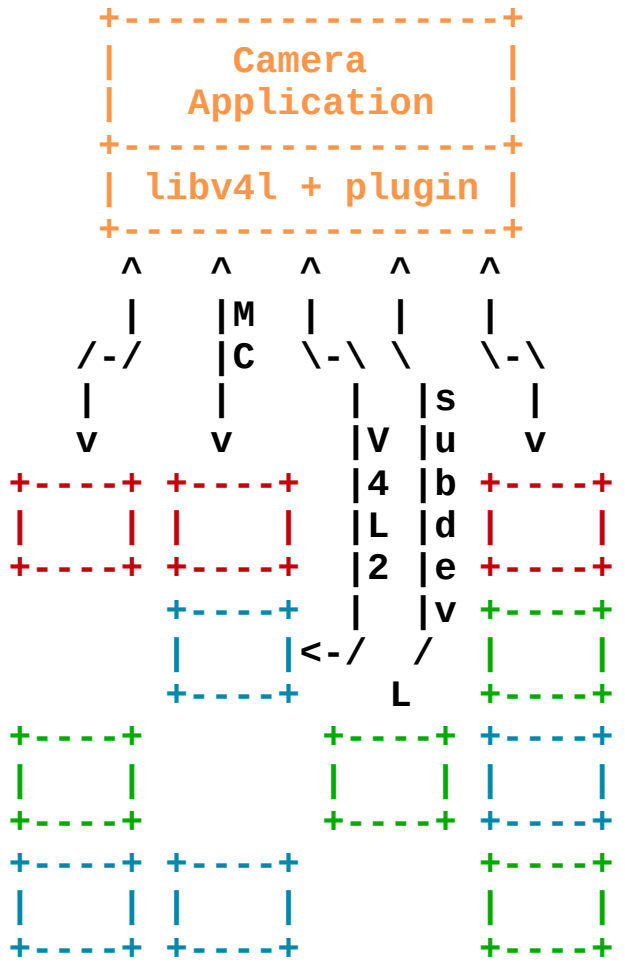
Then the world became complex...

OMAP3 Camera in Nokia N900

… and application developers were left suffering.



Solutions were proposed...



… but never implemented.

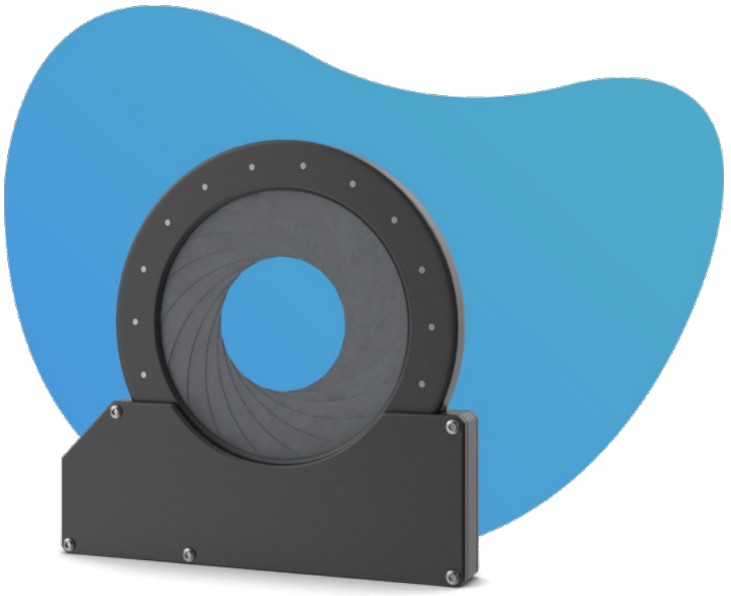
The world turned dark...

IDEAS ON BOARD

Acer Chromebook Tab 10

Dell Latitude 7285

...then hope came back.



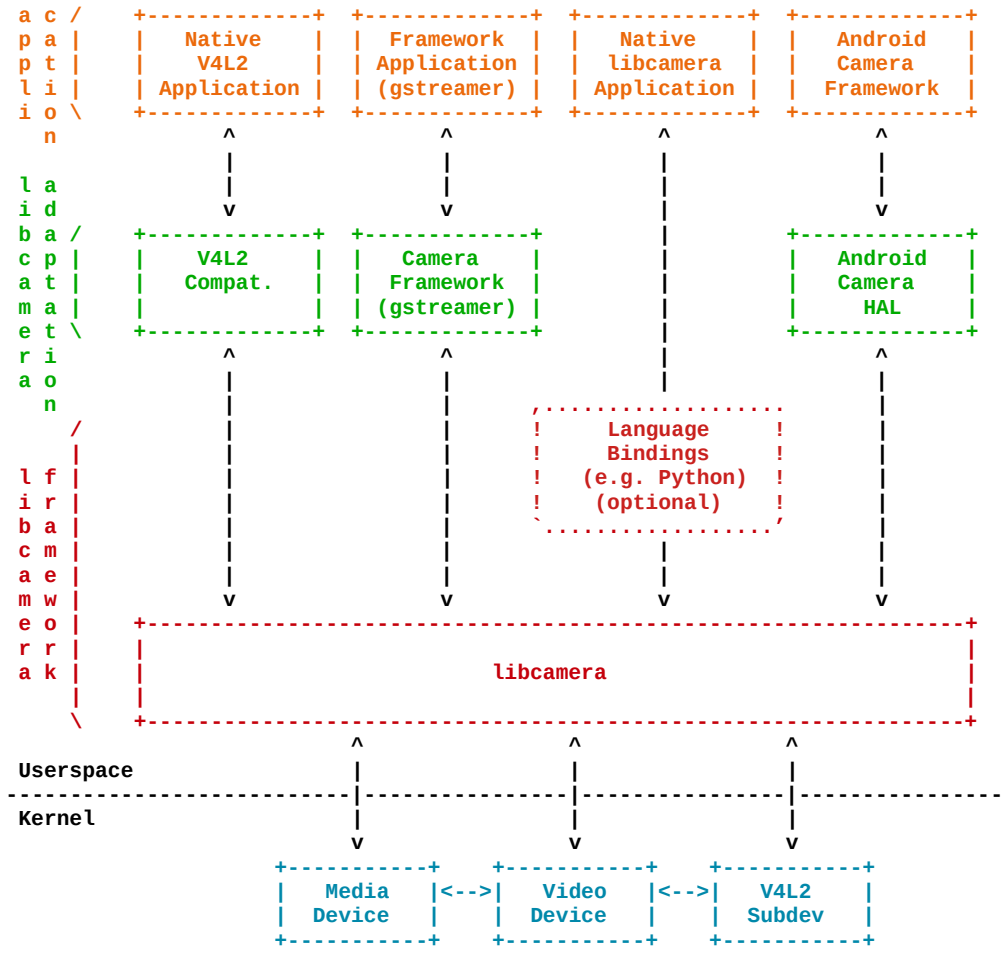
Hi, we're libcamera.

An open source camera stack and framework for Linux, Android, and ChromeOS

Getting Started

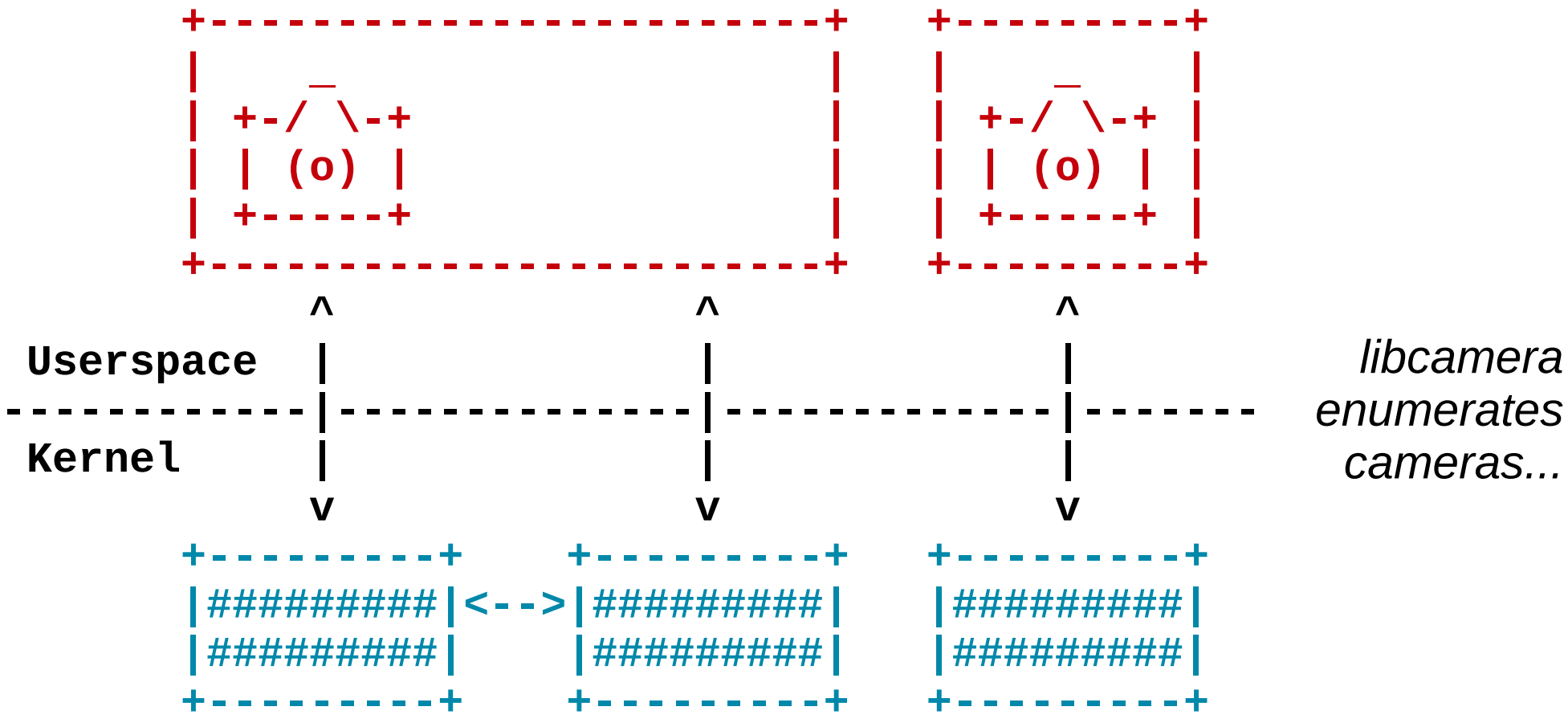
IDEAS ON BOARD

libcamera provides a complete userspace camera stack.

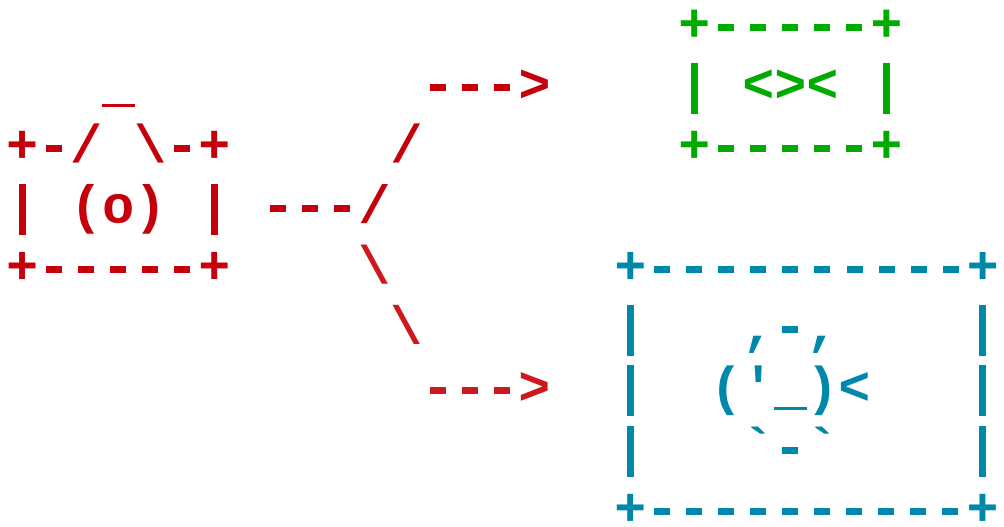


The 'Mesa' of the camera world.

Camera Stack

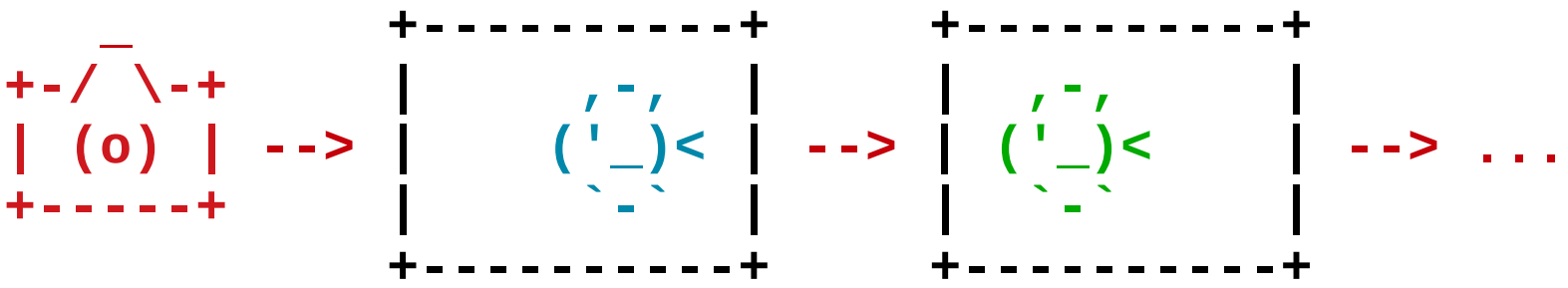


Camera Devices & Enumeration



It supports multiple concurrent streams for the same camera...

Streams



… and per-frame controls.

