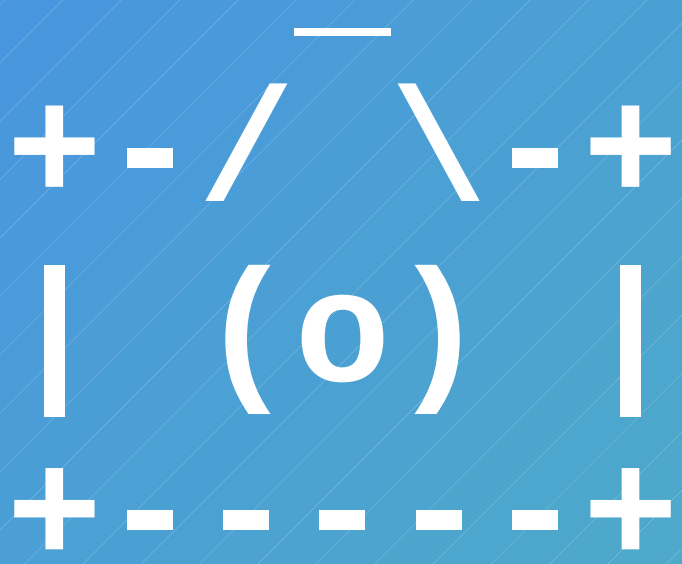


This is how libcamera will support your platform

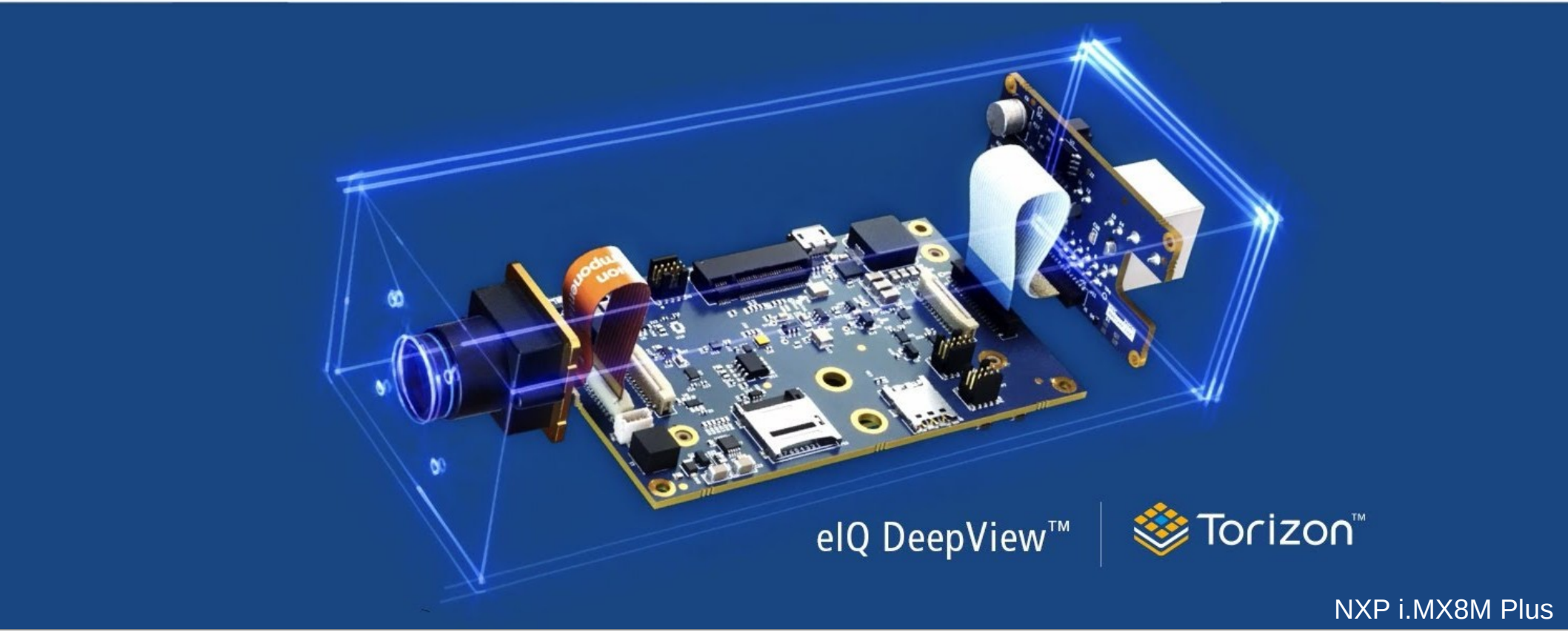
Embedded Recipes 2022
Paris, 2022-05-31

Laurent Pinchart
laurent.pinchart@ideasonboard.com

The use case

IDEAS ON BOARD

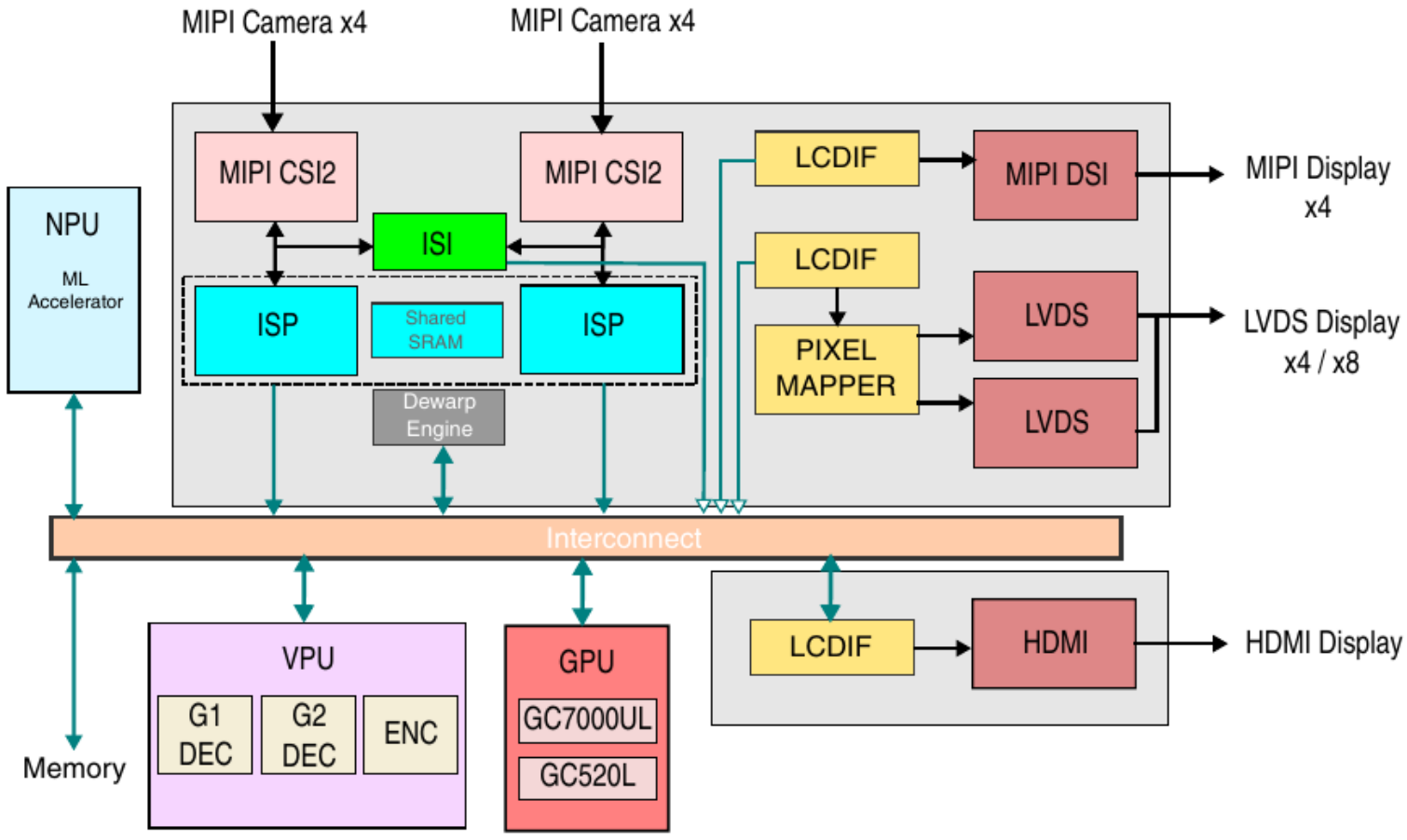
Toradex Swiss. Embedded. Computing. | Au-Zone Technologies Inc. | VC vision components® | NXP



NXP i.MX8M Plus

IDEAS ON BOARD

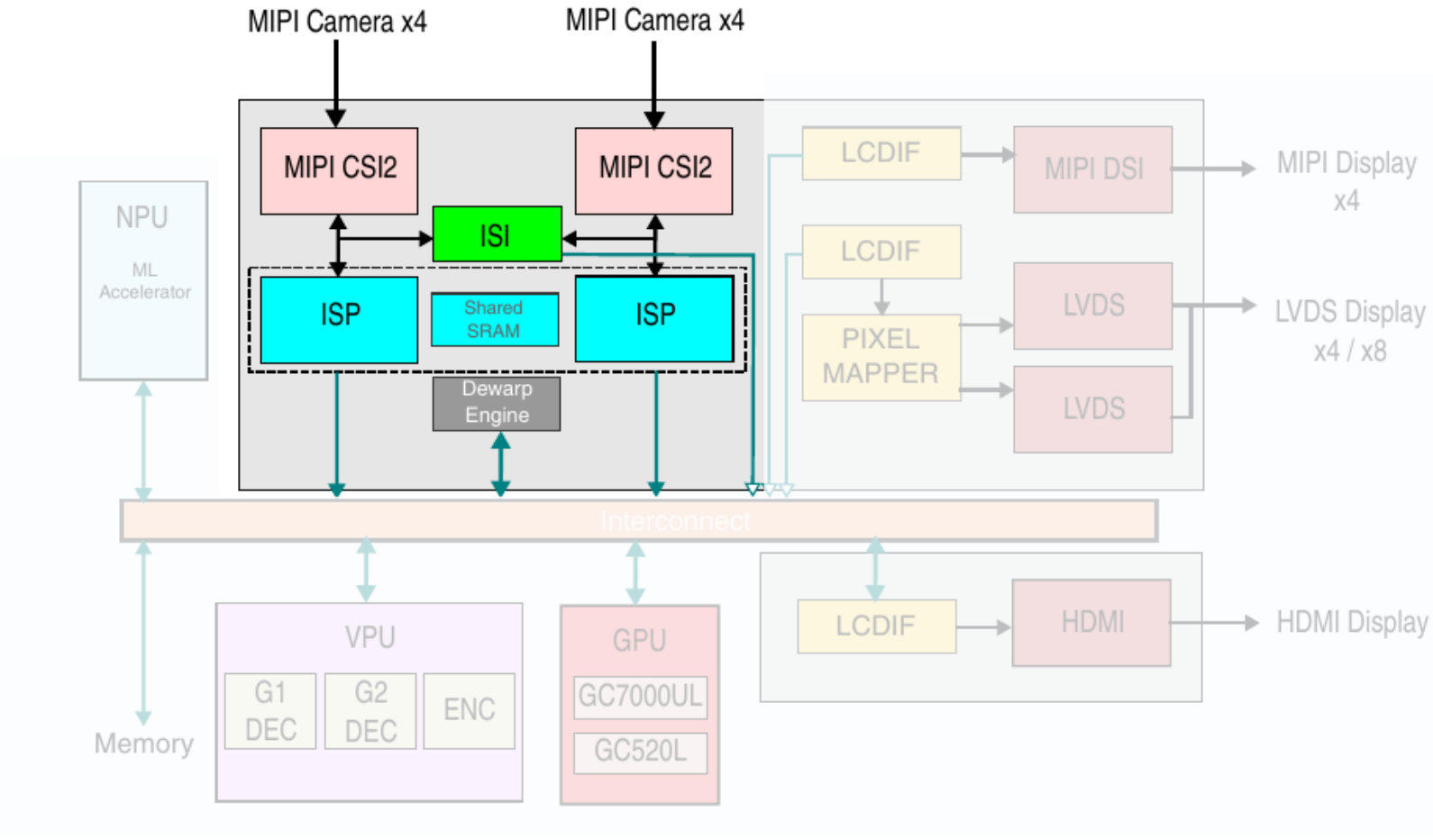
Maivin (NXP i.MX8MP)