Per-Frame Controls

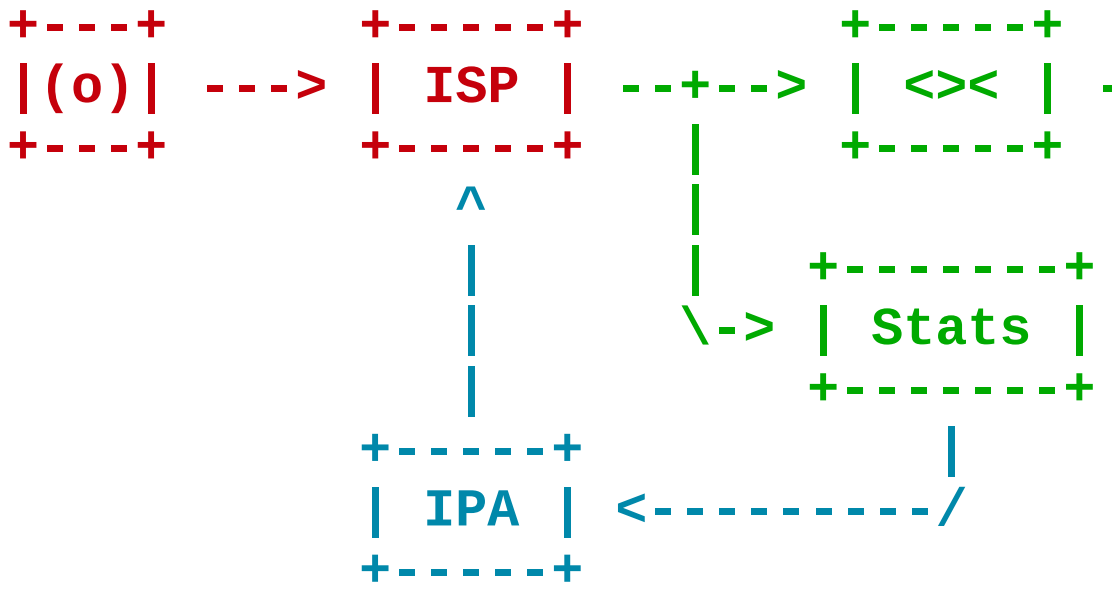
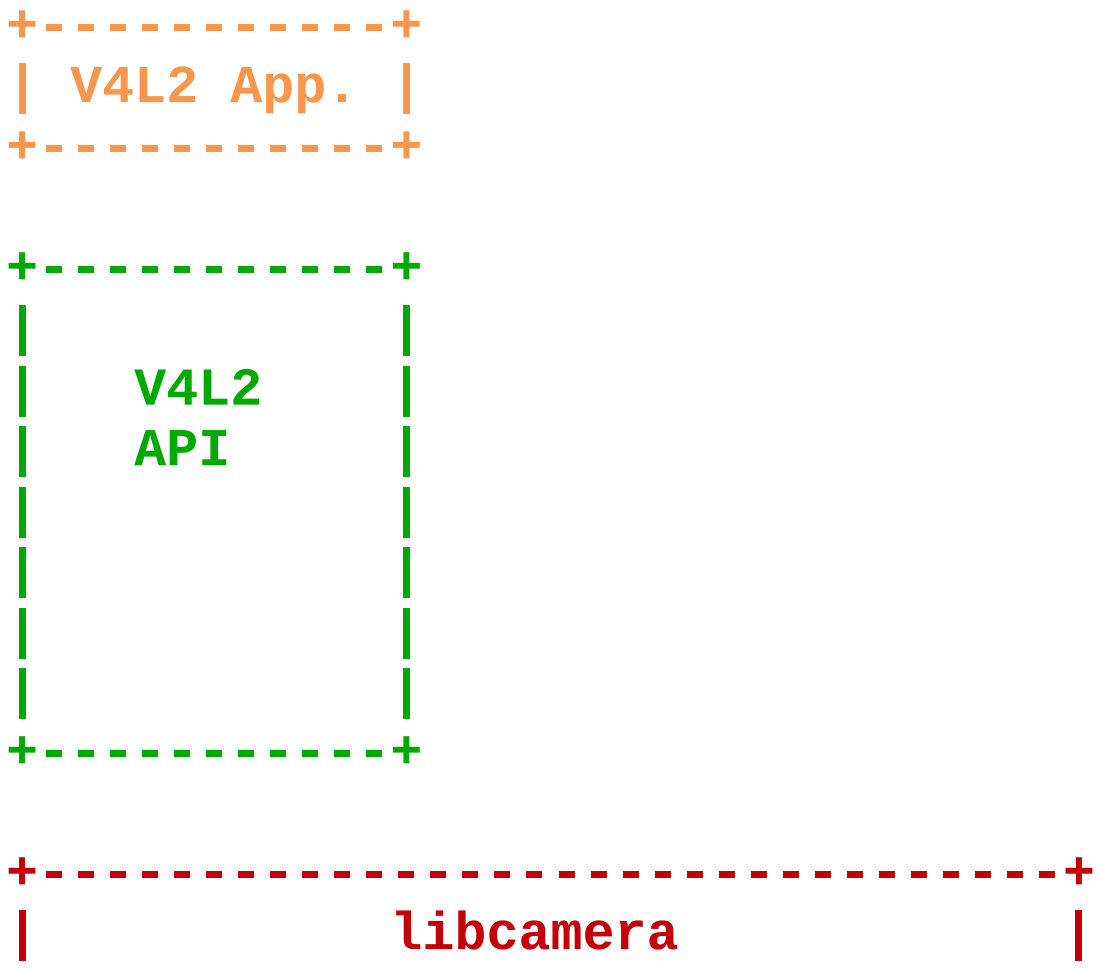


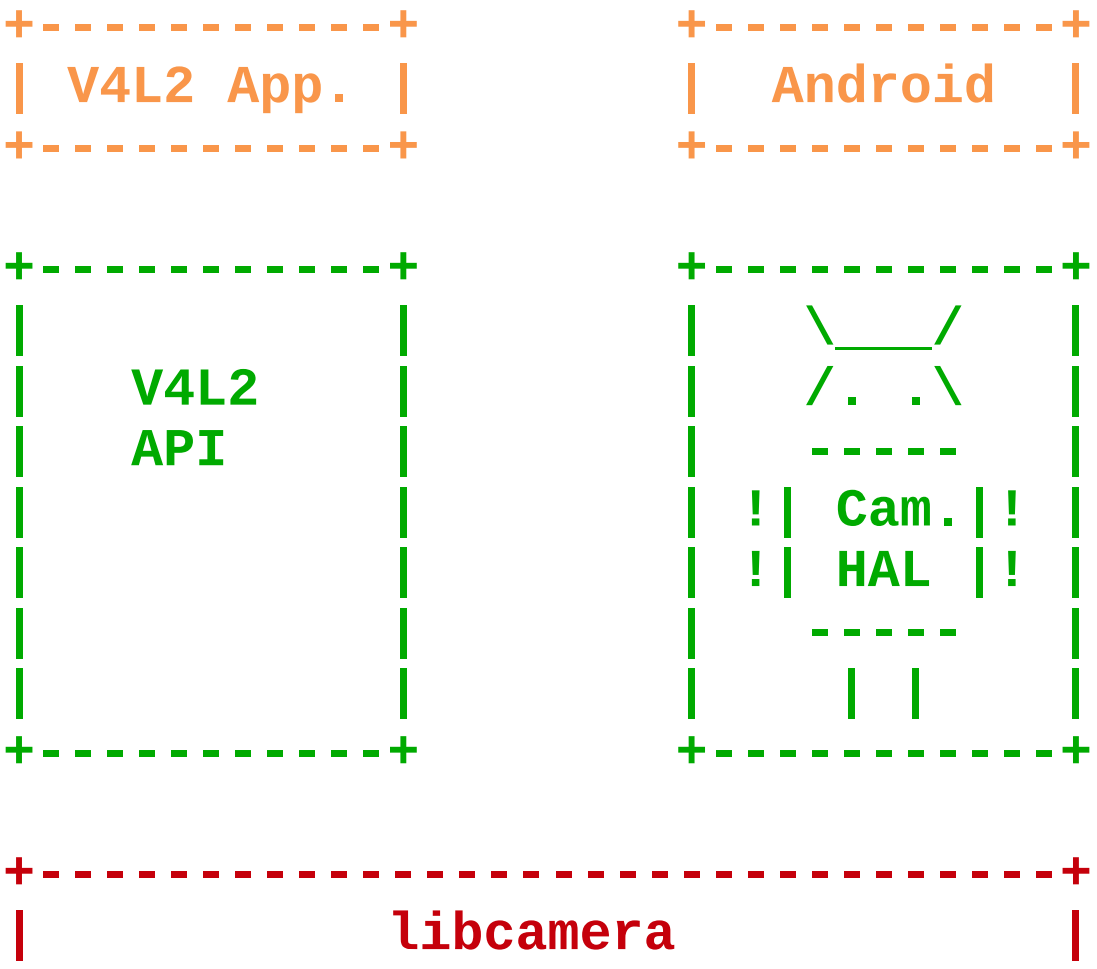
Image Processing Algorithm are loaded as external modules.

Image Processing Algorithms (3A)



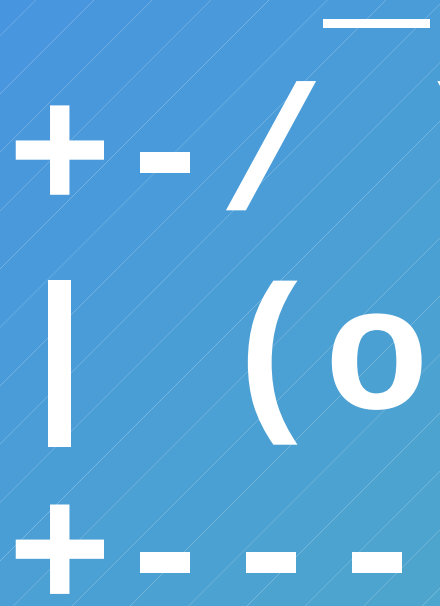
Adaptation layers offer backward compatibility with existing APIs...

Adaptation



… and integrate libcamera with other operating systems.

Adaptation



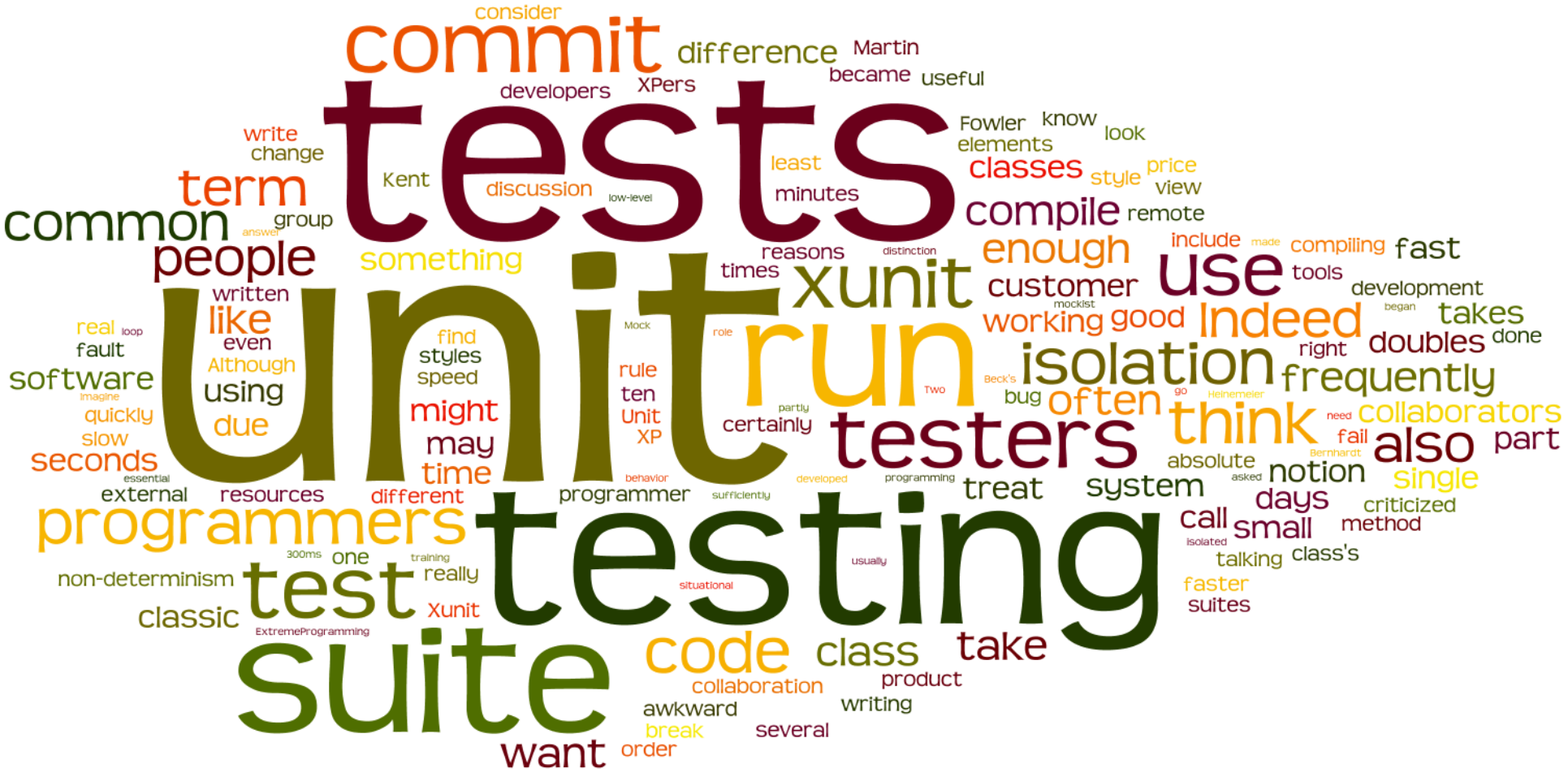
The libcamera Journey

IDEAS ON BOARD

Intel IPU3 (Kaby Lake)
on HP Chromebook x2

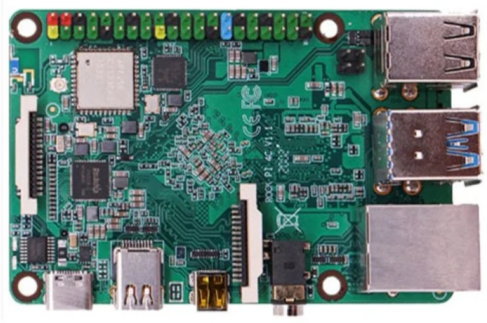
USB Video Class (UVC)

Our Initial Targets



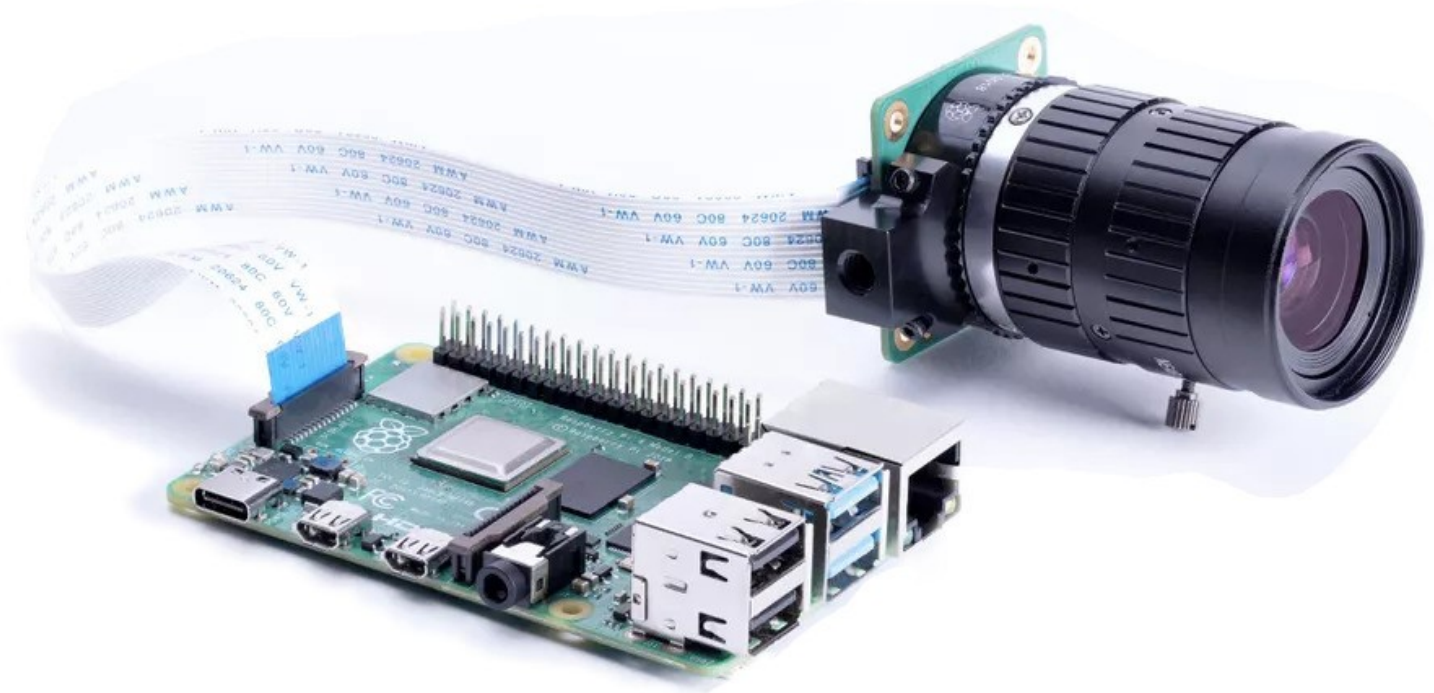
Test, Test, Test

Acer Chromebook Tab 10



ROCK PI 4

And ARM Too (RK3399)



IDEAS ON BOARD

Raspberry Pi 4 + IMX477

An open source camera stack for Raspberry Pi using libcamera

4th May 2020 David Plowman 39 comments

Since we released the first Raspberry Pi camera module back in 2013, users have been clamouring for better access to the internals of the camera system, and even to be able to attach camera sensors of their own to the Raspberry Pi board. Today we're releasing our first version of a new open source camera stack which makes these wishes a reality.

(Note: in what follows, you may wish to refer to the glossary at the end of this post.)

We've had the building blocks for connecting other sensors and providing lower-level access to the image processing for a while, but Linux has been missing a convenient way for applications to take advantage of this. In late 2018 a group of Linux developers started a project called libcamera to address that. We've been working with them since then, and we're pleased now to announce a camera stack that operates within this new framework.

RELATED POSTS

New product: Raspberry Pi High Quality Camera on sale now at $50

Controlling Telescopes with Raspberry Pi and Mathematica

NEXT POST

How to work from home with Raspberry Pi | The Magpi 93

PREVIOUS POST

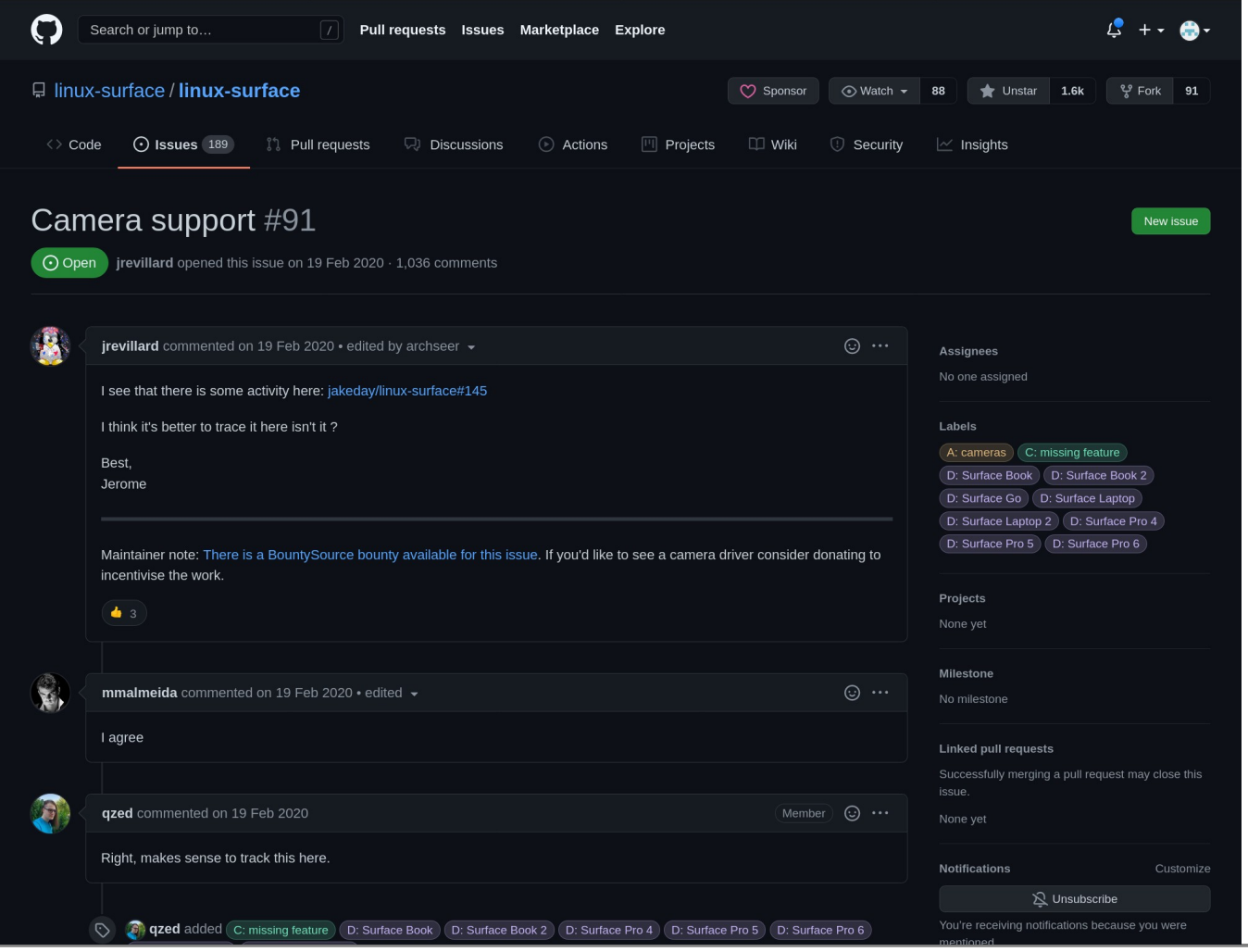
New book: The Official Raspberry Pi Camera Guide

IDEAS ON BOARD

An Unexpected Friend

IDEAS ON BOARD

Microsoft Surface Go 2

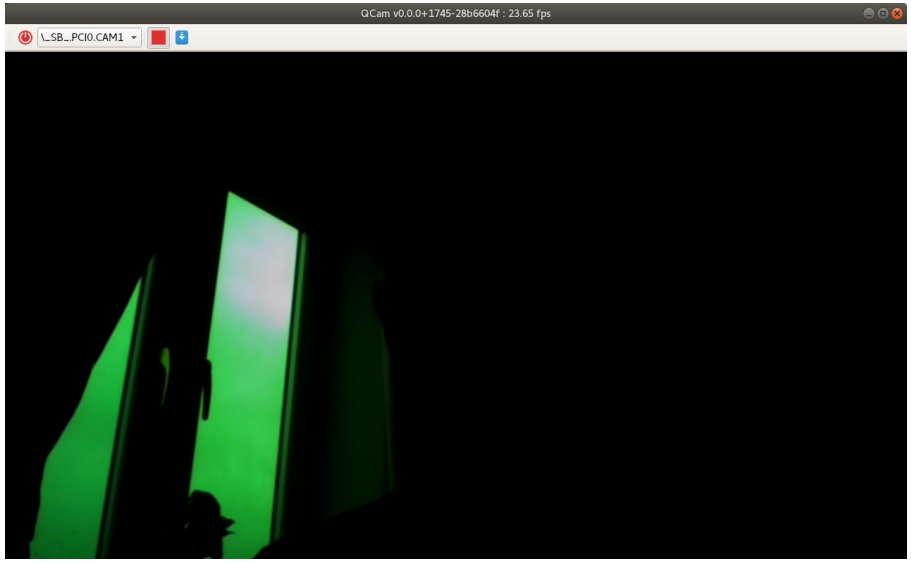


“I found libcamera based on this bug report, it seems to have the required userspace code to have ipu3 working on 5.0.”

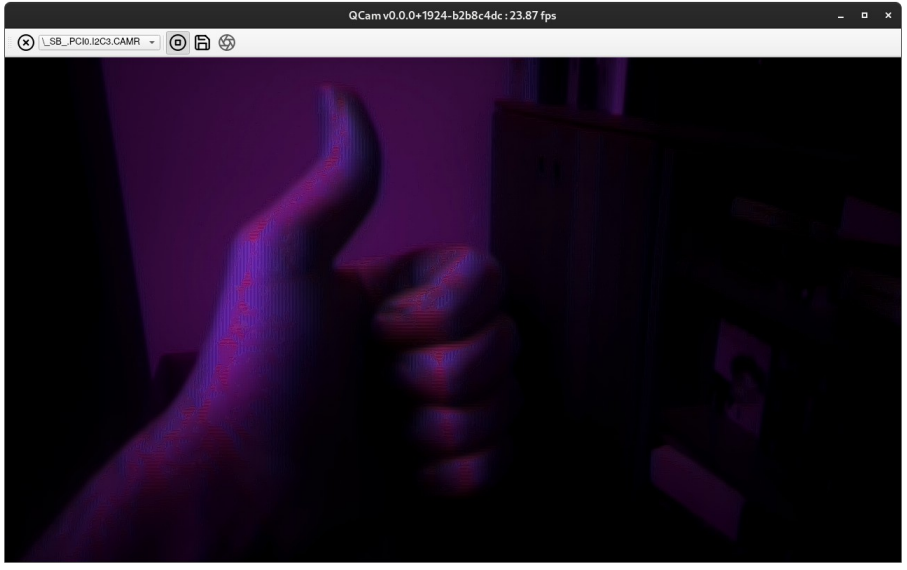
(archseer)

IDEAS ON BOARD

github.com/linux-surface



Initial support status with work on kernel drivers from djrscally, kitakar5525 and qzed

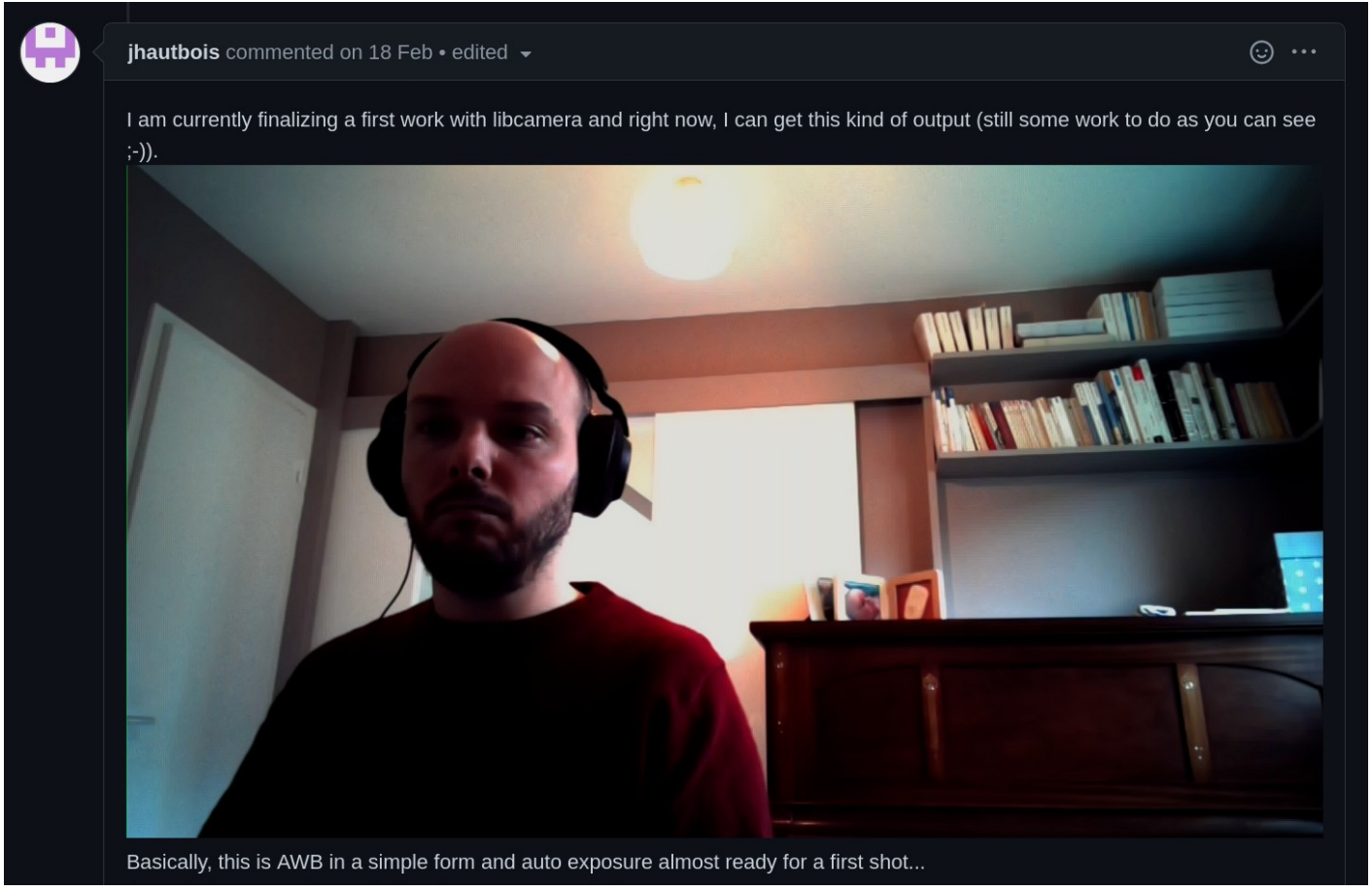


linux-surface

It seems that it tends to be purple-ish when it's dark and tends to be green-ish when it's bright.