i.MX 8M Plus Applications Processor Reference Manual, Rev. 1, 06/2021

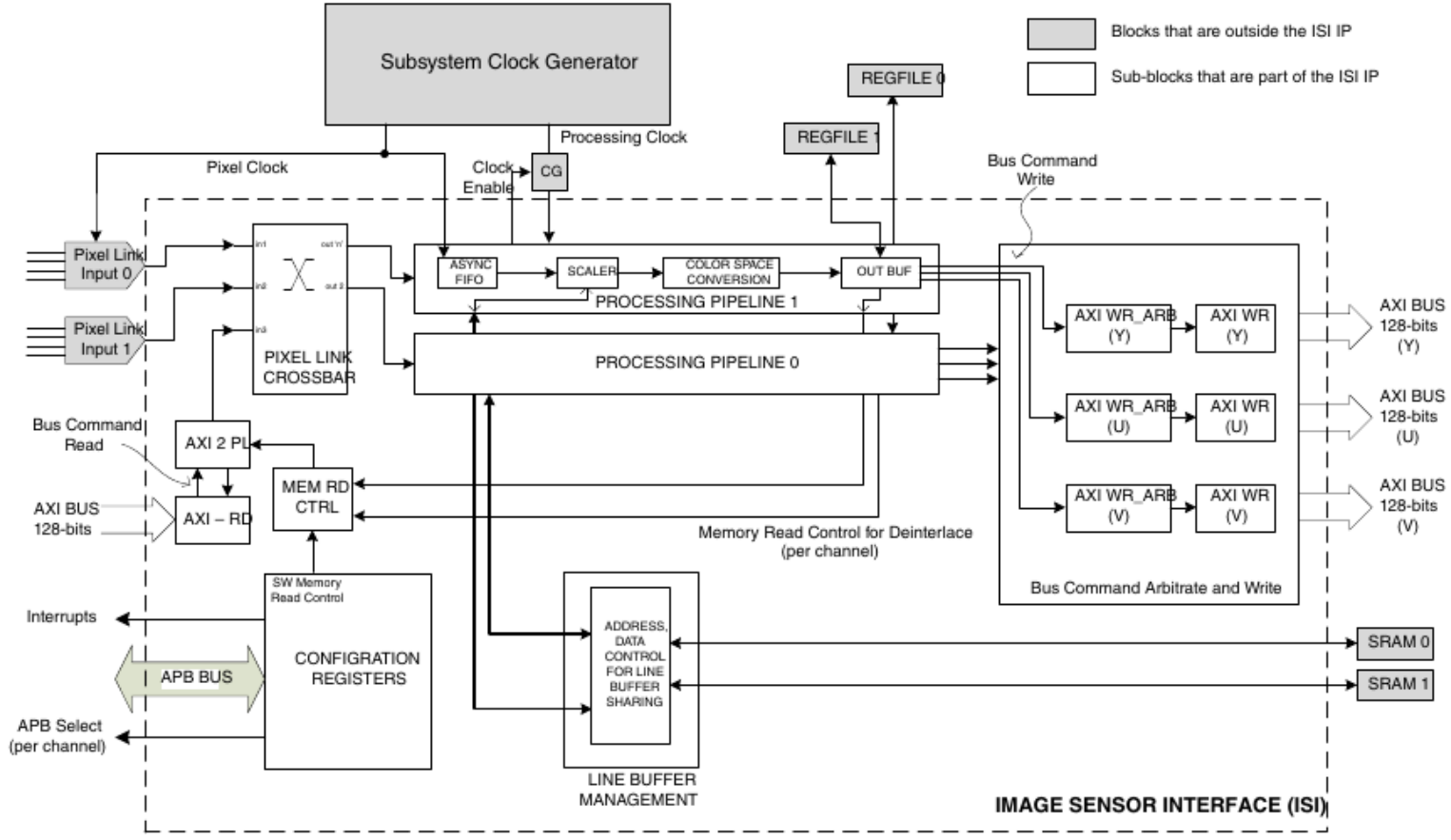
IDEAS ON BOARD

i.MX8MP Hardware Architecture



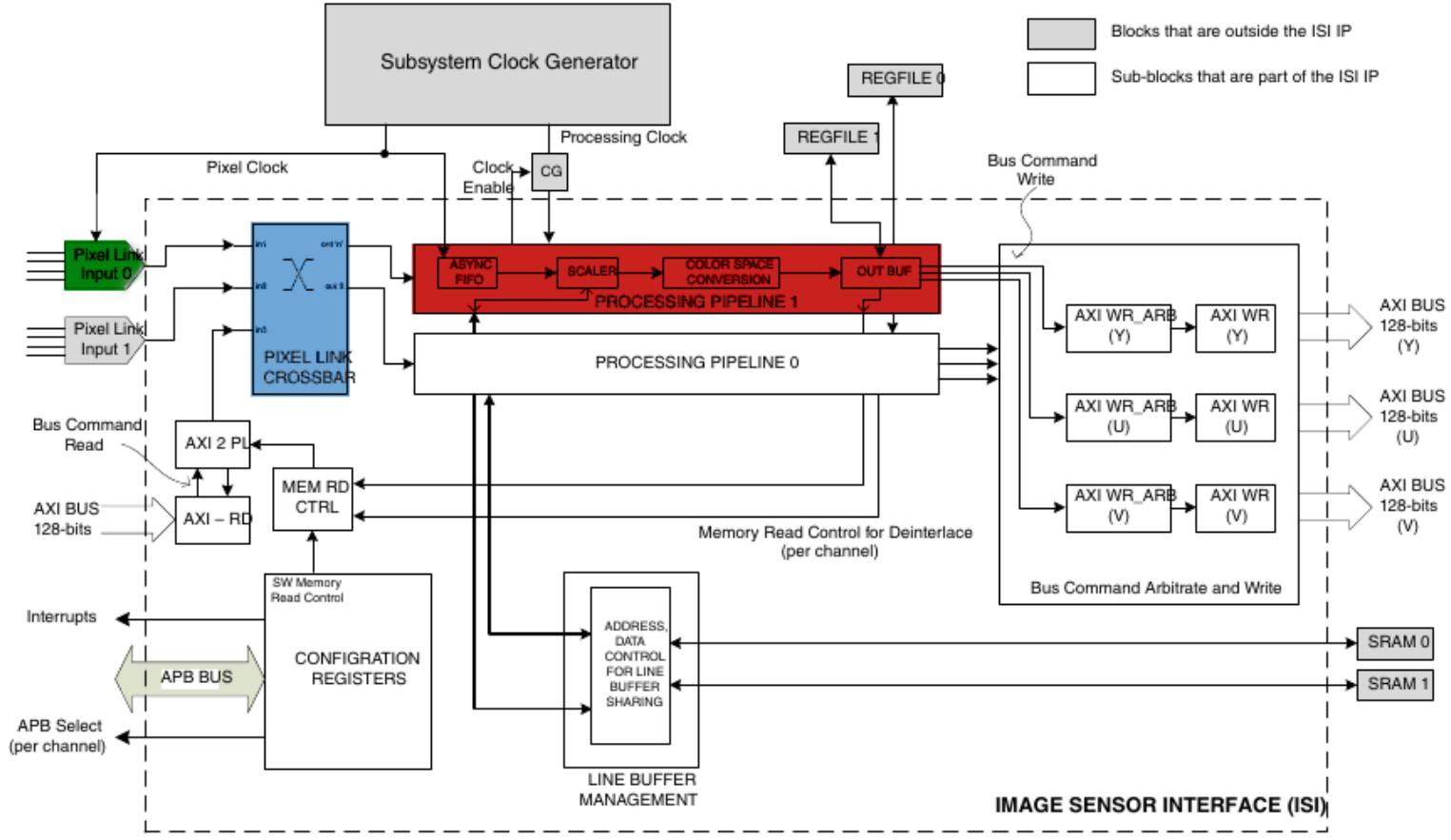
i.MX 8M Plus Applications Processor Reference Manual, Rev. 1, 06/2021

i.MX8MP Hardware Architecture



i.MX 8M Plus Applications Processor Reference Manual, Rev. 1, 06/2021

Image Sensing Interface (ISI)



i.MX 8M Plus Applications Processor Reference Manual, Rev. 1, 06/2021

Image Sensing Interface (ISI)

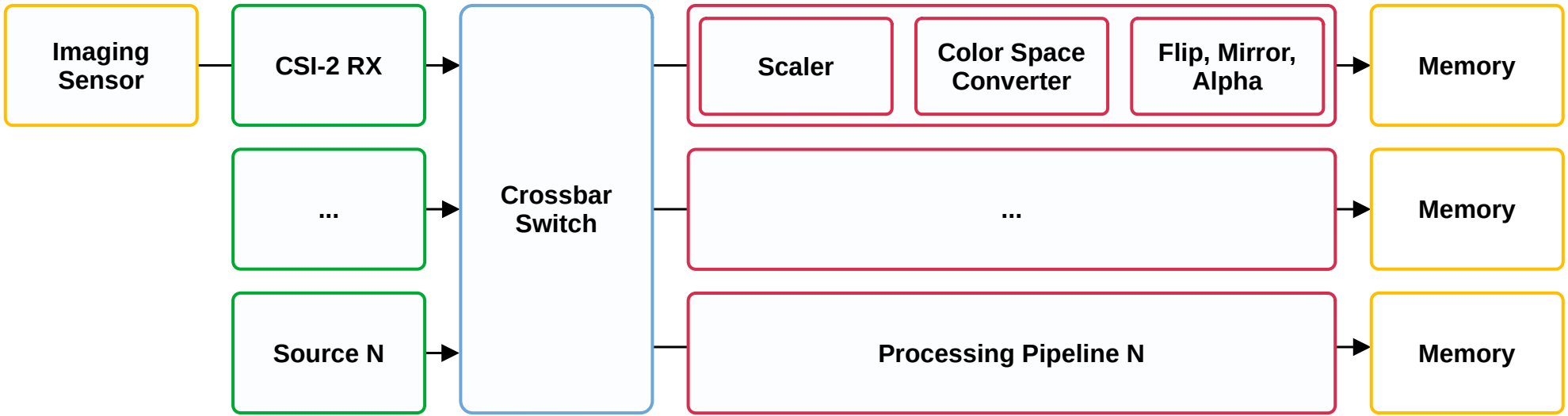
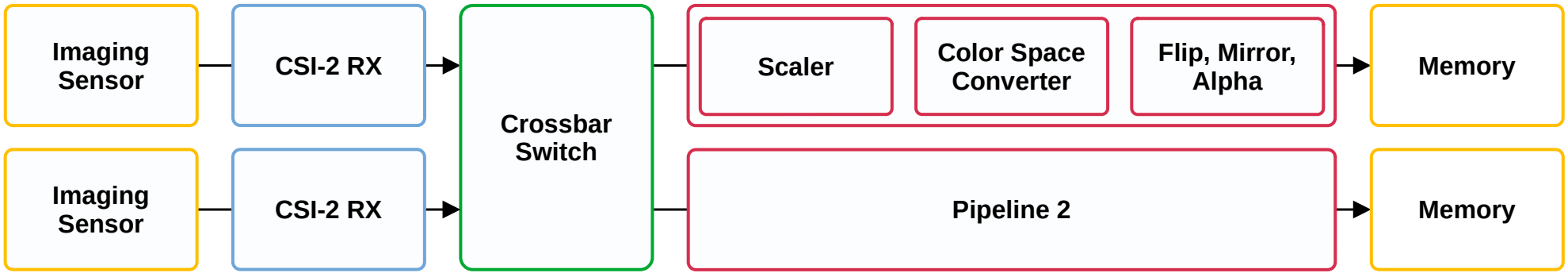
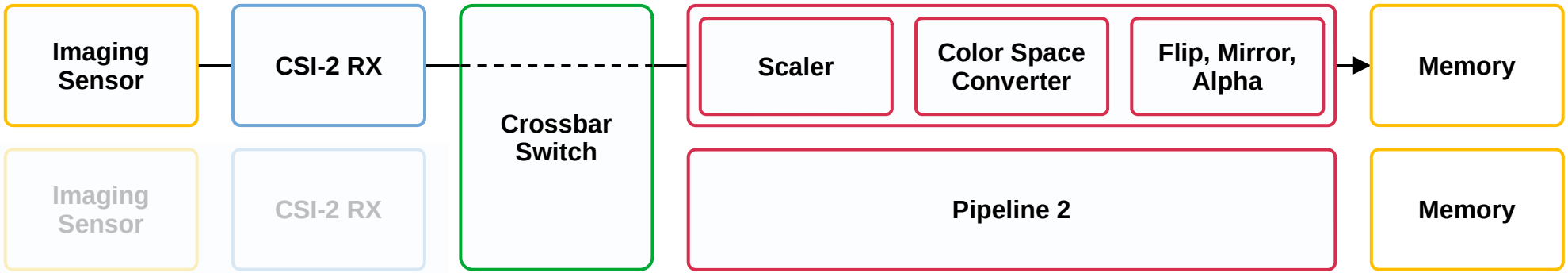


Image Sensing Interface (ISI)



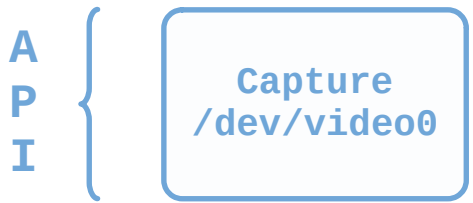
i.MX8MP Image Sensing Interface (ISI)



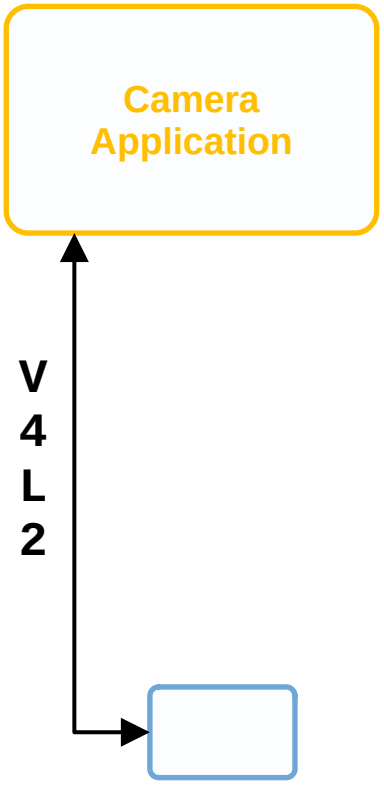
First Use Case: ISI, Single Camera

Why libcamera

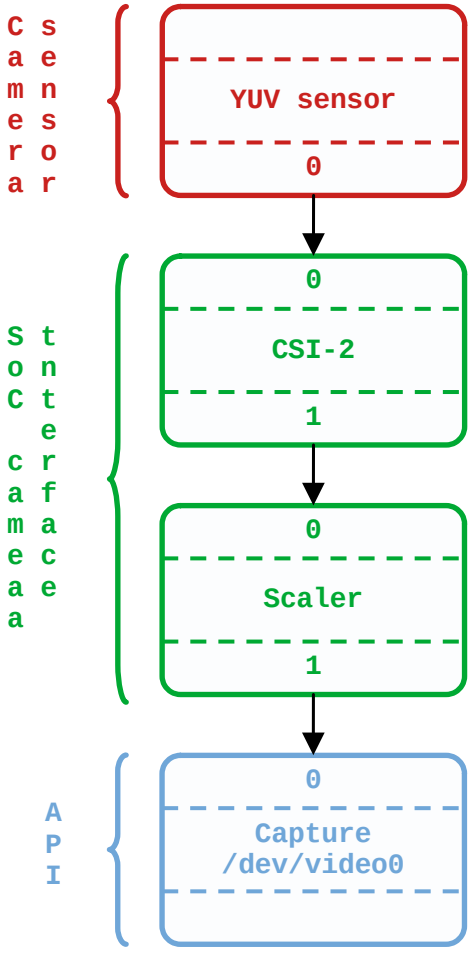
A monolithic API for TV grabbers and webcams alike.