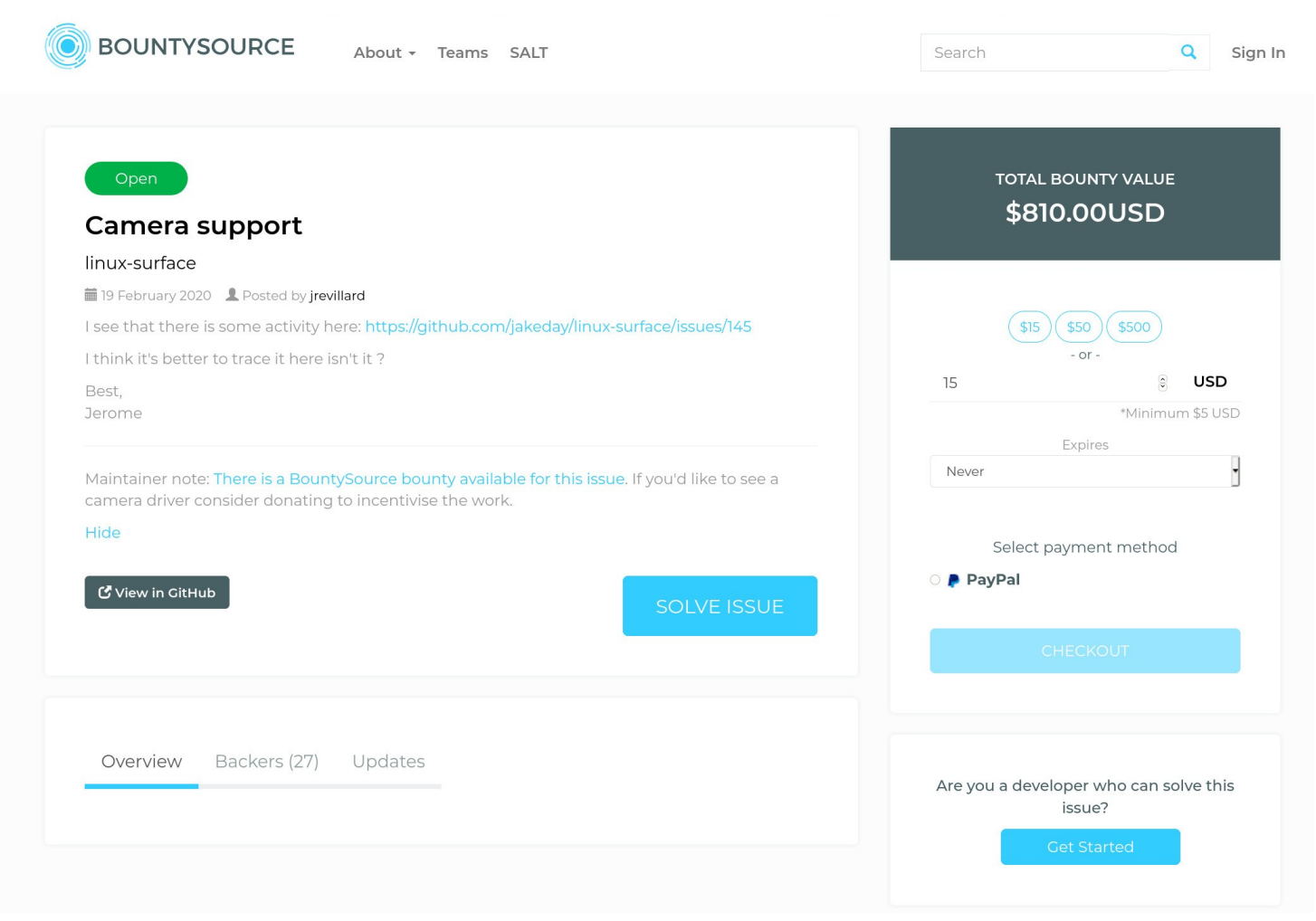
The sky after rain with leaf taken by surface-ipu3-cameras/ov8865_from_ov8856

Artwork



IDEAS ON BOARD

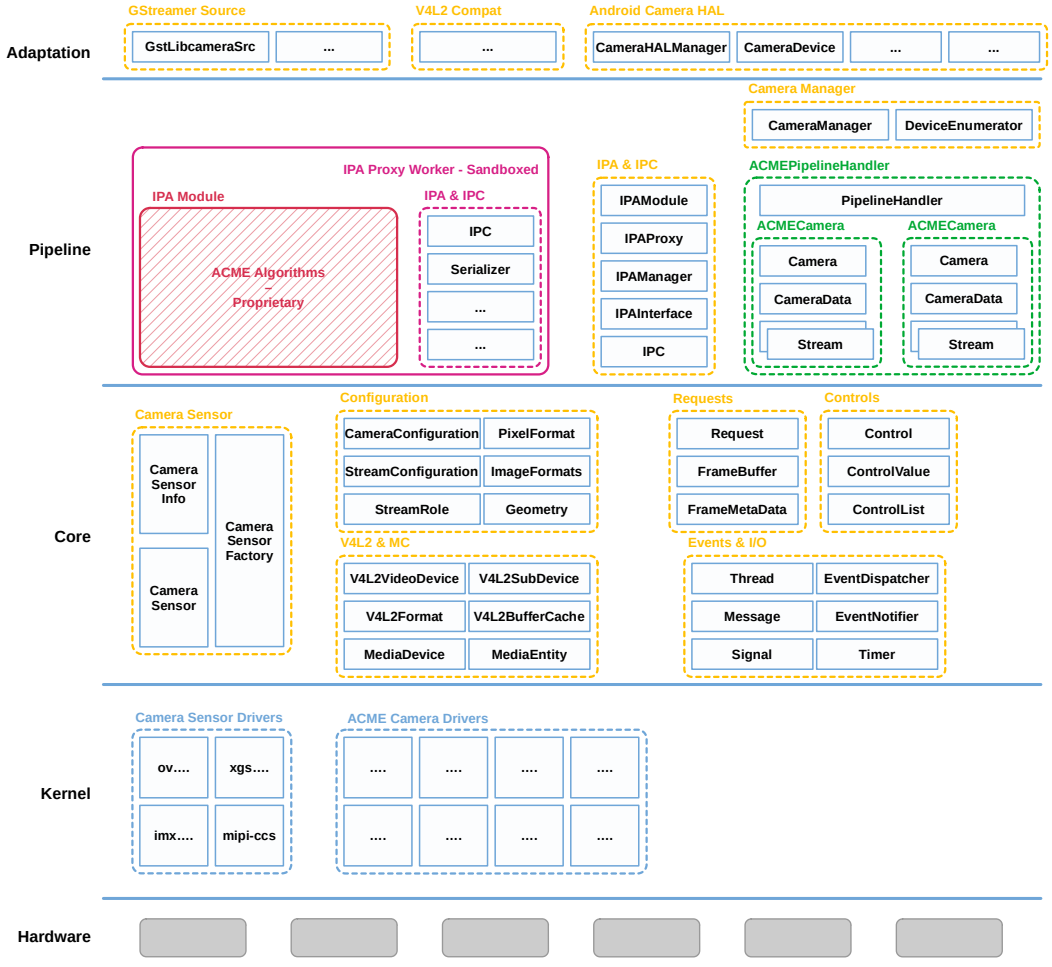
libcamera Involvement



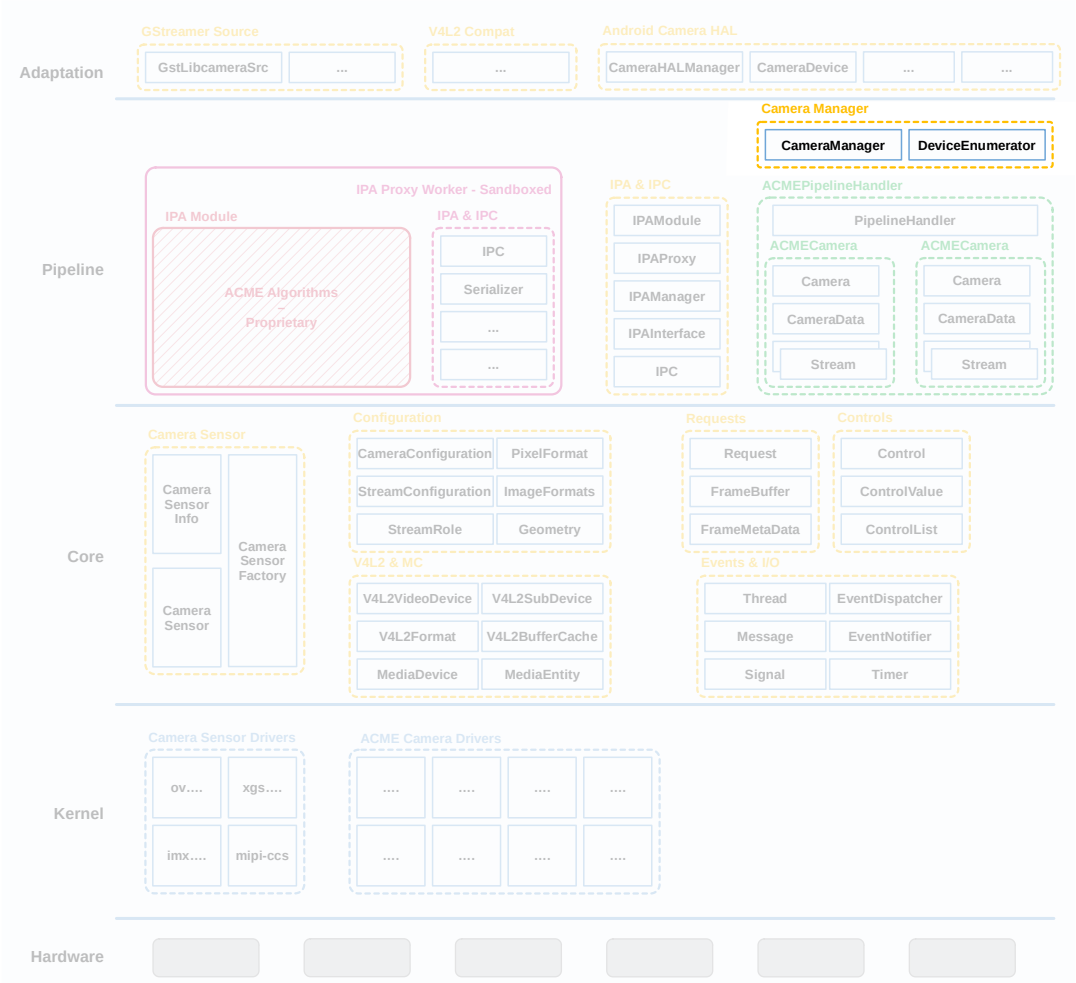
IDEAS ON BOARD

Budget Expectations

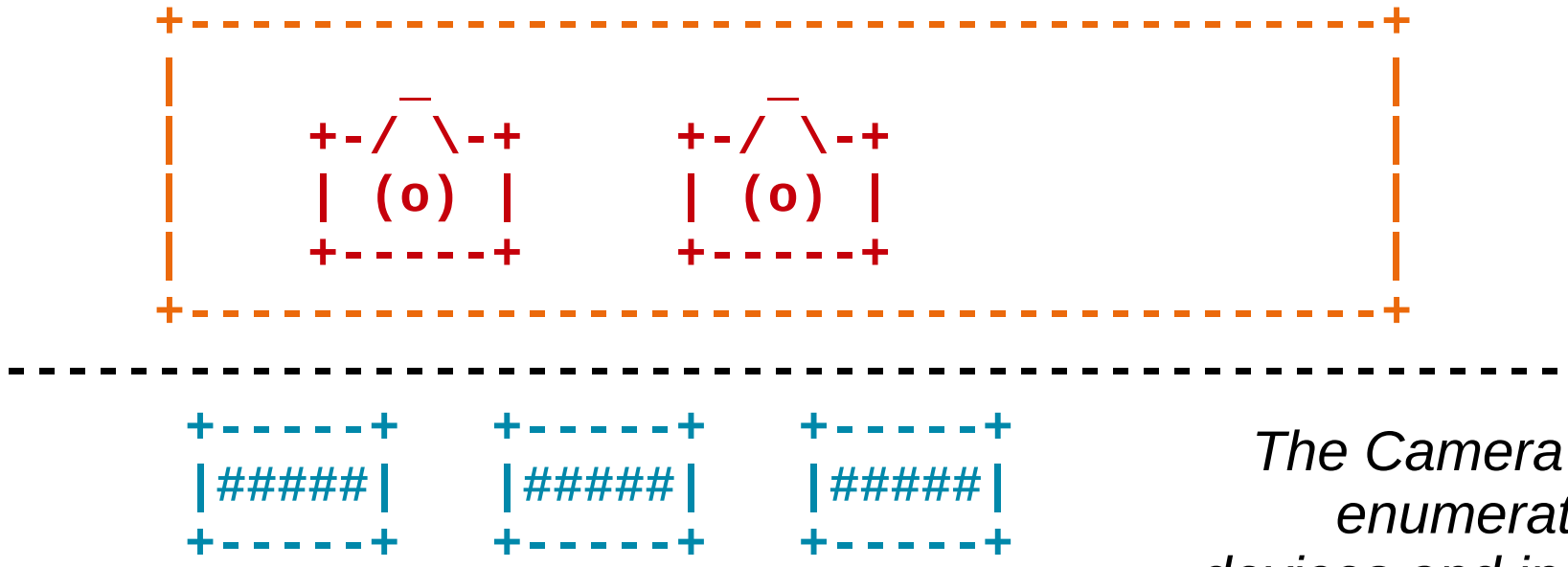
libcamera Today



The Camera Stack

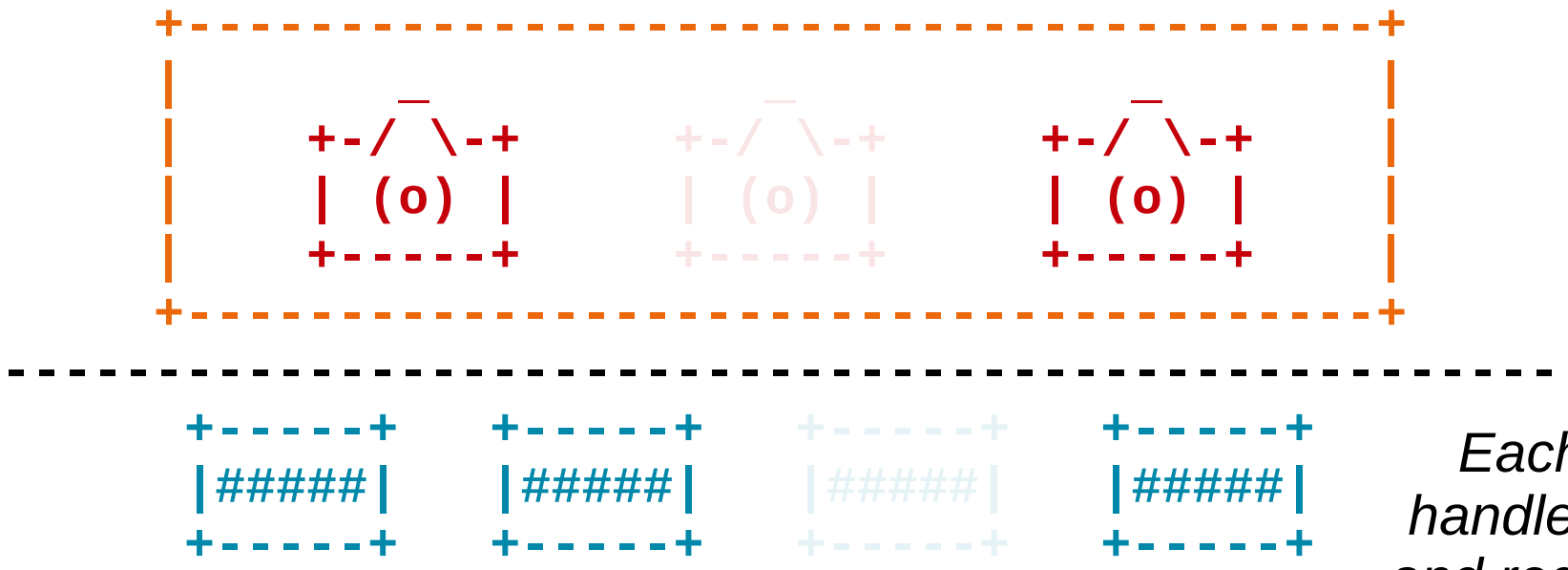


The Camera Manager



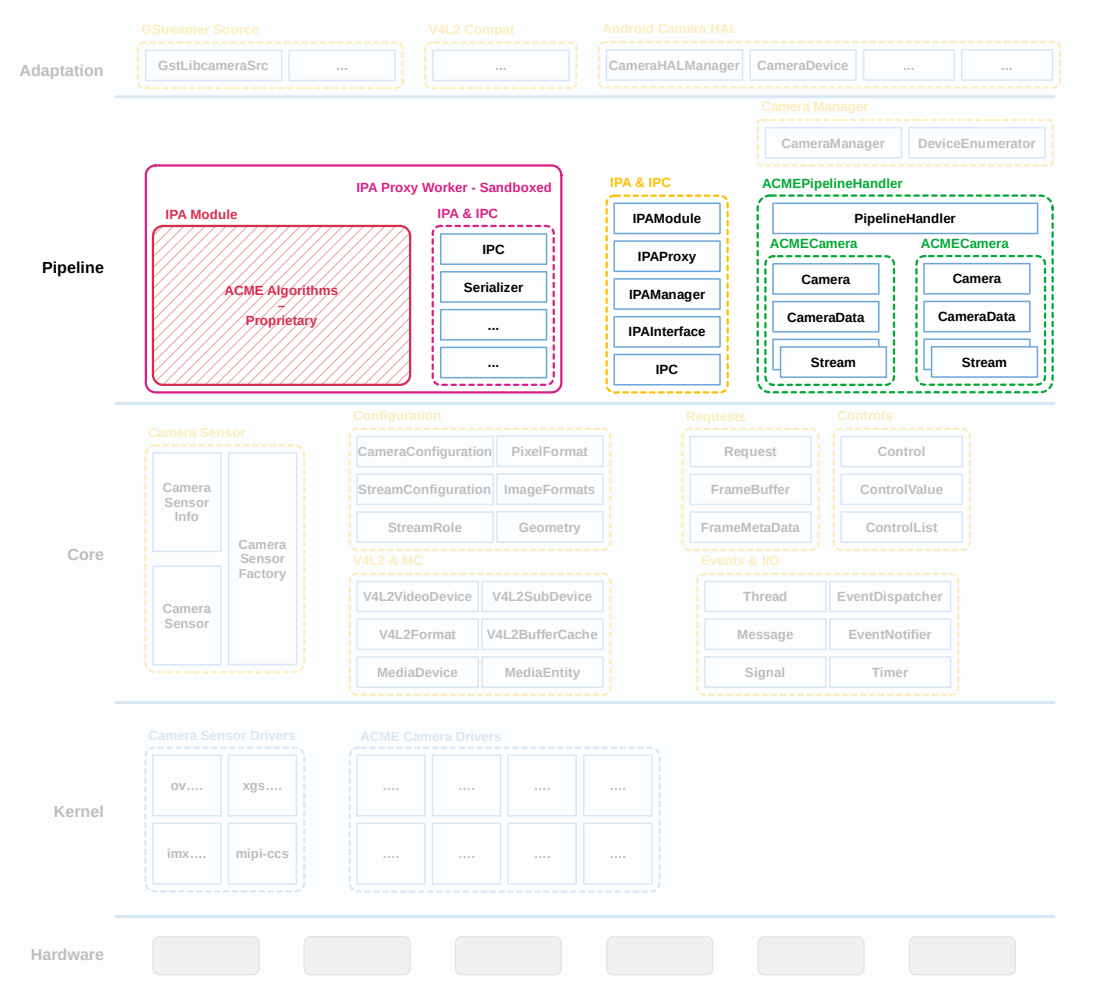
The Camera Manager enumerates media devices and instantiates corresponding pipeline handlers.

The Camera Manager

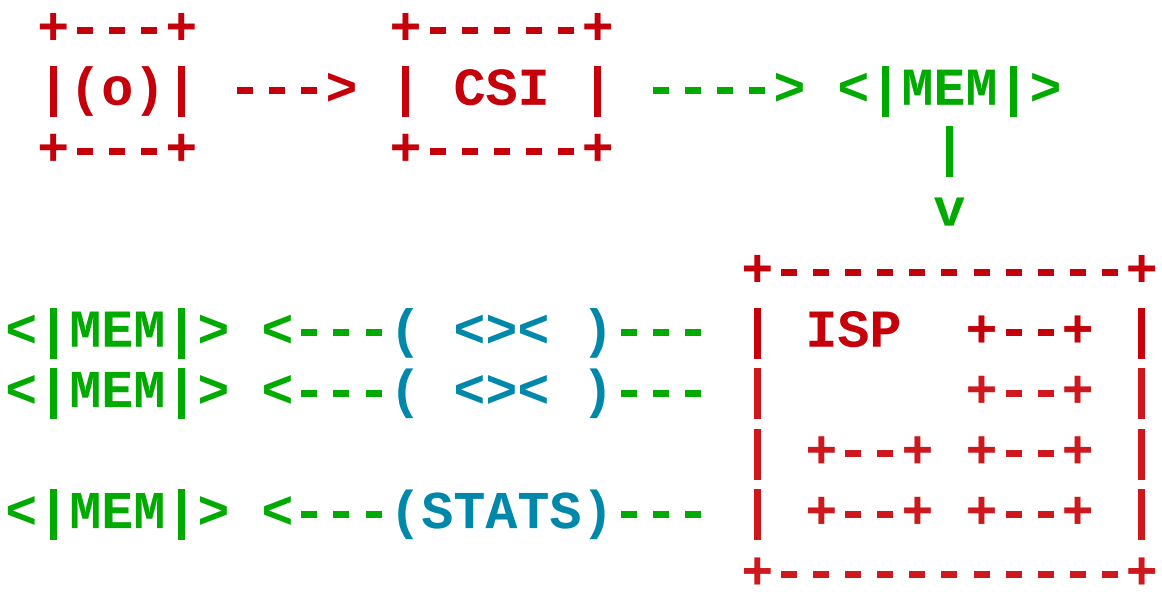


Each pipeline handlers create and register one or more cameras.

The Camera Manager



The Pipeline



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

The Pipeline Handler

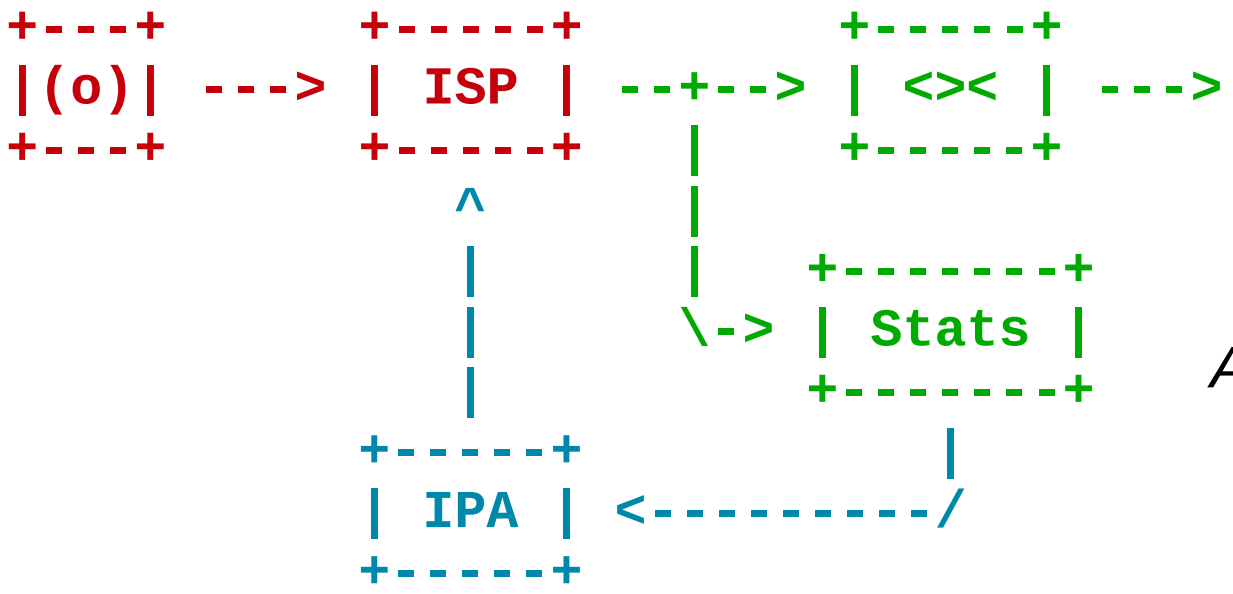
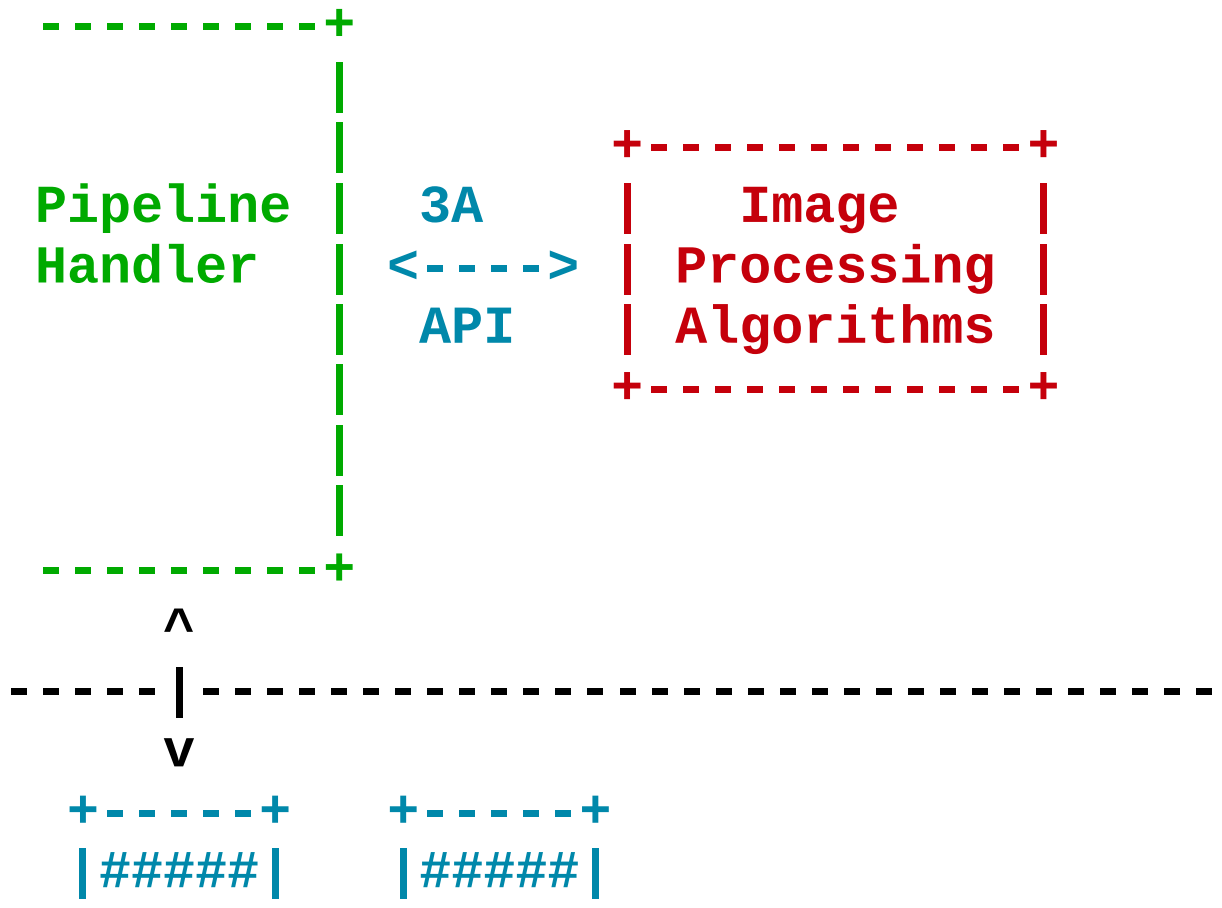


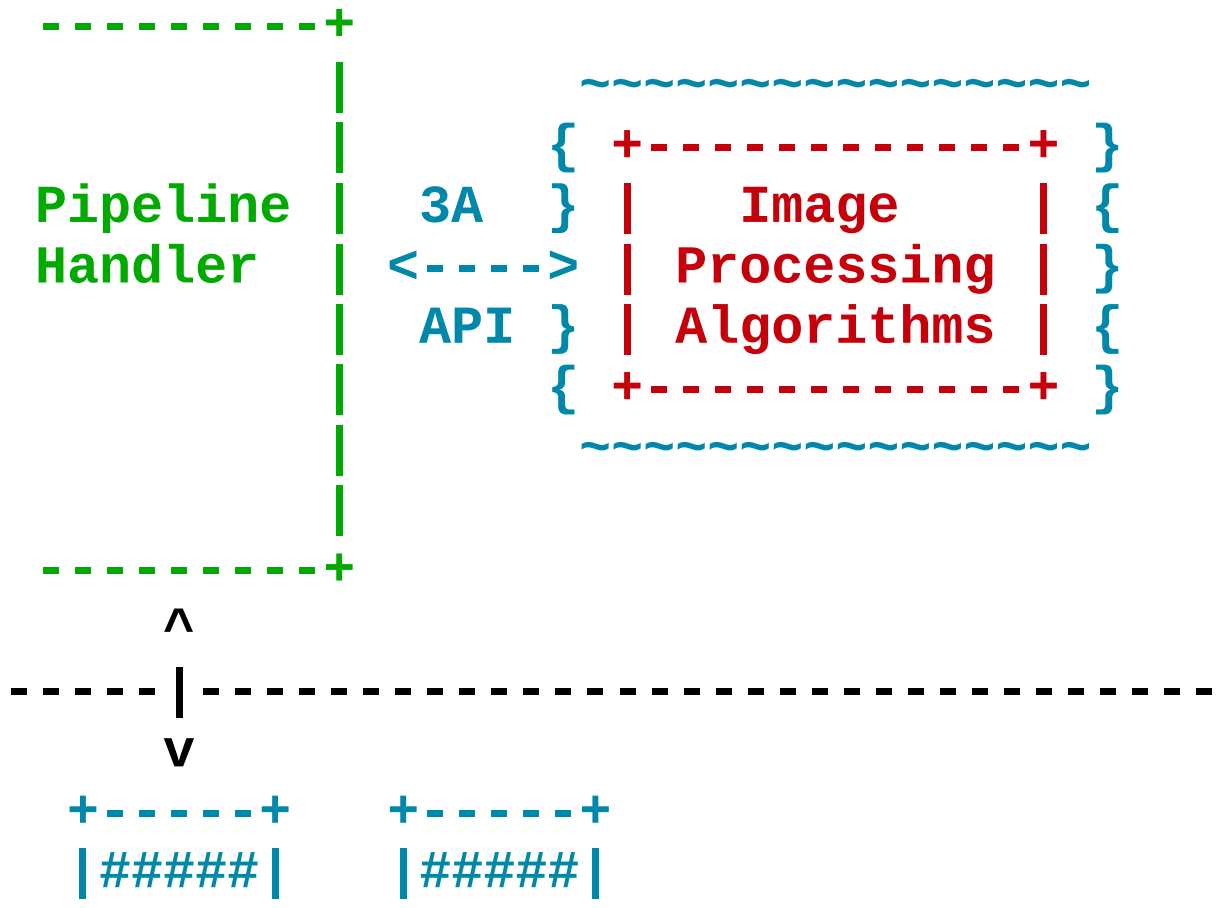
Image Processing Algorithms (IPA) receive statistics from the hardware and compute optimal image parameters.