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

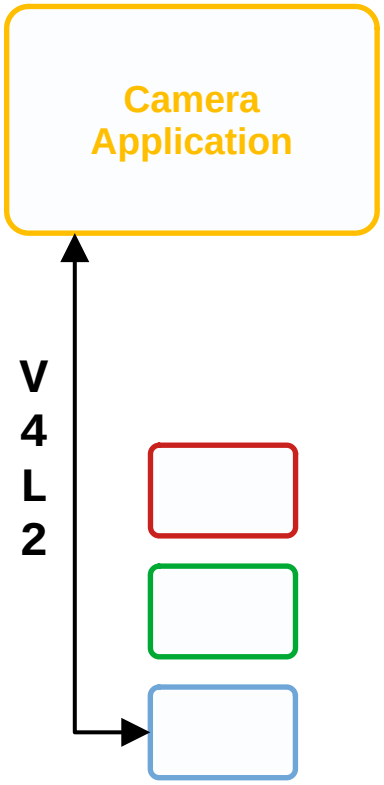


Enables development of universal applications.



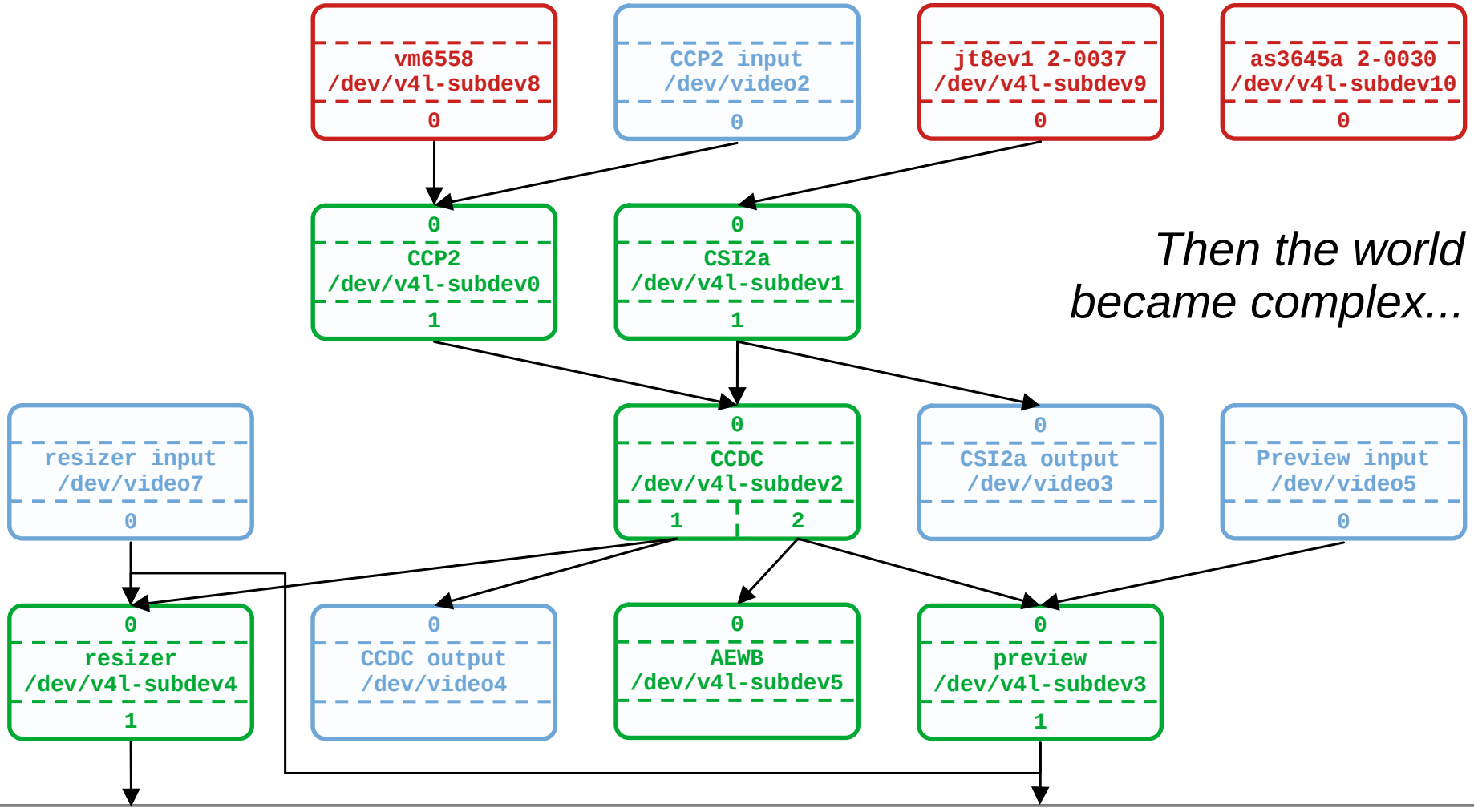
In the beginning were simple pipelines...

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



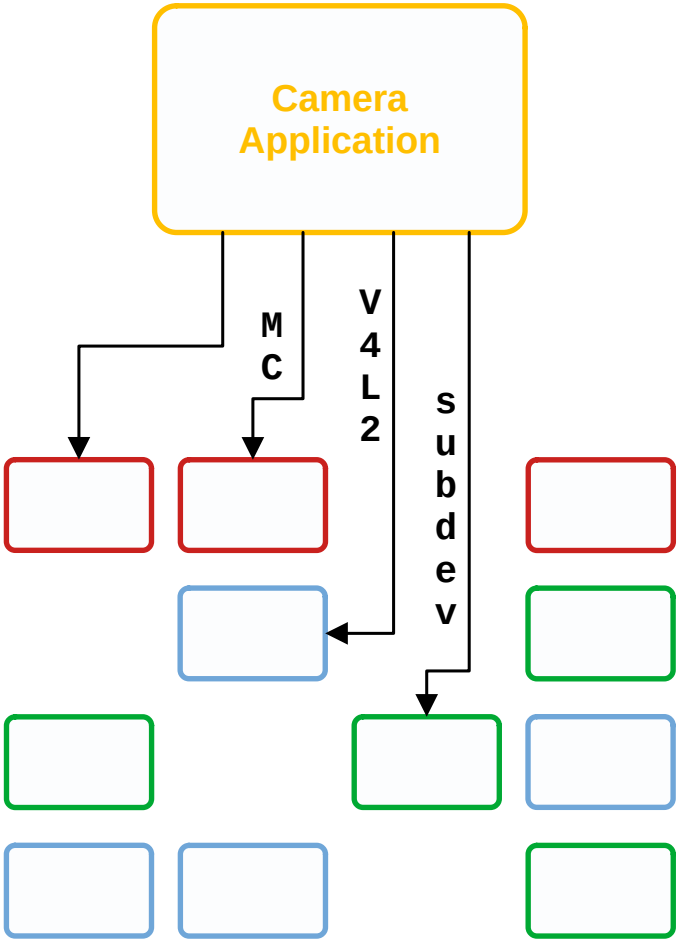
IDEAS ON BOARD

Then the world became complex

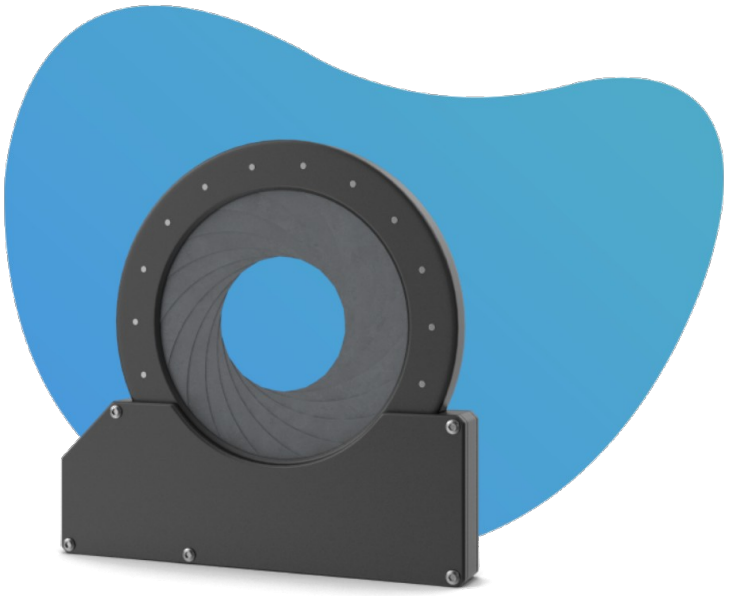


OMAP3 Camera in Nokia N900

… and application developers were left suffering.



Then hope came back.

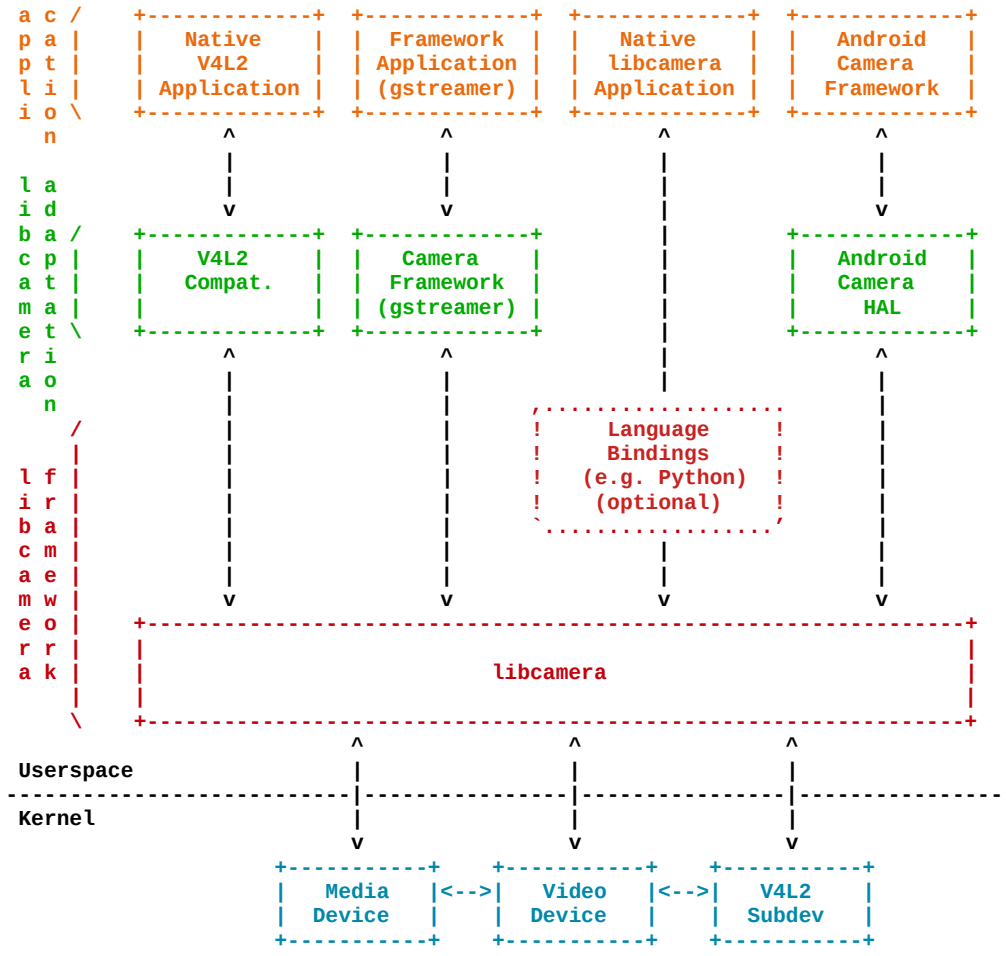


Hi, we're libcamera.

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

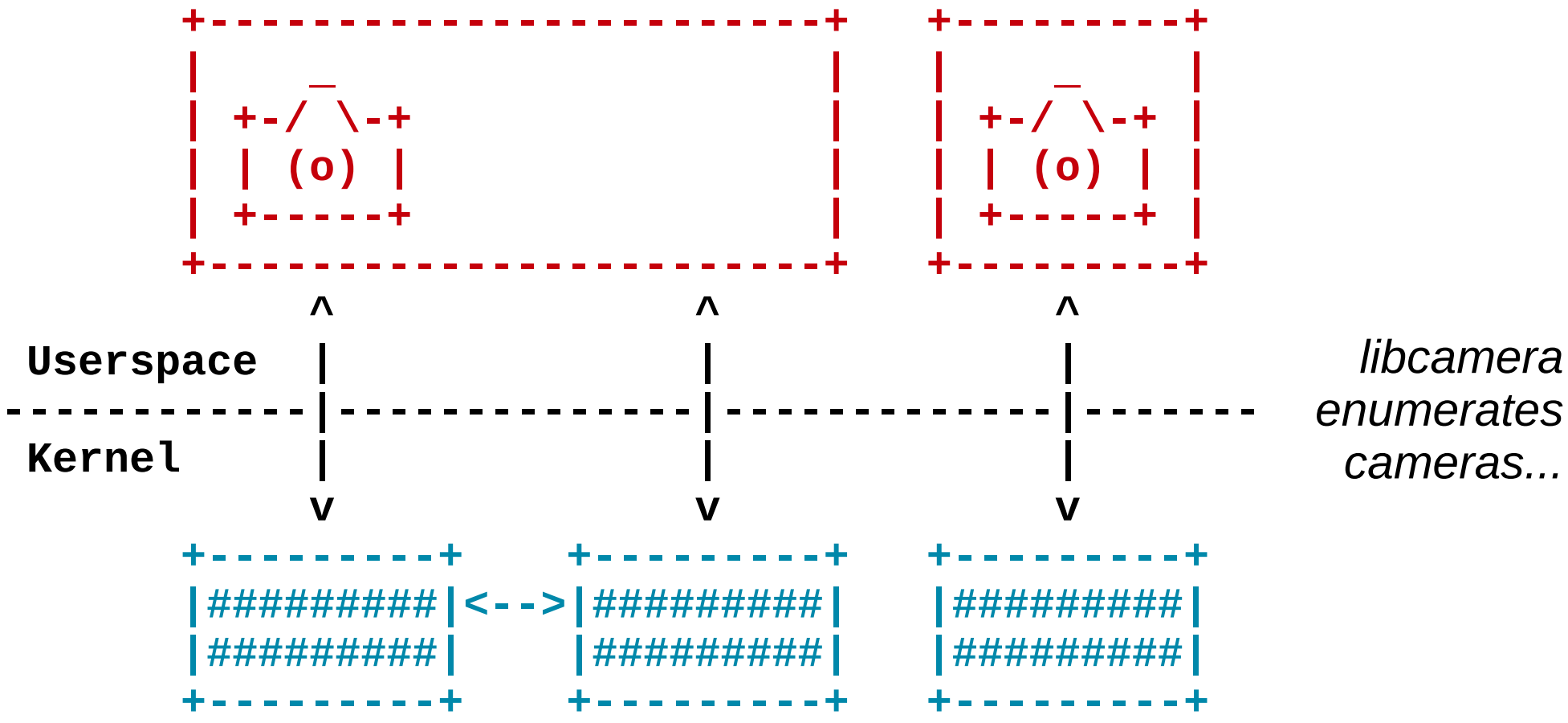
Getting Started

libcamera provides a complete userspace camera stack.

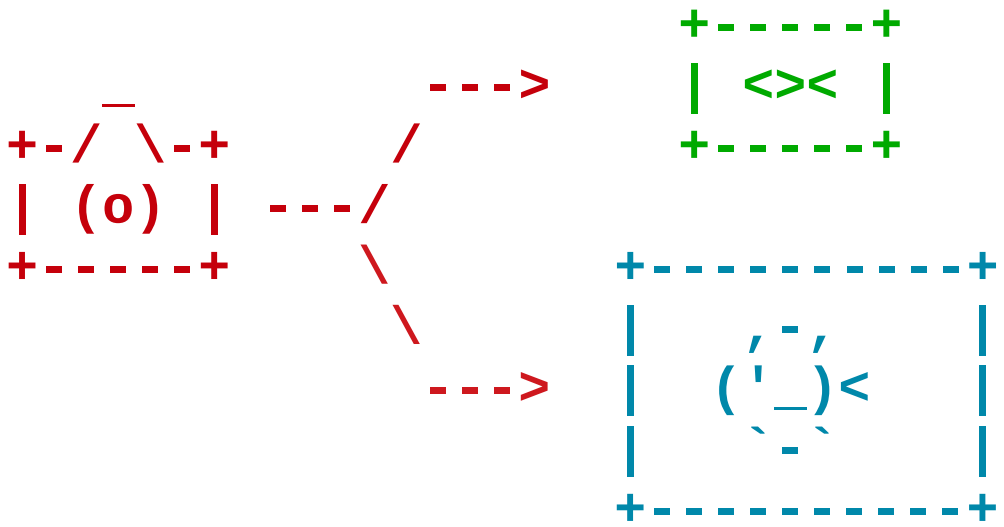


The 'Mesa' of the camera world.

Camera Stack

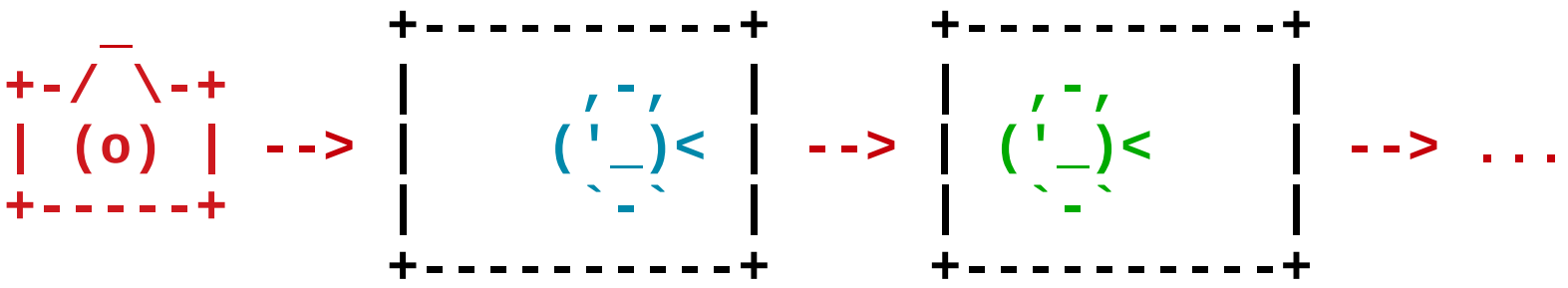


Camera Devices & Enumeration



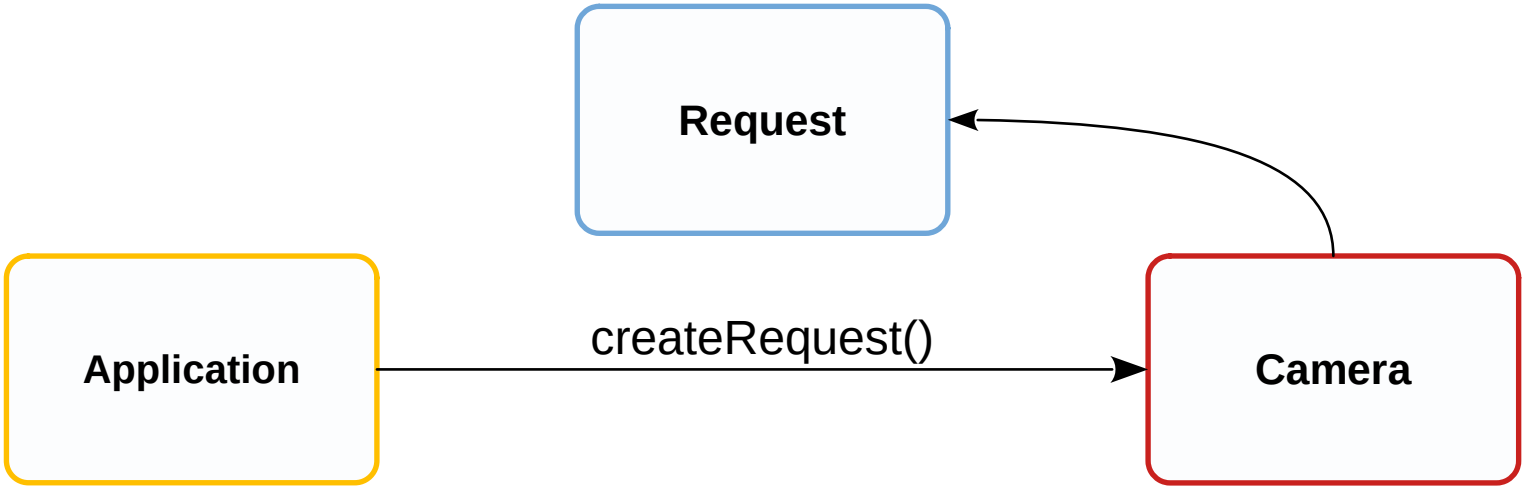
It supports multiple concurrent streams for the same camera...

Streams

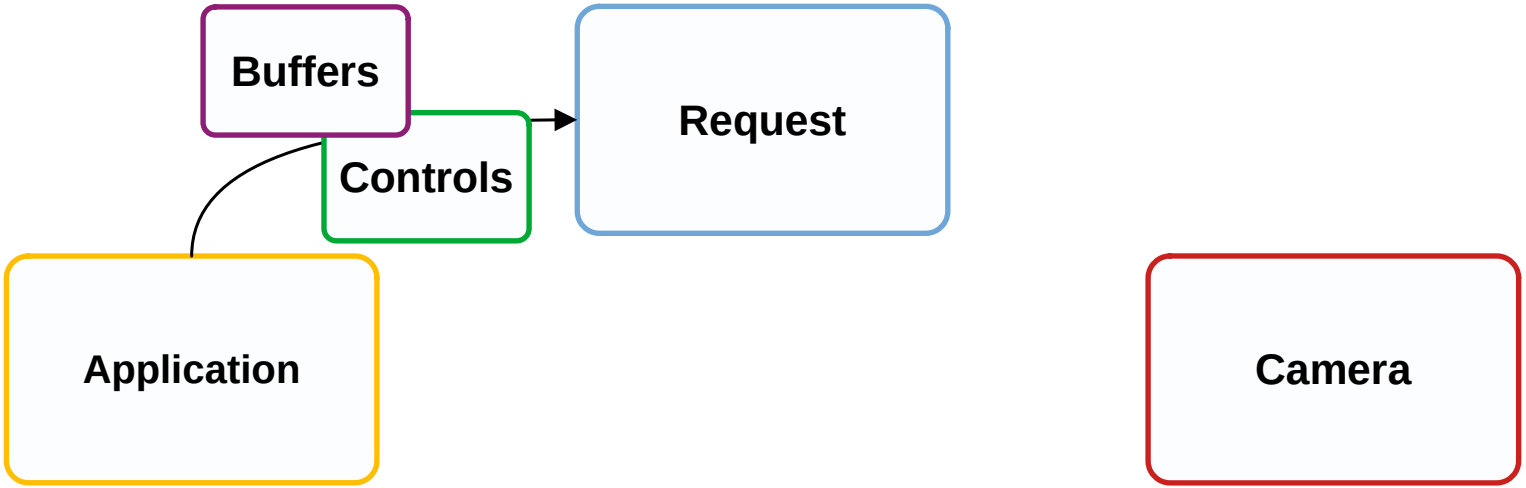


… and per-frame controls.