The Image Processing Algorithms



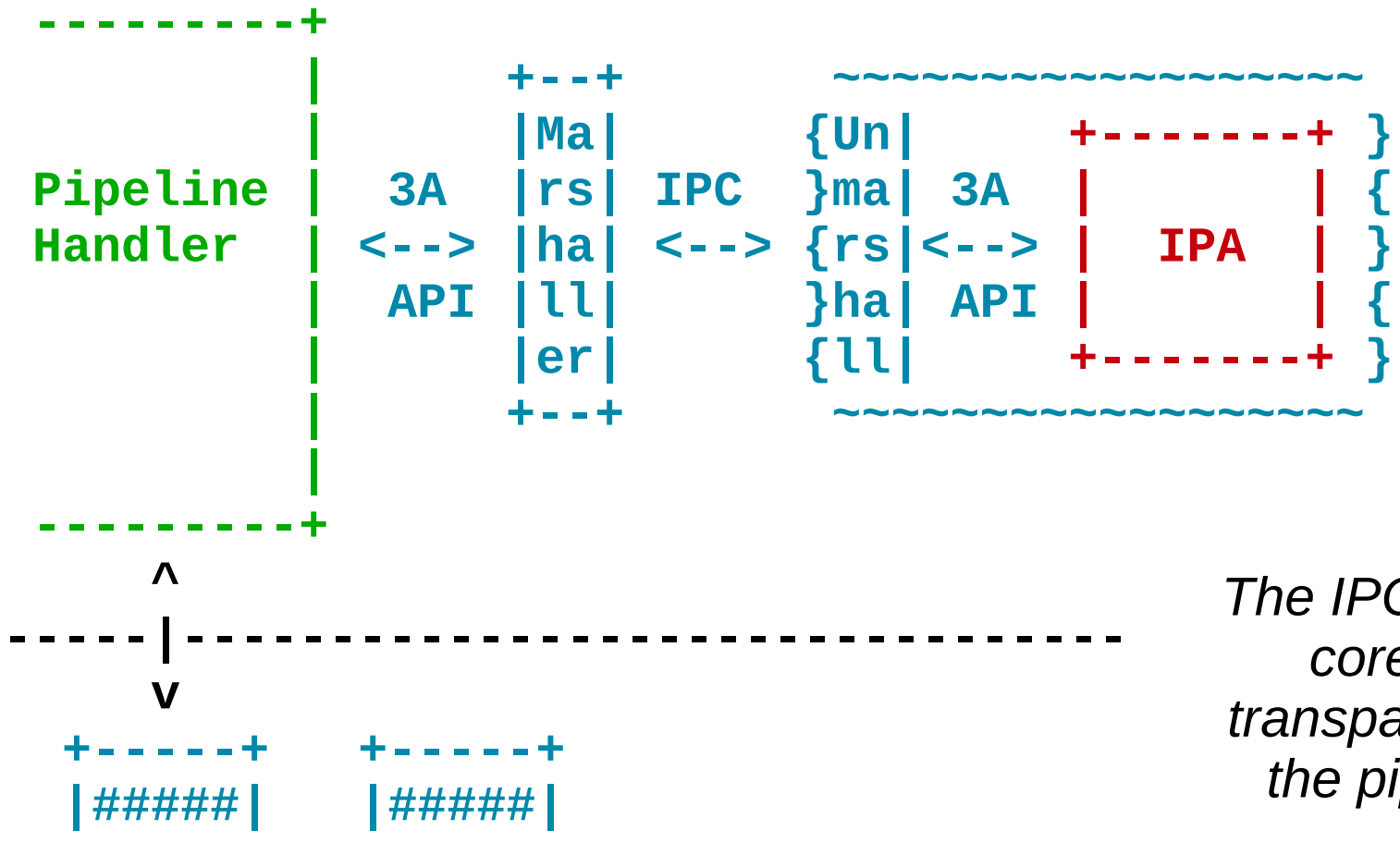
IPAs are separate modules that don't access kernel devices directly. They only have access to their pipeline handler through the IPA API.

The Image Processing Algorithms



Out-of-tree (including closed-source) IPAs are sandboxed in a separate process. They communicate with the pipeline handler through IPC.

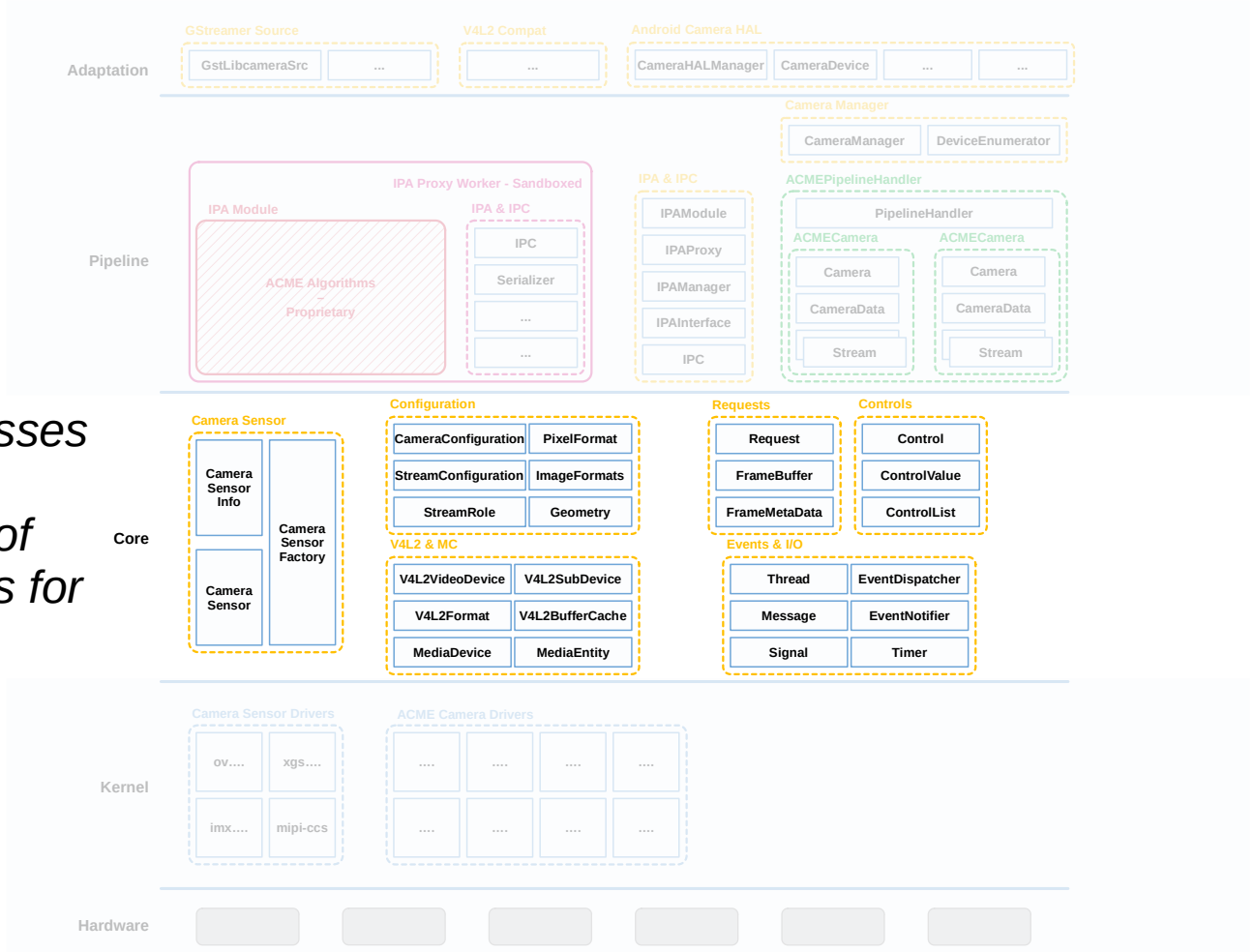
The Image Processing Algorithms



The IPC is handled in core components, transparently for both the pipeline handler and the IPA.

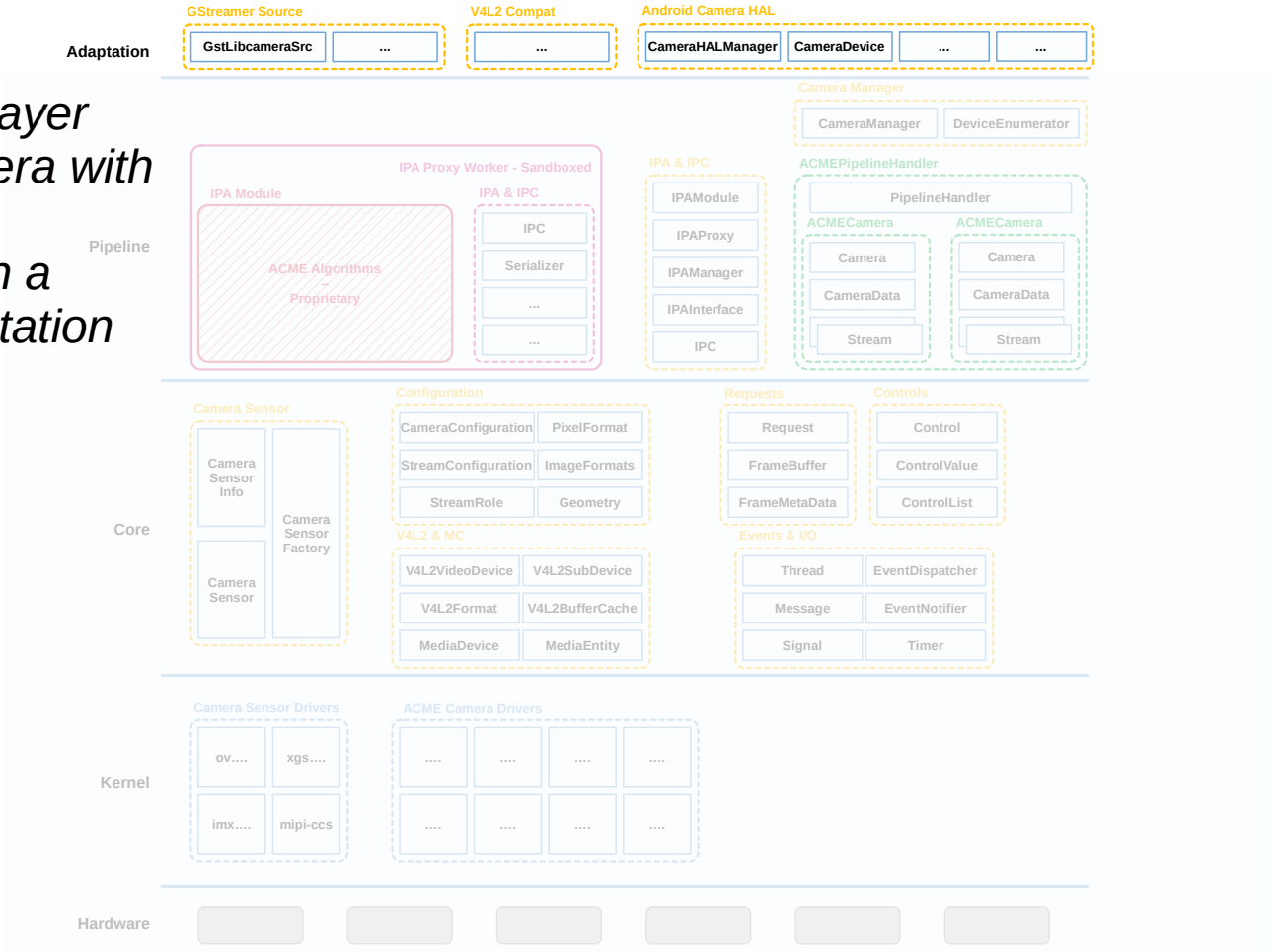
The Image Processing Algorithms

Many helper classes ease the implementation of pipeline handlers for device vendors.

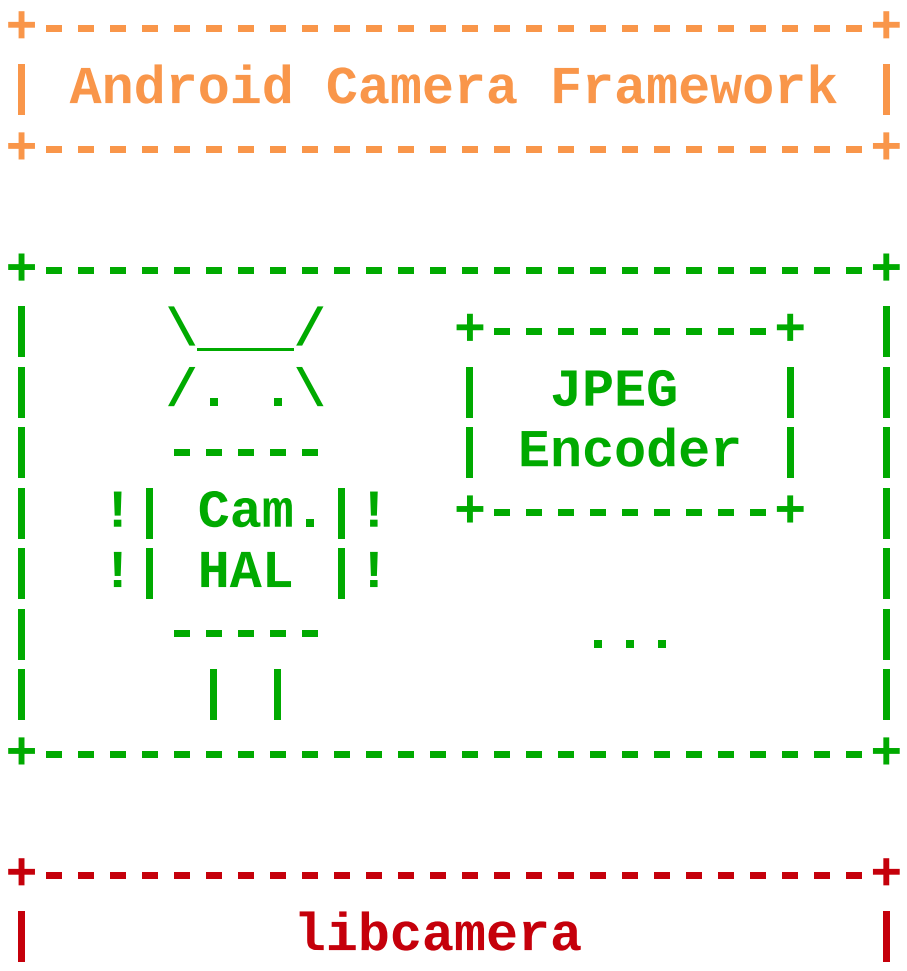


The Helpers and Support Classes

The adaptation layer interface libcamera with other APIs and frameworks, with a single implementation for all supported devices.



The Adaptation Layer

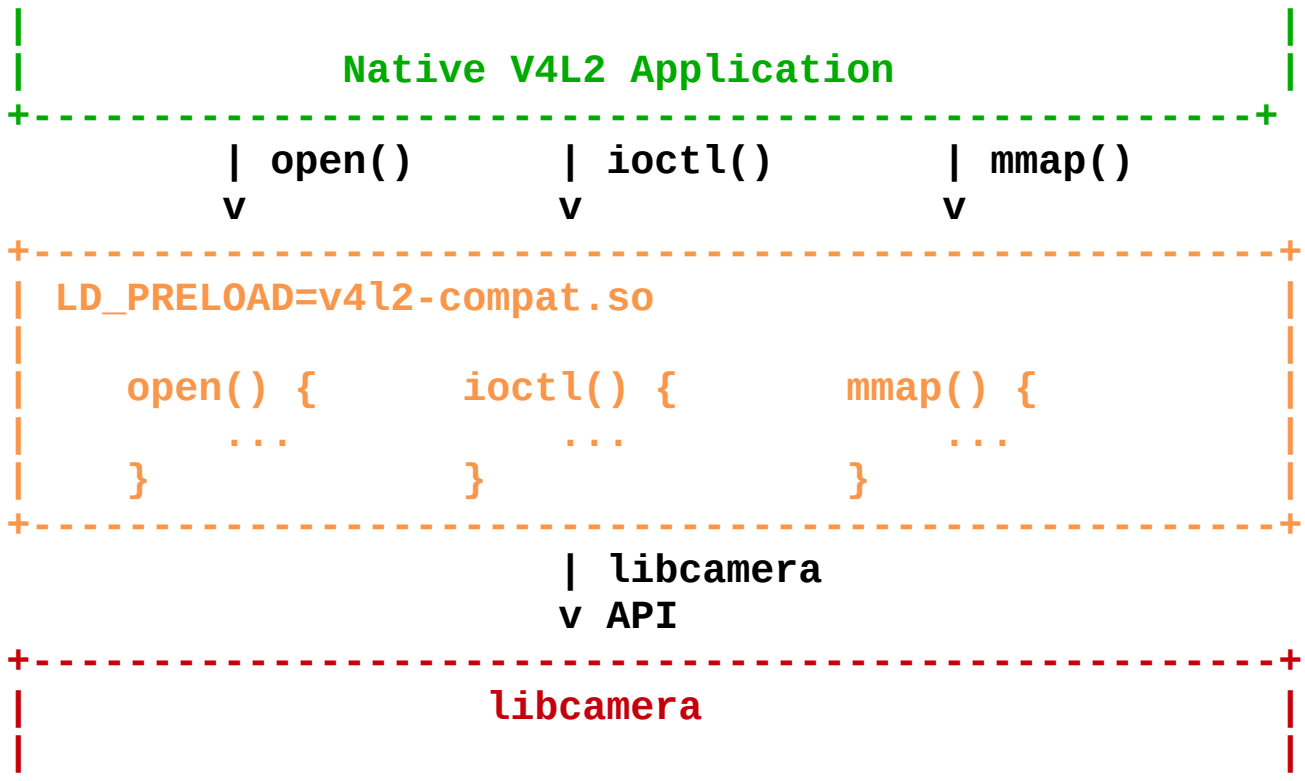


A single Android camera HAL module implementation for all devices supported by libcamera.