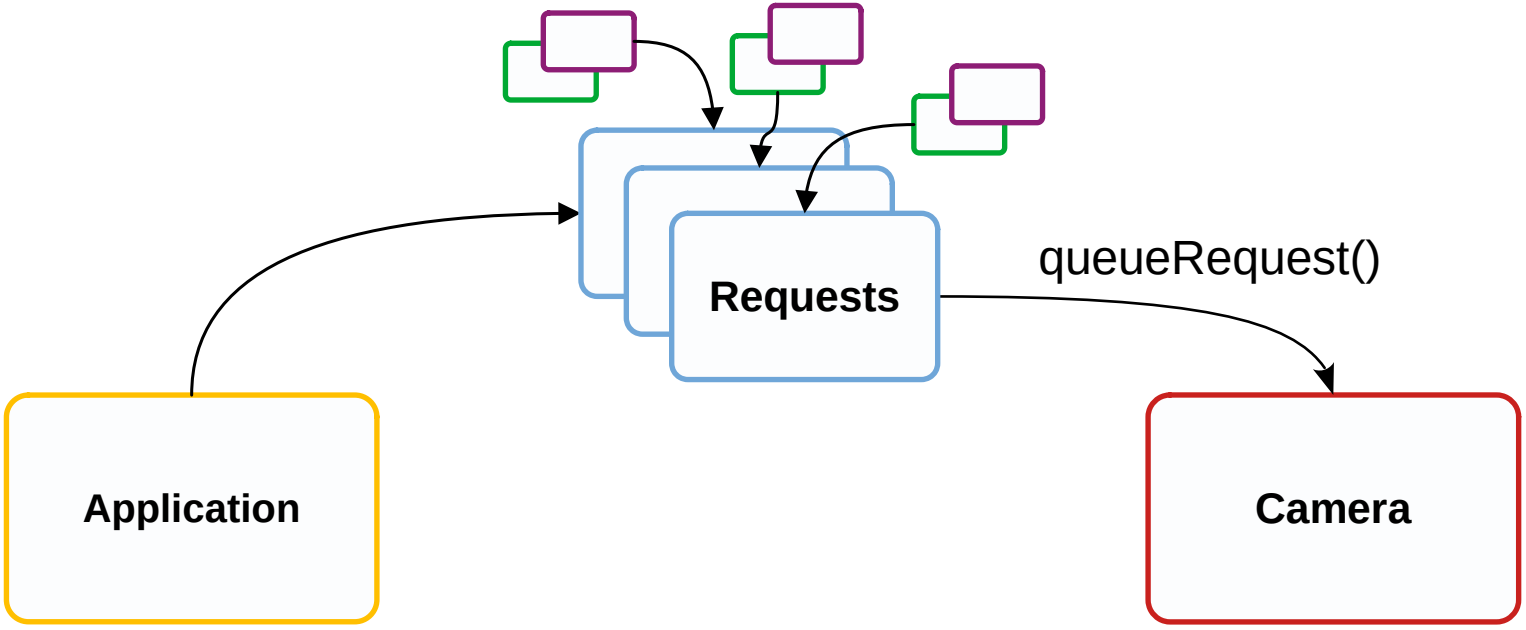
Per-Frame Controls



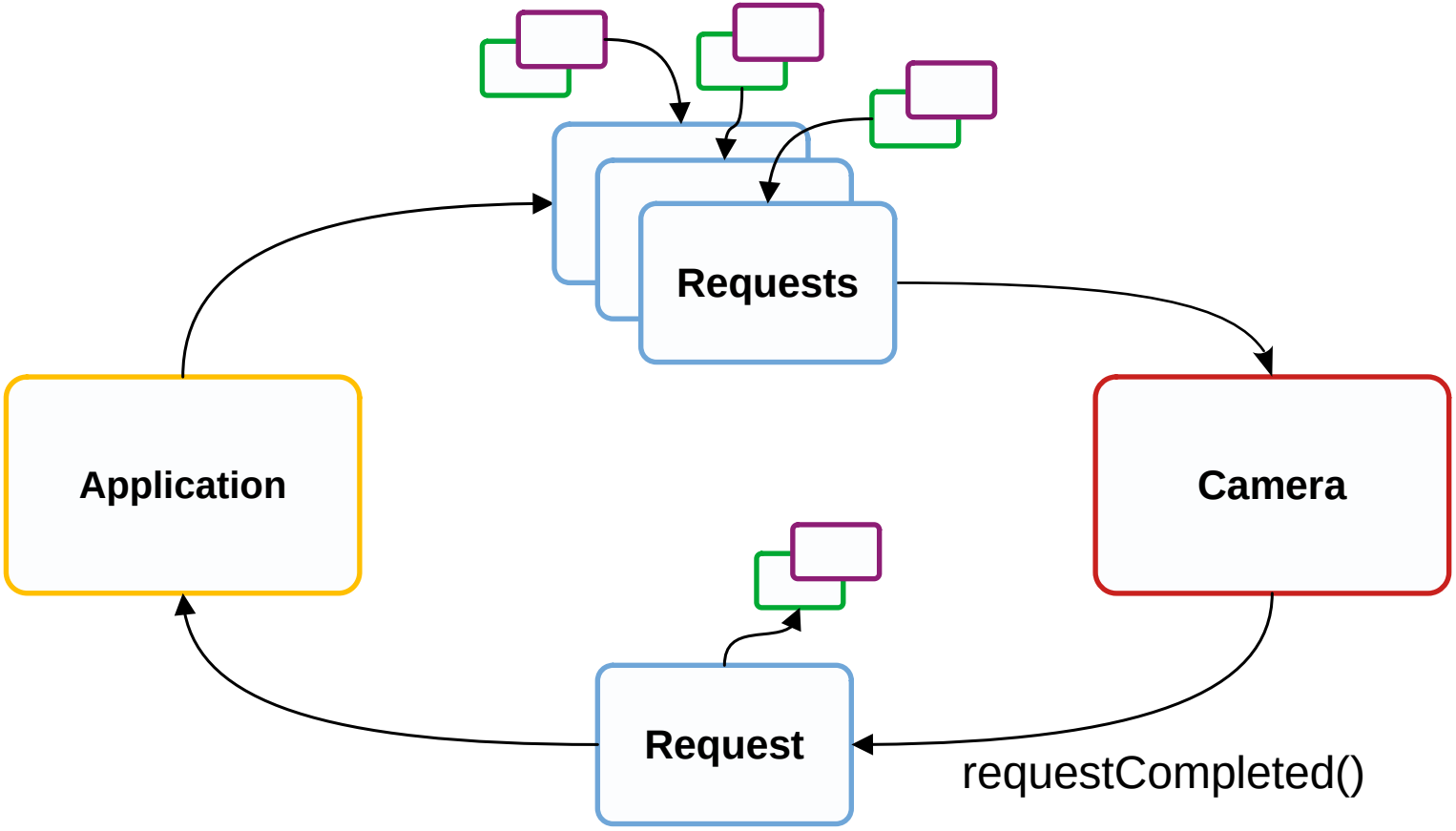
Capture Requests



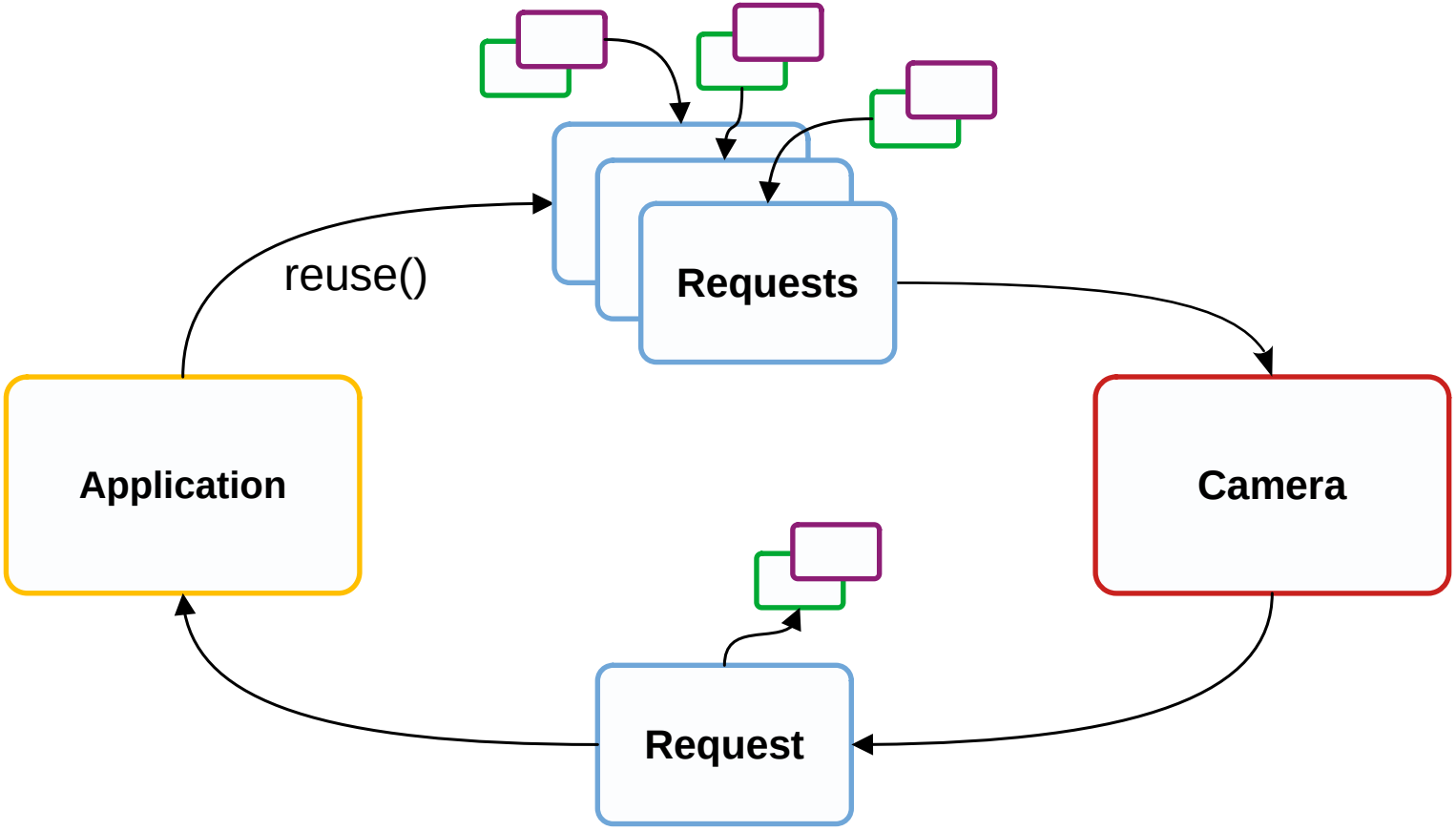
Capture Requests



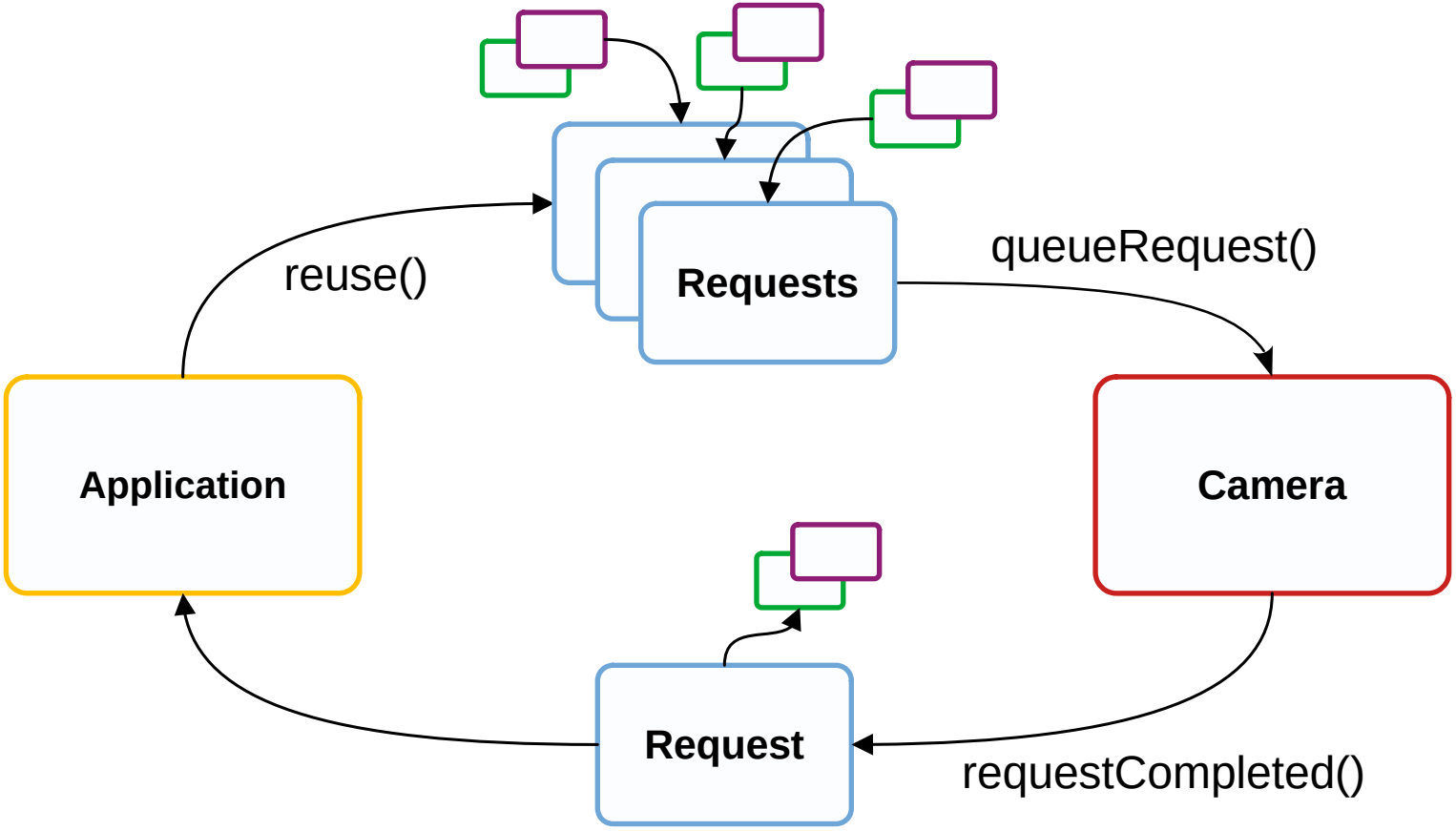
Capture Requests



Capture Requests

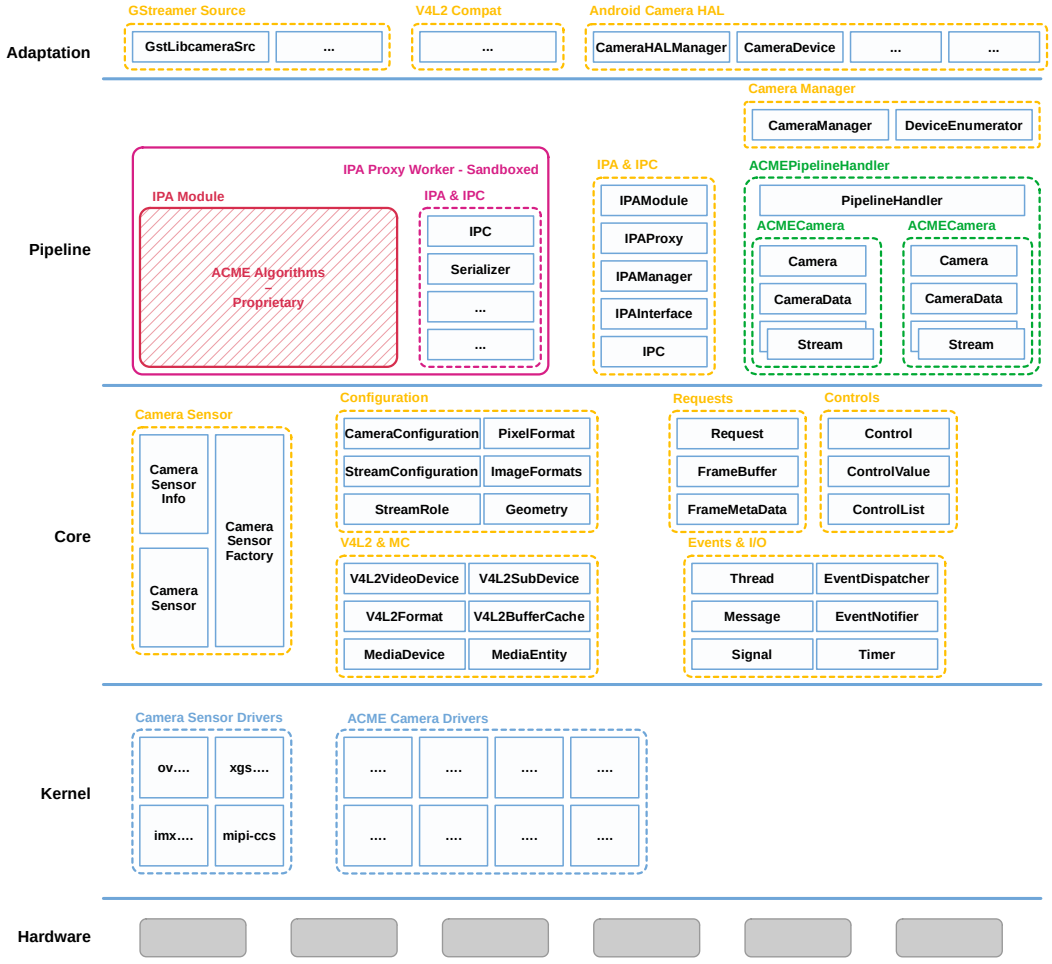


Capture Requests