Android Camera HAL

“libcamerasrc” offers a multi-stream source element for GStreamer applications.

GStreamer

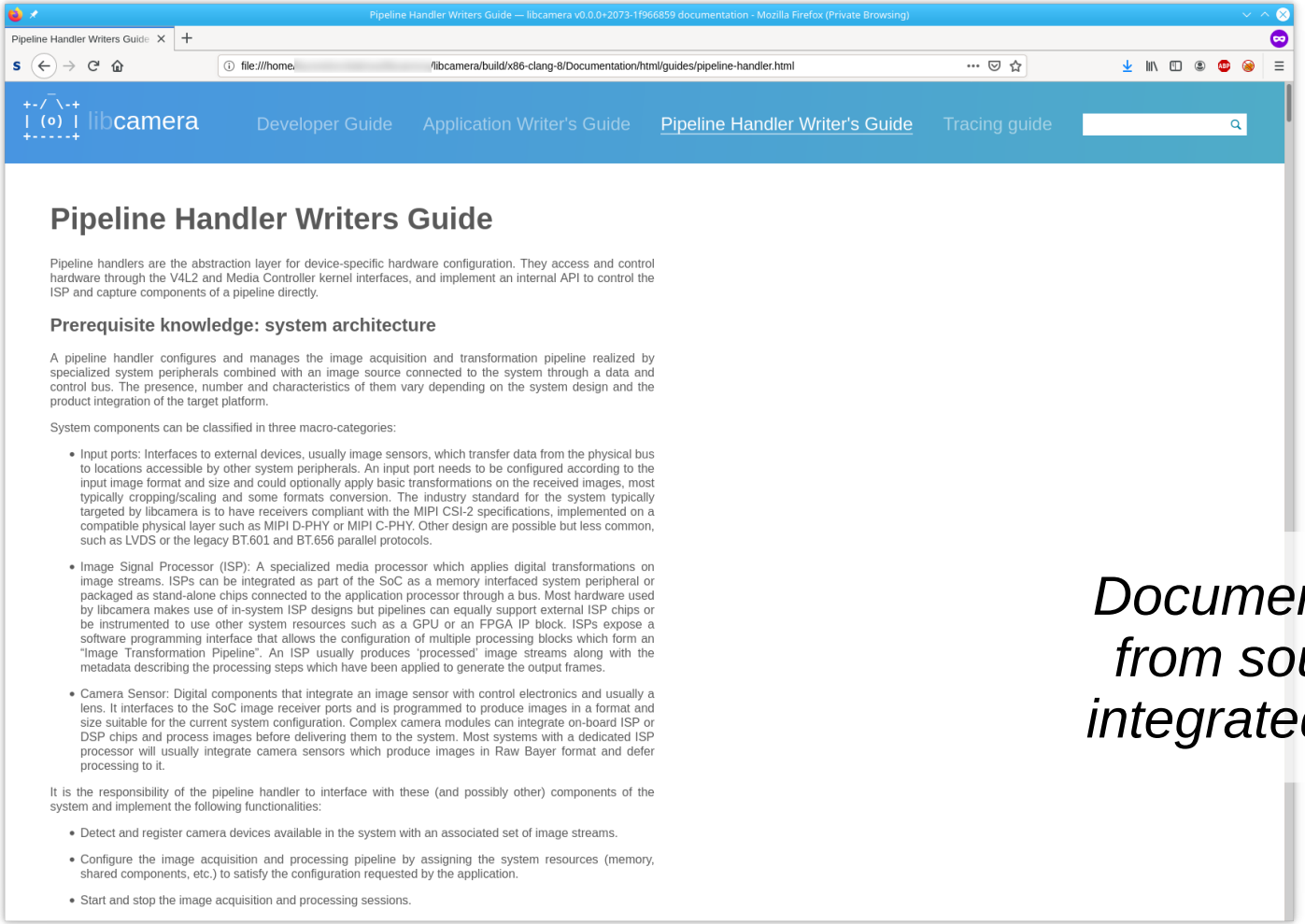


Native V4L2 applications are supported through a transparent compatibility layer.

Native V4L2 Compatibility

Features	Status
Core	Multi-camera, multi-stream, per-frame control, hotplug
Supported platforms	Raspberry Pi 3&4, Intel IPU3 (Kaby Lake), Rockchip RK3399, UVC, NXP i.MX7, Allwinner A31
IPA modules	Raspberry Pi, Intel IPU3 IPA module isolation with IPC (based on mojom IDL)
Adaptation layers	GStreamer source element (with multi-stream), Android camera HAL v3.3, V4L2 emulation
Tooling	Camera Tuning Tool (Rasperry Pi), tracing infrastructure and analysis script
Applications	cam (command line Swiss army knife), qcam (GUI), simple-cam (tutorial)
Documentation	Extensive API documentation and high-level tutorials and guides available

Summary of Supported Features



Documentation compiled from source tree, will be integrated in the website.

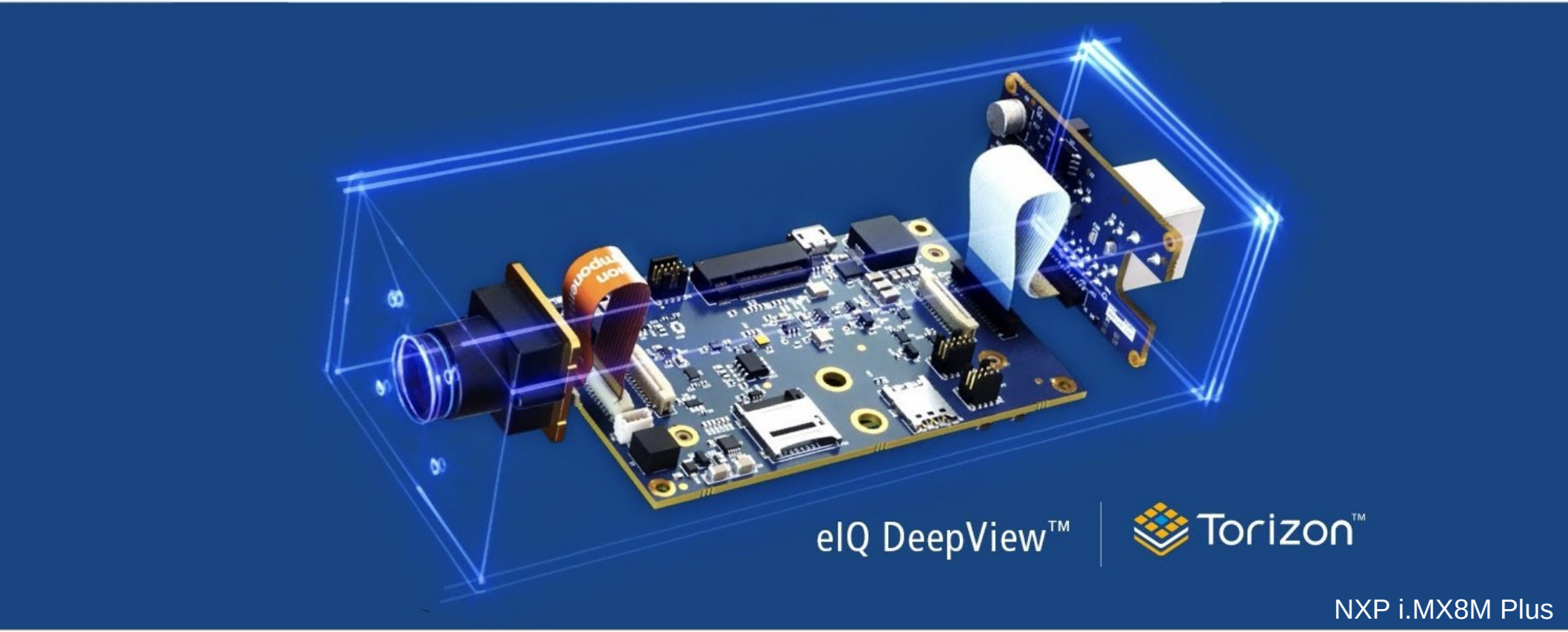
Guides

MEDIATEK | OLogic

MediaTek Pumpkin i500 (MT8385)

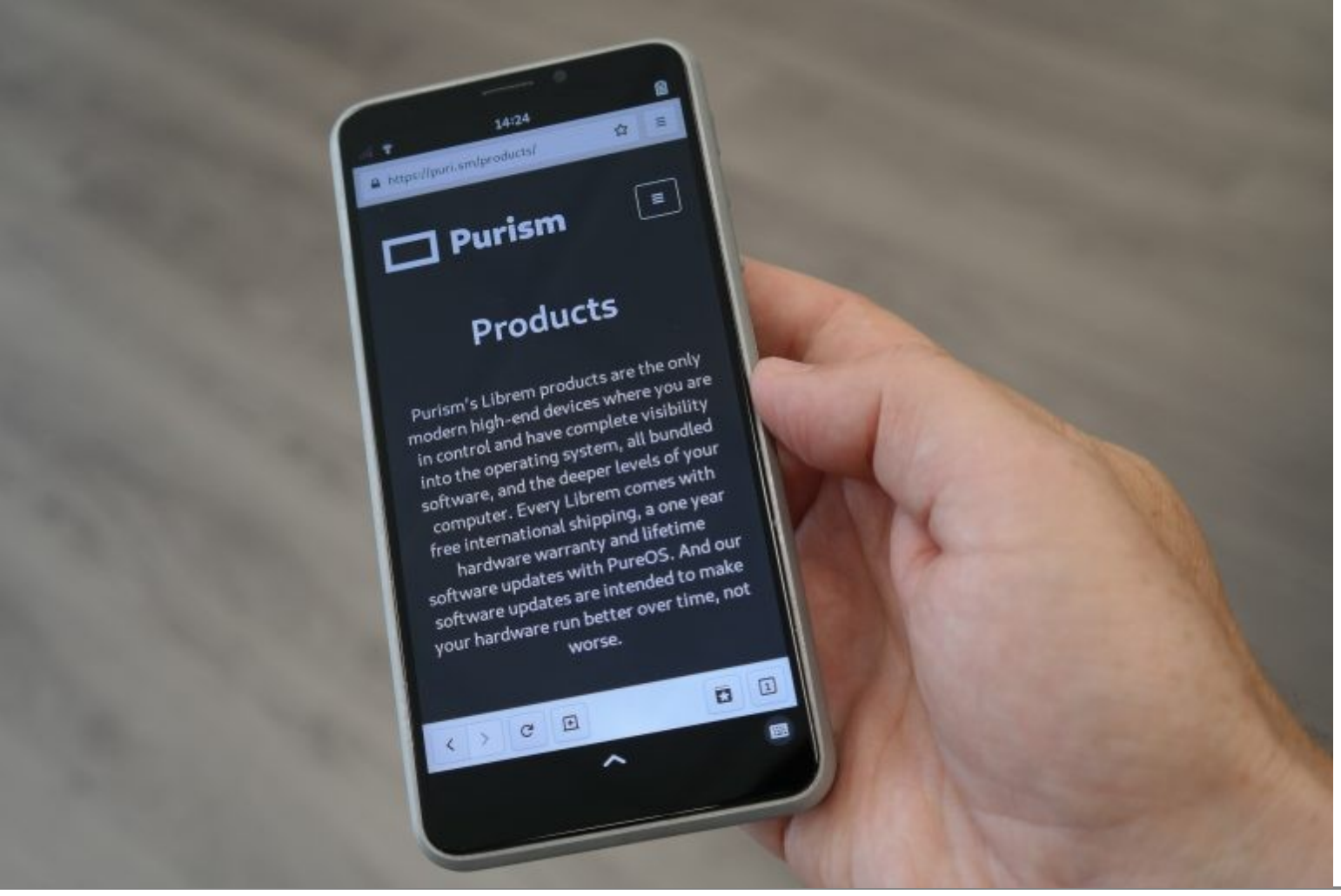
New Platforms

Toradex Swiss. Embedded. Computing. | Au-Zone Technologies Inc. | VC vision components® | NXP



IDEAS ON BOARD

New Platforms



Purism Librem 5

IDEAS ON BOARD

New Platforms

Features	Status
New platforms	MediaTek MT8385 (with YUV sensors), NXP i.MX8M Plus, Librem 5
Open-source IPA modules	Intel IPU3, Rockchip ISP, I.MX8M Plus
Reprocessing API	Work in progress in the libcamera core, Android HAL support will follow
Controls and properties	New controls and properties are continuously added on a per-need basis
API cleanups	Moving toward the API freeze for a 1.0 release, API changes will remain backward-compatible (extensible API design, d-pointer design pattern, …)
Language bindings	Python bindings in progress
Android LIMITED and FULL CTS compliance	Core infrastructure ready, controls and properties (static, control and dynamic metadata) being developed incrementally
Integration	Native support in Chromium web browser available at https://github.com/libcamera-org/chromium.