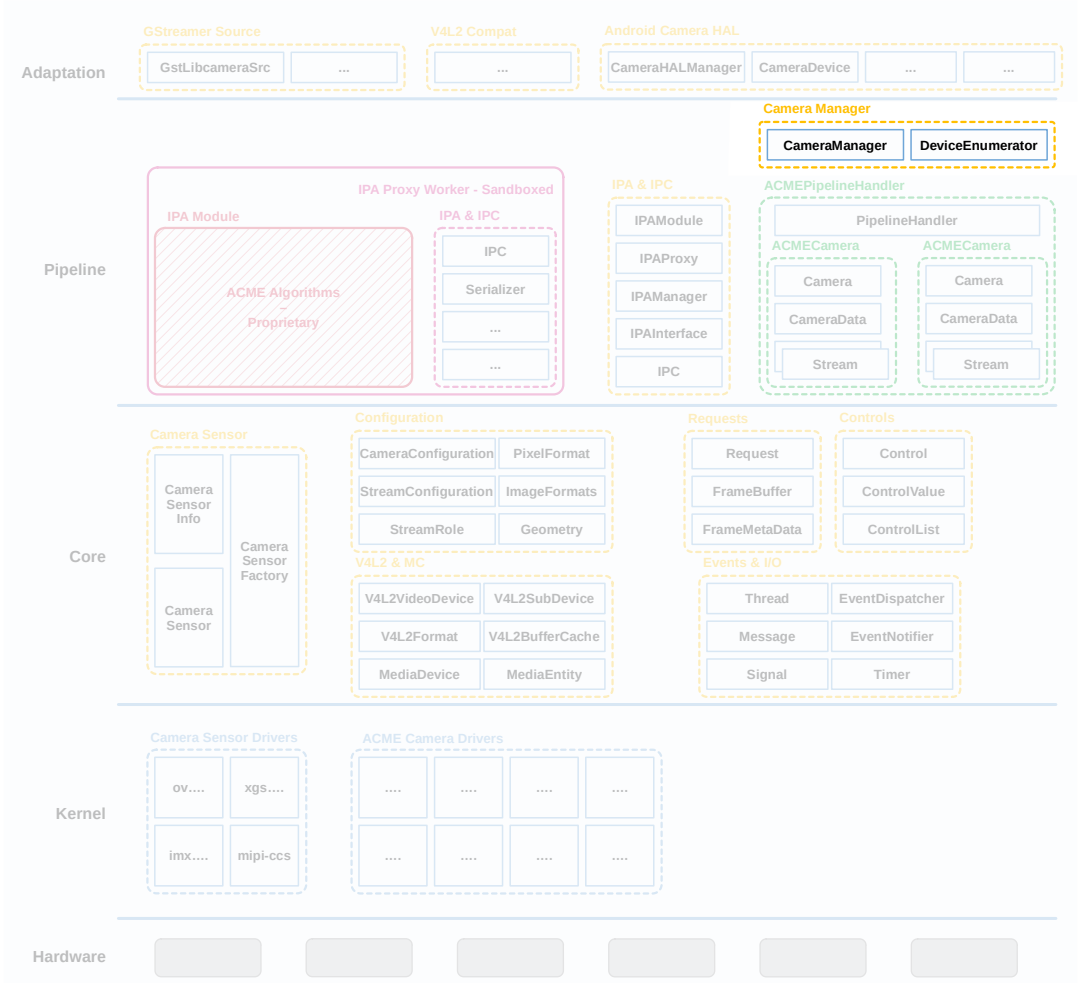


Capture Requests

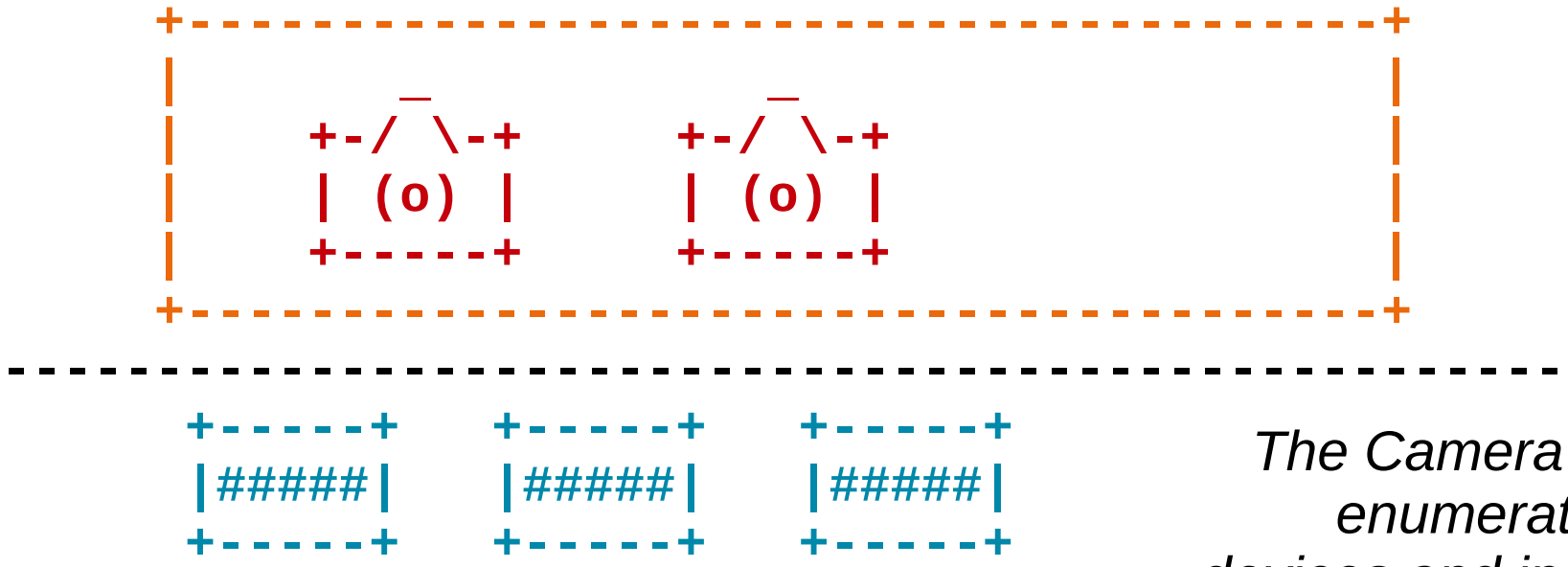
libcamera architecture



The Camera Stack

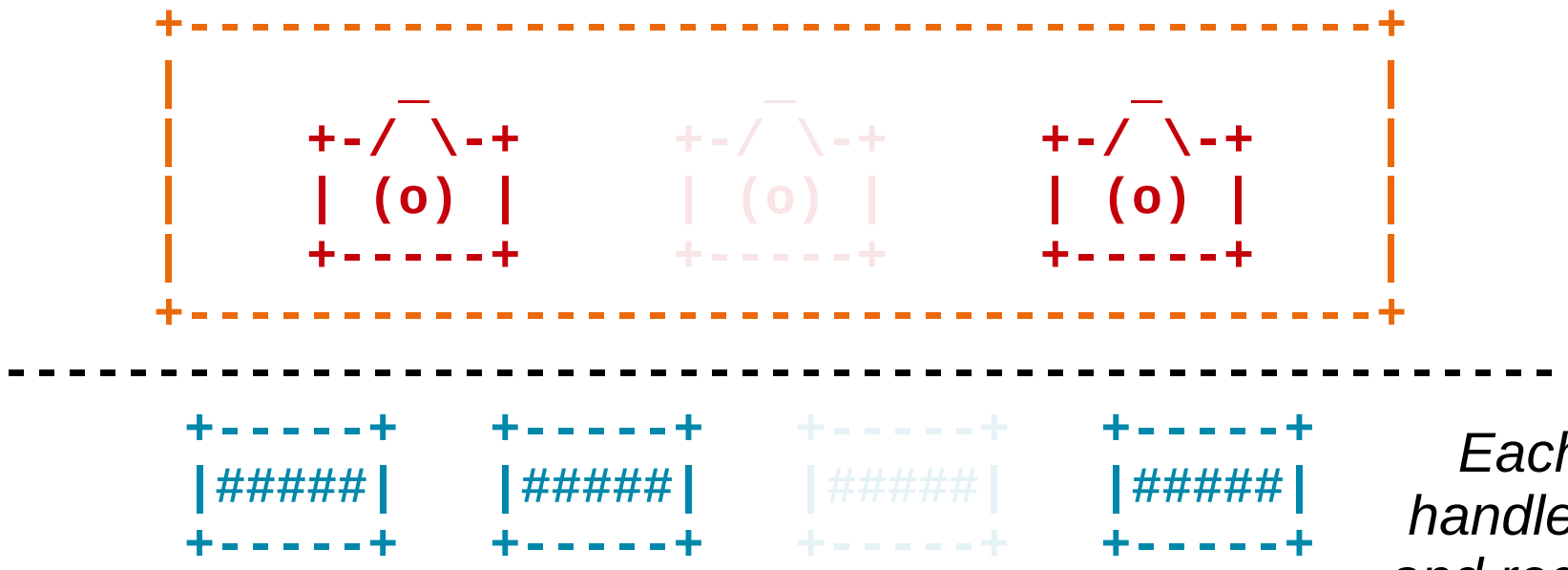


The Camera Manager



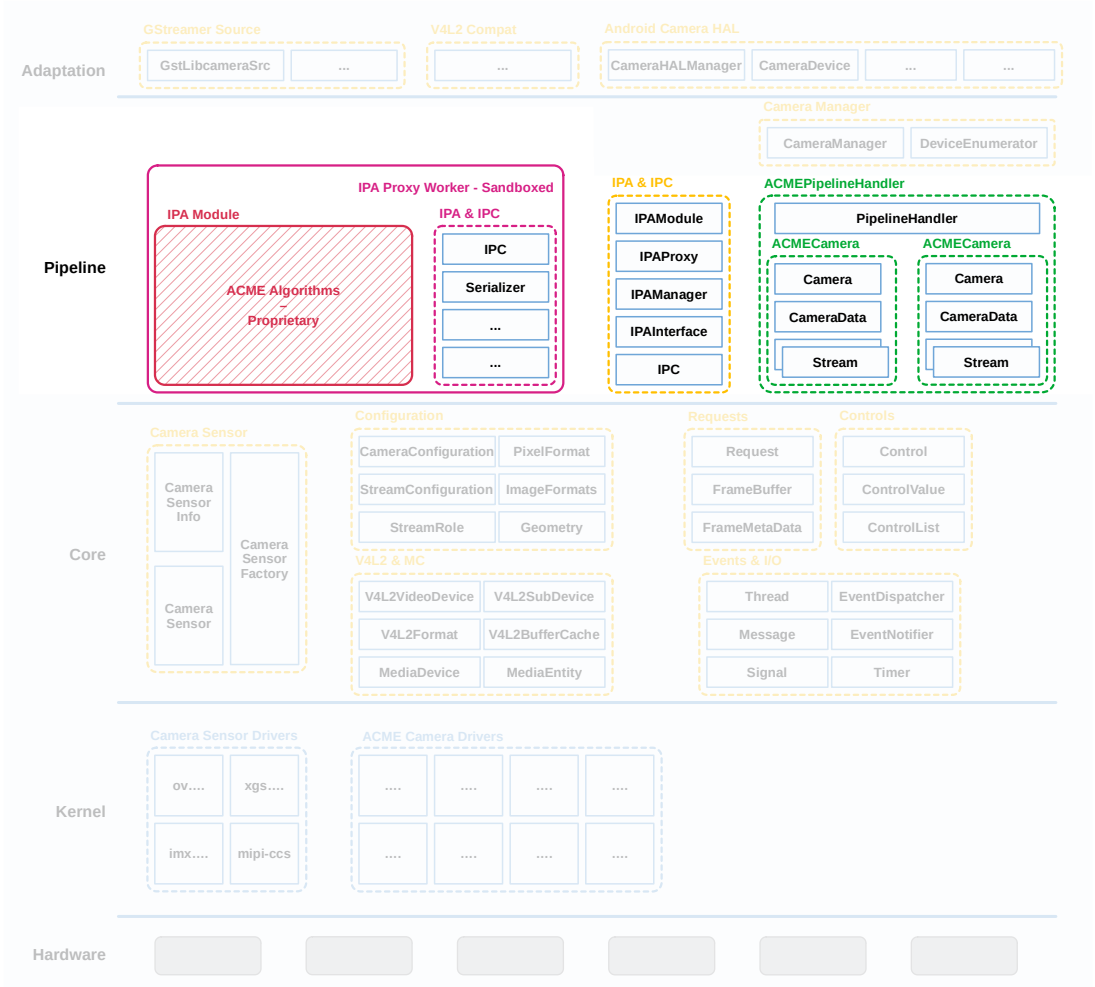
The Camera Manager enumerates media devices and instantiates corresponding pipeline handlers.

The Camera Manager

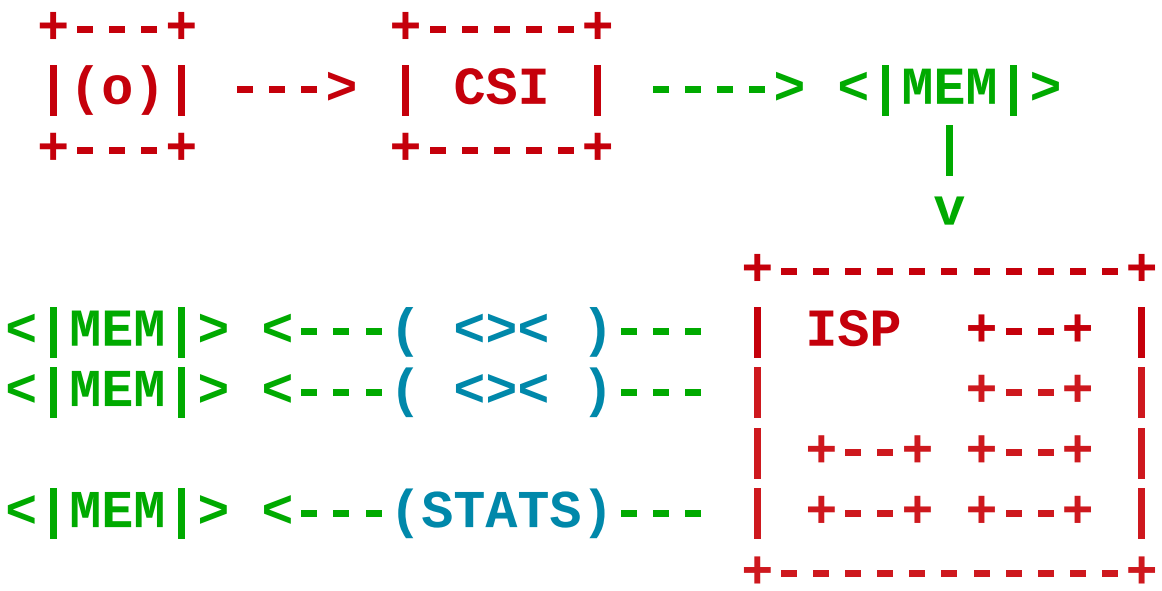


Each pipeline handlers create and register one or more cameras.

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

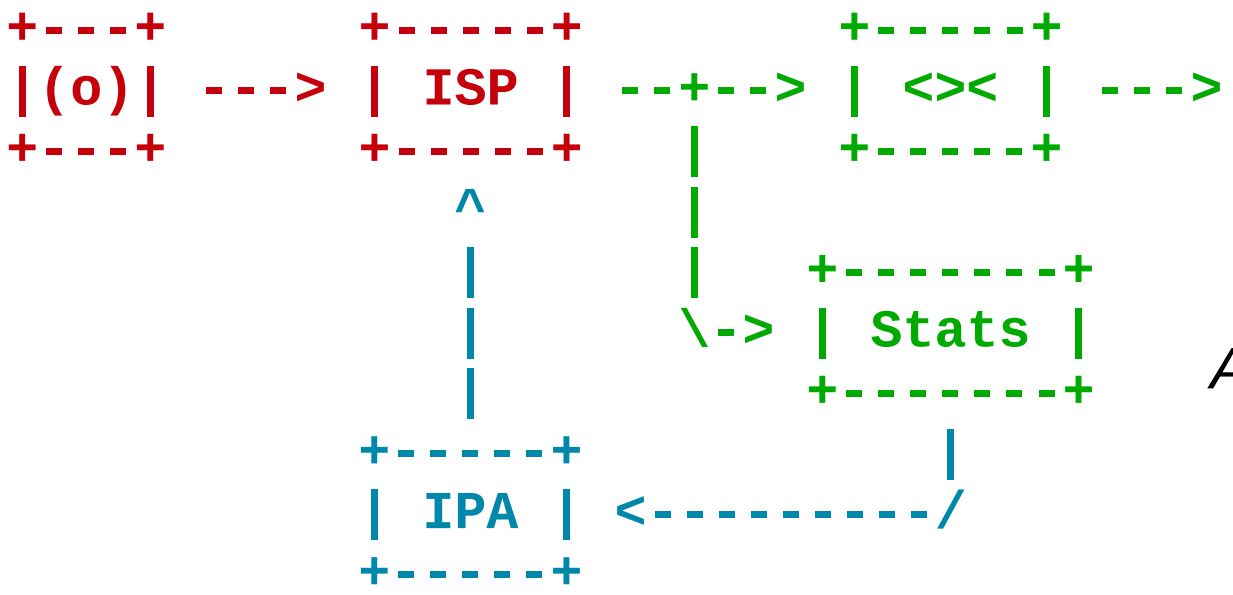
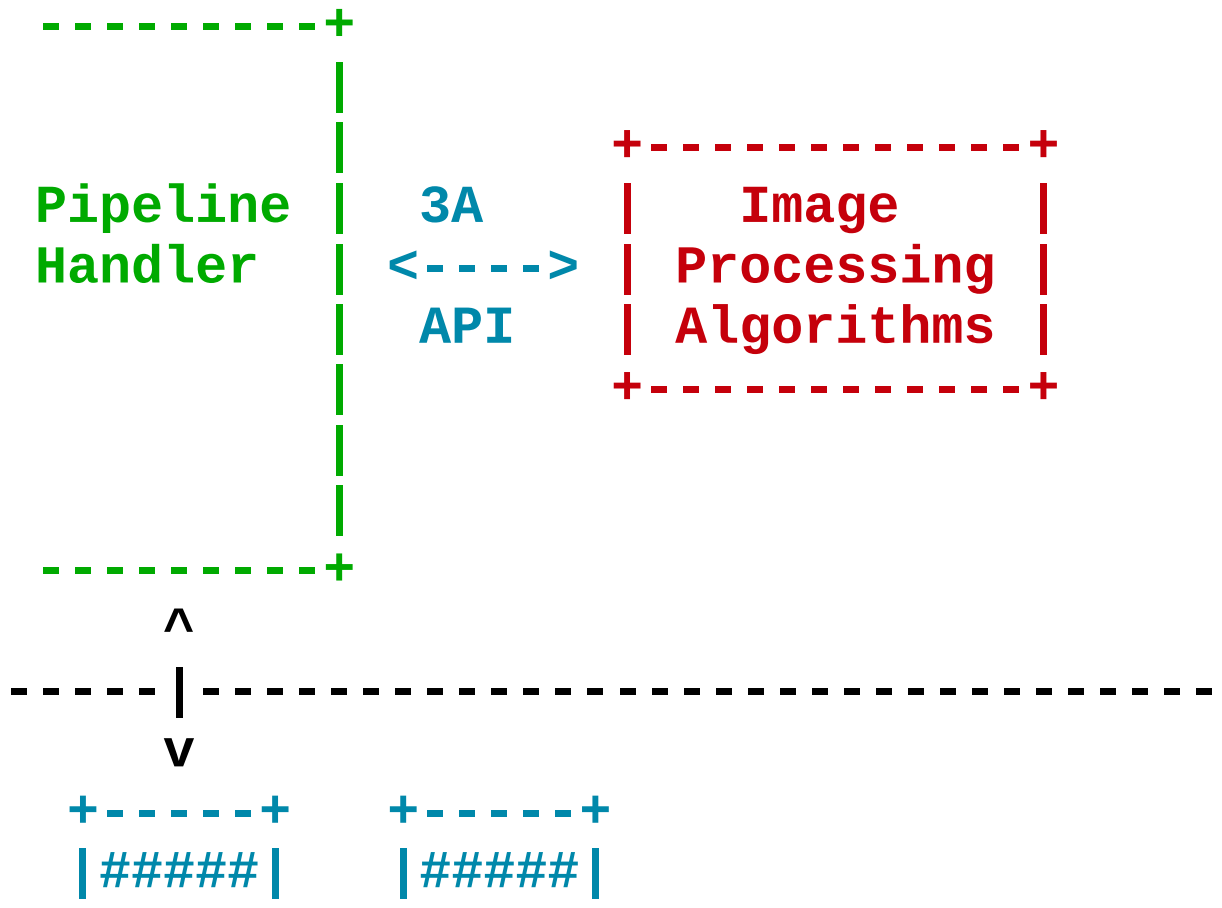


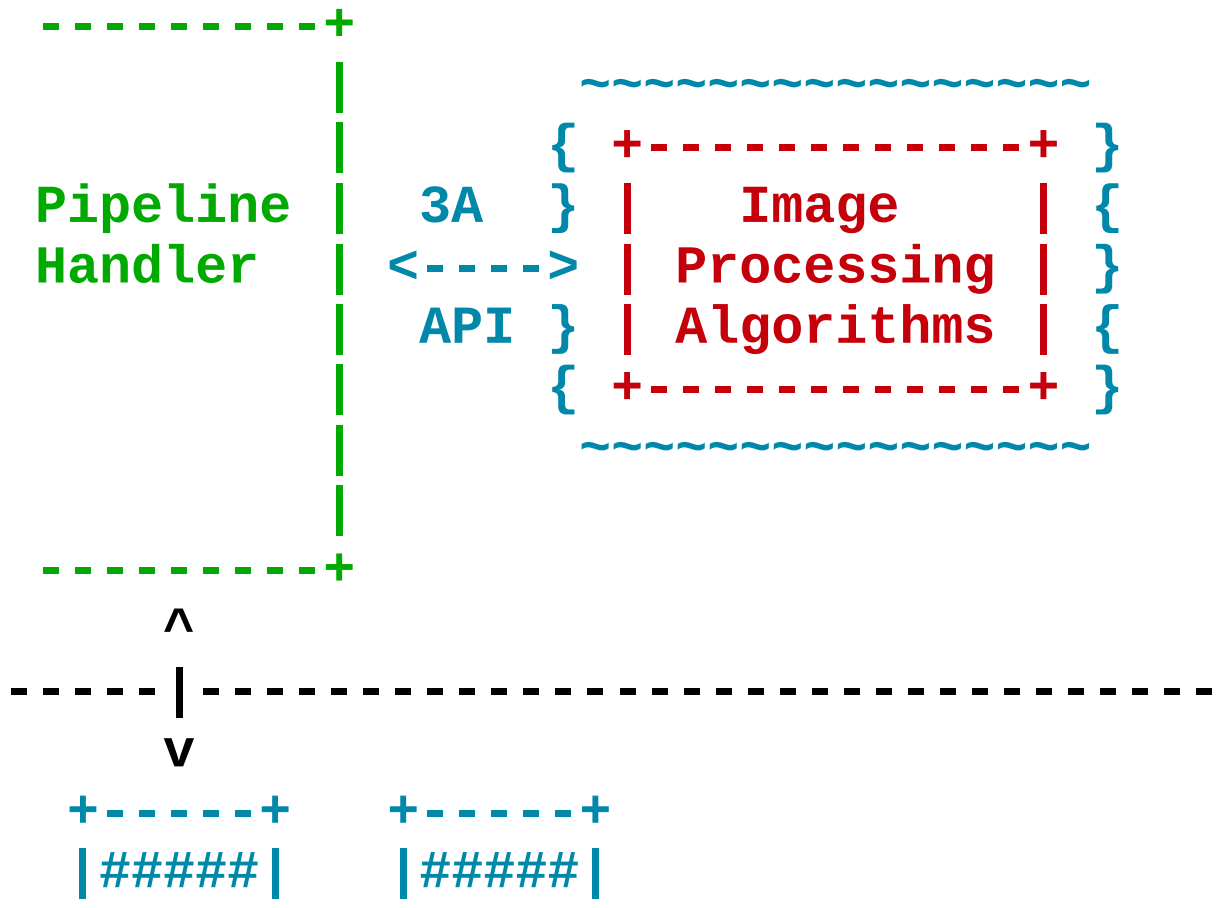
Image Processing Algorithms (IPA) receive statistics from the hardware and compute optimal image parameters.