Work In Progress

Chromium (on MS Surface Go 2)

Embedded
Camera

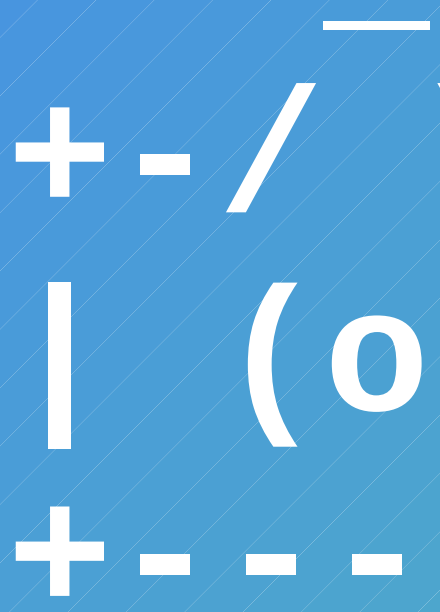
Exploratory Group for Embedded Camera and Sensors

HOSTED BY:

emva
european machine vision association

KHRONOS GROUP

Participation In Industry Initiatives



For Camera Vendors

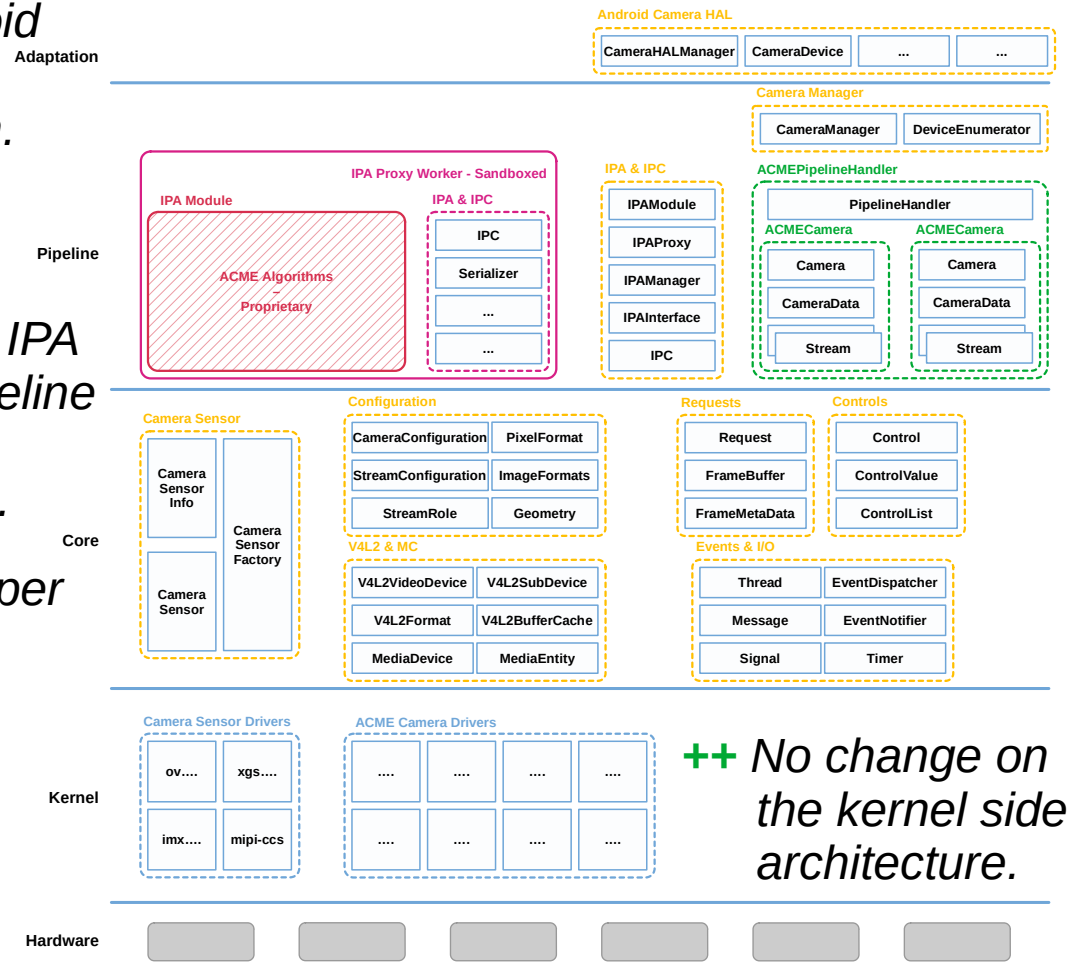
IDEAS ON BOARD

++ *Standard Android Camera HAL Implementation.*

++ *GStreamer, V4L2, ...*

/!\ *Custom API for IPA module <-> pipeline handler communication.*

++ *libcamera wrapper classes reduce custom code.*



++ *No change on the kernel side architecture.*

/!\ *Pipeline handler is ACME-specific development.*

++ *Development support available.*

/!\ *Implementation changes may be required to mainline drivers.*

Platform Enablement

We drive MC and V4L2 standardization and extensions development according to our needs.

Kernel APIs

We drive MC and V4L2 standardization and extensions development according to our needs.

libcamera is a userspace framework, not a hostile takeover of kernel development.

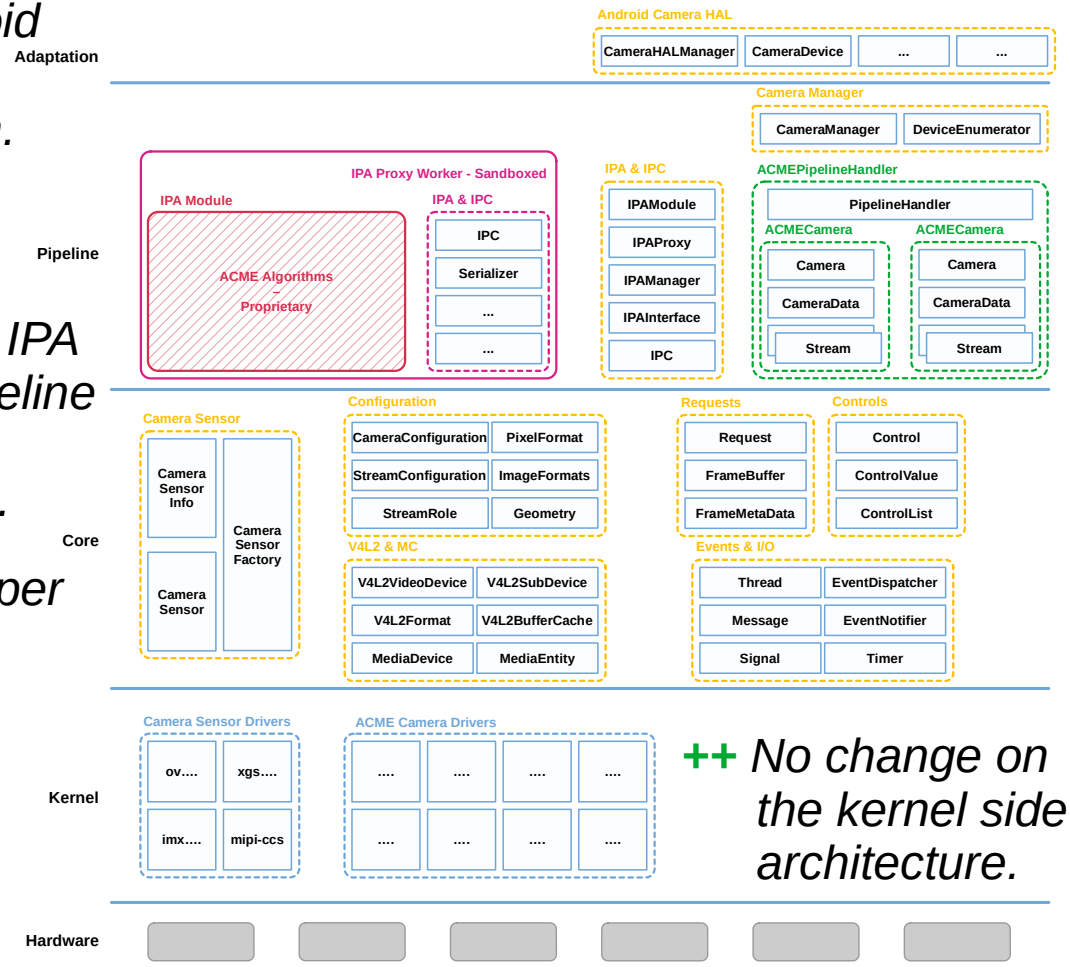
Kernel APIs

++ *Standard Android Camera HAL Implementation.*

++ *GStreamer, V4L2, ...*

/!\ *Custom API for IPA module <-> pipeline handler communication.*

++ *libcamera wrapper classes reduce custom code.*



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/!\ *Implementation changes may be required to mainline drivers.*

Platform Enablement

The libcamera core is licensed under the LGPL v2.1 or later.

Licensing

The libcamera core is licensed under the LGPL v2.1 or later.

Changes need to be published according to the license. This includes pipeline handlers.

Licensing

The libcamera core is licensed under the LGPL v2.1 or later.

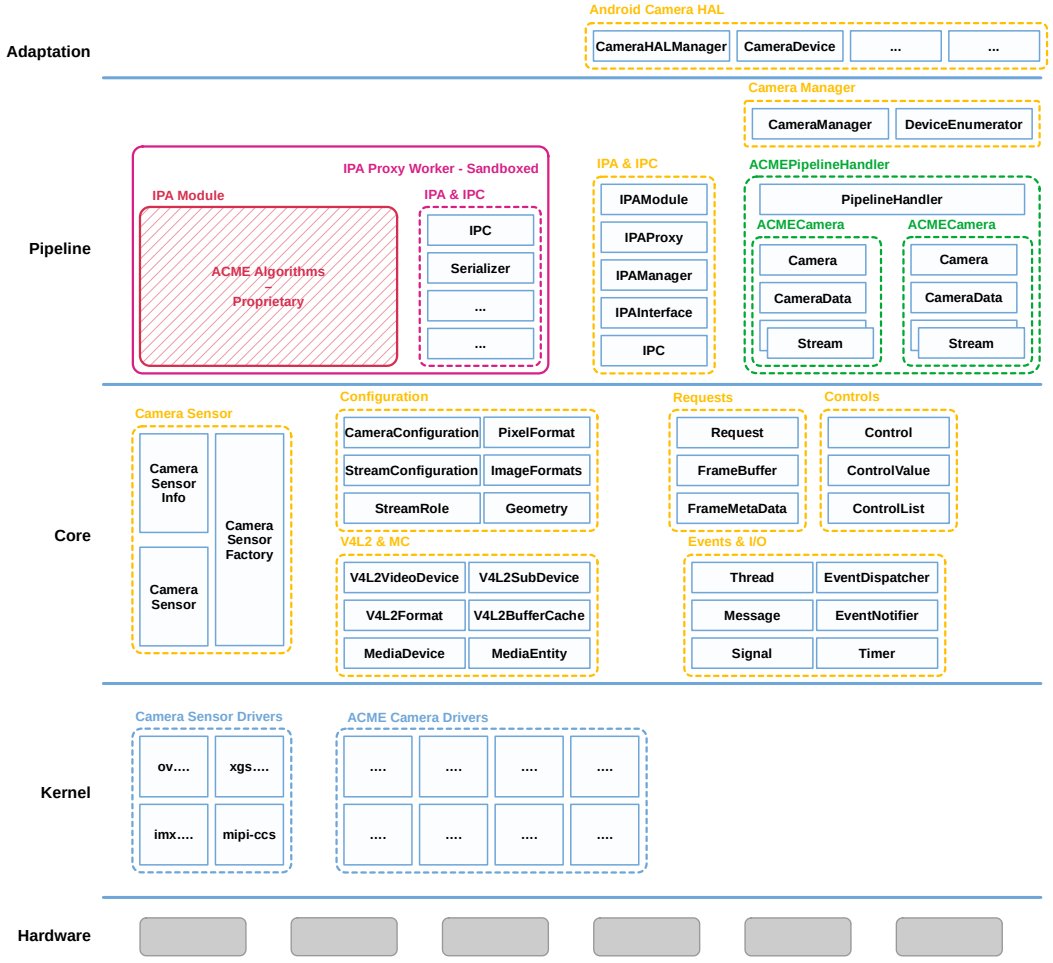
Changes need to be published according to the license. This includes pipeline handlers.

Upstreaming is not mandatory but highly recommended (forks are costly to maintain).

Licensing

Closed-source IPA modules are fully supported.

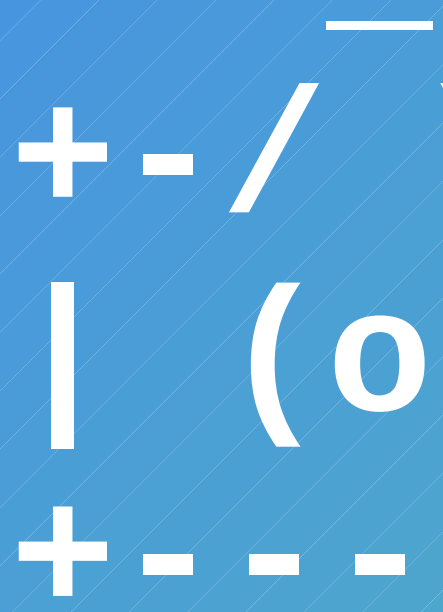
Pipeline handlers and IPA modules can link to third-party libraries.



The libcamera core, pipeline handlers and adaptation are licensed under LGPL v2.1 or later

Kernel code is licensed under GPL v2.0.

Licensing



An Exciting Future

Features	Status
Per-stream controls	Concept approved, will be scheduled in the future.
Zero shutter lag	Will be possible through the reprocessing API. We are considering a high-level “use cases” library on top of libcamera for ZSL and similar features.
Exposure bracketing HDR	Similarly to ZSL, could be implemented in a “use cases” library. A solution for device-assisted HDR (hardware merging or software merging based on hardware-generated metadata) is needed.
Logical camera devices (W+T zoom, power saving, ...)	Not planned yet, missing development and test platform.
Still image trigger sequence (focus & flash)	Not planned yet, missing development and test platform.

Future Features – Core

Features	Status
Open-source IPA modules	Cross-platform core library, long term work to convince device vendors
GPU-based processing	Proof of concept shader code in qcam test application, should be leveraged to create GPU-based ISP for platforms without a hardware ISP (Librem 5).
New devices support	Ongoing discussions with SoC/system vendors, community-driven effort on legacy devices (any volunteer for the N900/N9 ?)

Future Features – Devices

Wednesday, September 29 • 3:55pm - 4:45pm

Advanced Camera Support on Allwinner SoCs with Mainline Linux - Paul Kocialkowski, Bootlin

Capturing pixels with a camera involves a number of steps, from the ADC reading the photosites in the image sensor to the final pixel values that are ready for encode/display, with various processing and transmission taking place along the way. While simple cases put most of the heavy lifting on the image sensor's side (through its embedded processor) and use a simple parallel bus for transmission, advanced cases require more work to be done outside of the sensor. In addition, modern high-speed transmission buses also bring-in more complexity. This talk will present how support for such an advanced use case was integrated into the mainline Linux kernel, using the Media and V4L2 APIs. It involves supporting a sensor using the raw Bayer RGB format, transmission over the MIPI CSI-2 bus as well as support for the Image Signal Processor (ISP) found on Allwinner platforms. A specific focus will be set on this ISP, with details about the features it implements as well as the internal and userspace APIs that are used to support it. The integration between all of the involved components will also be highlighted.

Speakers

Paul Kocialkowski

Embedded Linux Engineer, Bootlin

Paul joined Bootlin in 2018 and started with bringing support for the Allwinner VPU to mainline Linux. He went on to cover more topics related to graphics and multimedia, with various contributions to the DRM and V4L2 Linux subsystems as well as various related projects. Before that... Read More →

Wednesday September 29, 2021 3:55pm - 4:45pm PDT
Room 4
Embedded Linux Conference (ELC), Streaming Media & Graphics
Experience Level Mid-level
Talk Type Virtual

New Platforms

Features	Status
HAL v3.5(+)	On the roadmap, on hold due to lack of development and test platform. Future Android camera HAL API extensions will be implemented (including extensions to the libcamera core if needed).
Zero Shutter Lag	HAL-based ZSL implemented using the libcamera reprocessing API.

Future Features – Android HAL

Features	Status
Frameworks	PipeWire, OpenCV, Qt Multimedia, Electron, <insert your framework here>, ...
Applications	Firefox, OBS, <insert your application here>, ...
Operating Systems	Chrome OS, Android, Linux distributions, Buildroot, OpenEmbedded, ...

Future Features – Integration

libcamera

libcamera-devel@lists.libcamera.org
irc://chat.freenode.net/#libcamera

laurent.pinchart@ideasonboard.com

Contact

Thank you.