The Image Processing Algorithms



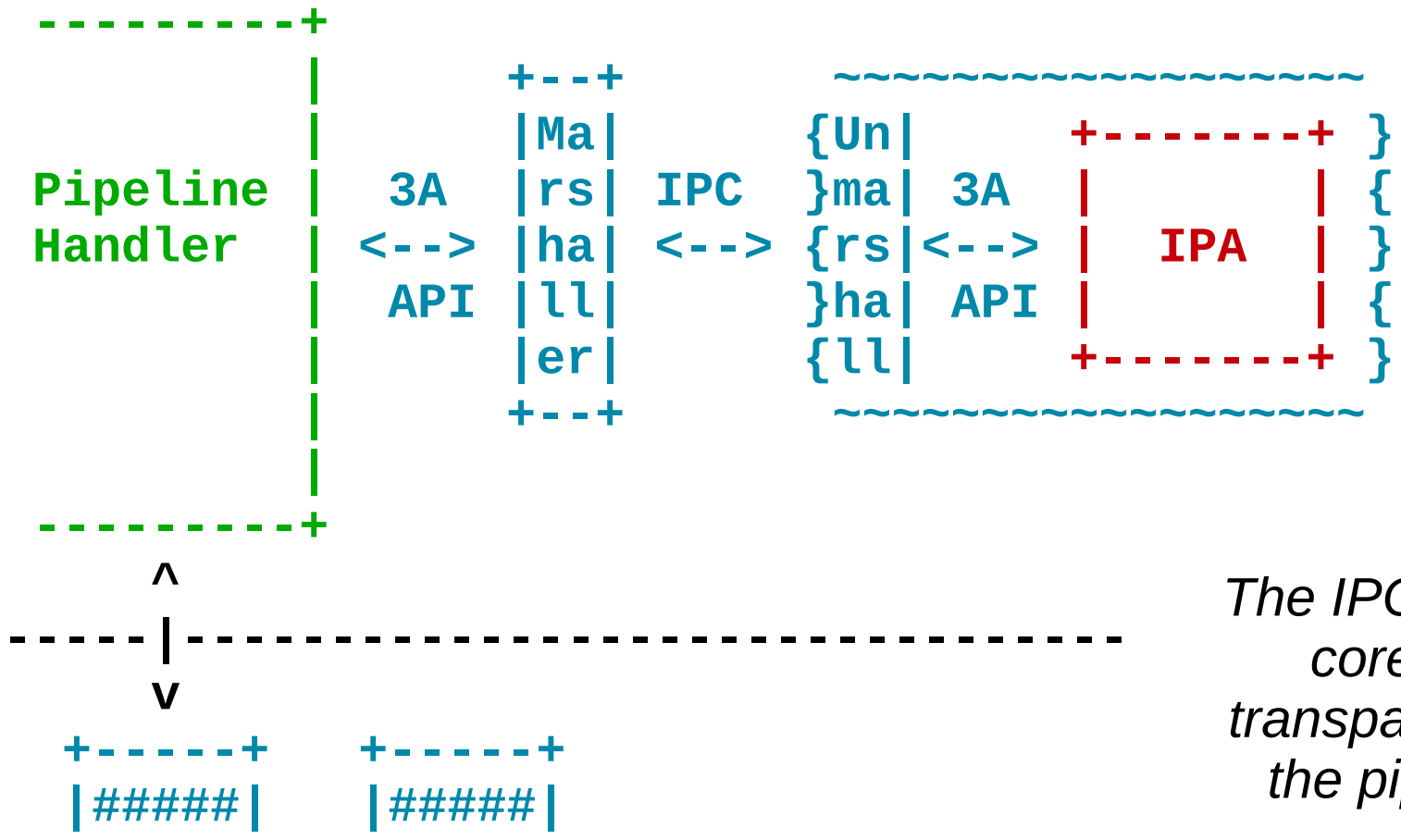
IPAs are separate modules that don't access kernel devices directly. They only have access to their pipeline handler through the IPA API.

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.

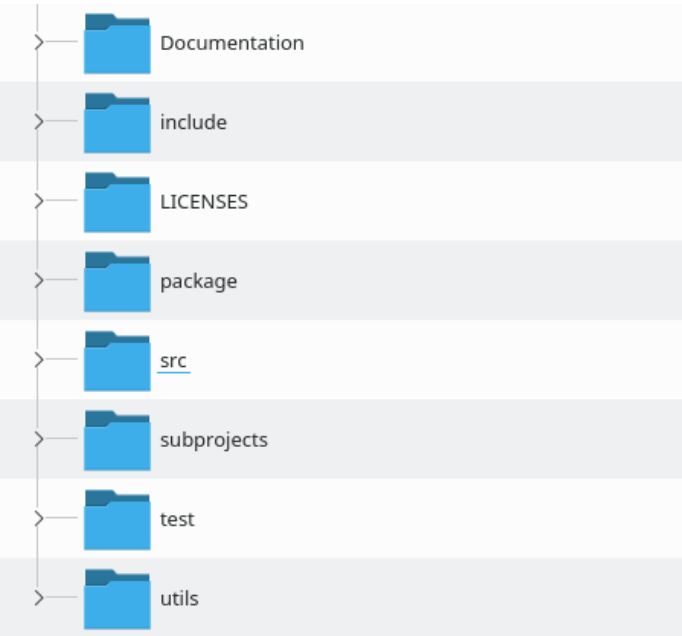
The Image Processing Algorithms



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

The Image Processing Algorithms

libcamera source tree



Documentation, guides, tutorials, …

Headers (public API, internal API, …)

Licenses

Distribution packaging

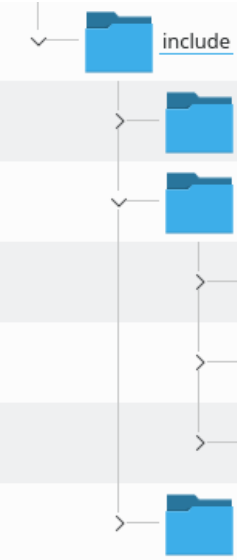
Source

Meson subprojects

Unit tests

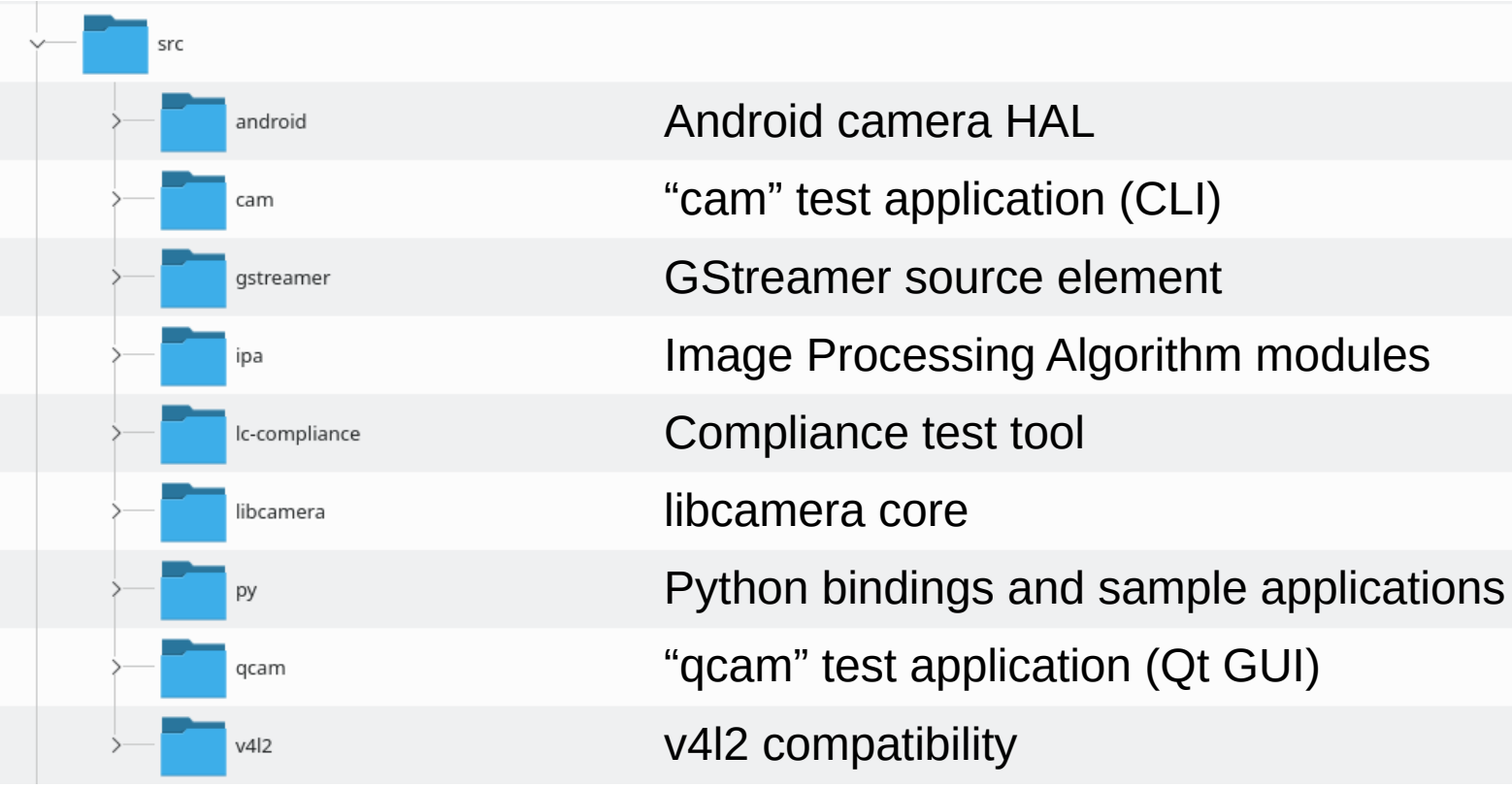
Miscellaneous utilities

Project Structure

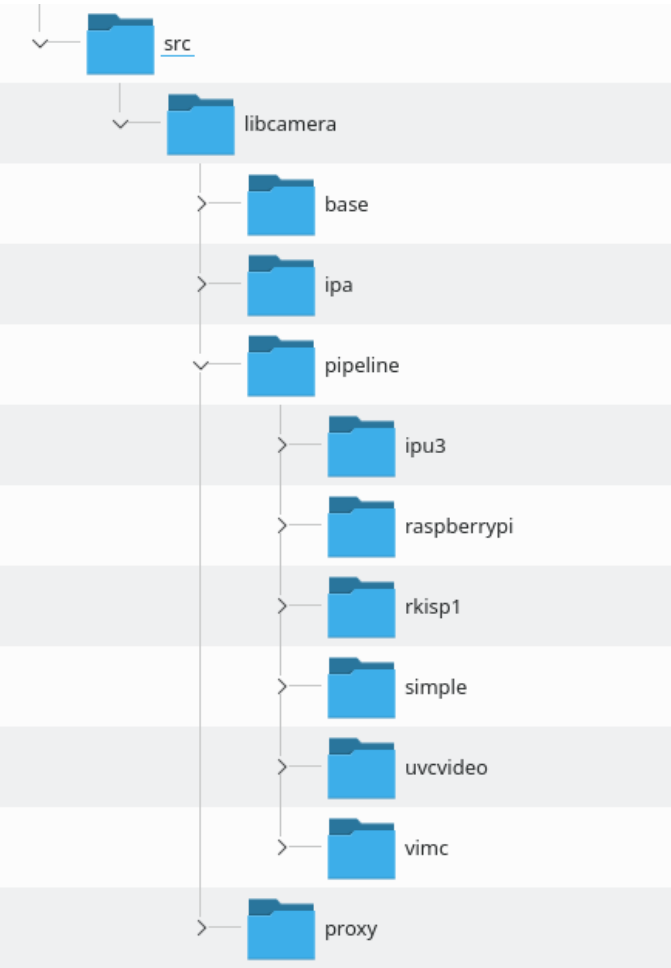


android	Android headers copied from Android sources
libcamera	libcamera public & internal APIs
base	Base API (a.k.a. “NIH boost”)
internal	Internal API
ipa	IPA module protocols
linux	Linux kernel headers copied from kernel source

Project Structure – /include



Project Structure – /src



Base helpers (a.k.a. “NIH boost”)

IPA IPC documentation (placeholder, auto-generated)

Pipeline handlers

Intel IPU3

Raspberry Pi

Rockchip ISP

“simple” pipeline handler

USB Video Class (USB webcams)

“vimc” (Virtual Media Controller)

IPA IPC code (placeholder, auto-generated)

IDEAS ON BOARD

Project Structure – /src/libcamera

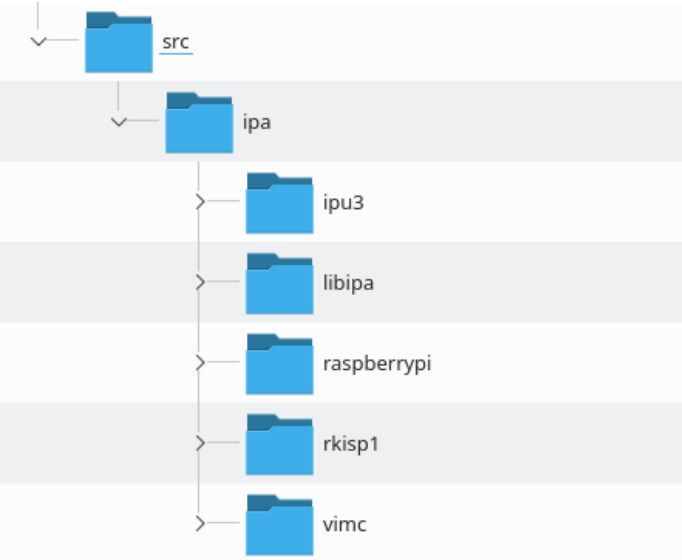


Image Processing Algorithm sources

Intel IPU3

Shared IPA helpers

Raspberry Pi

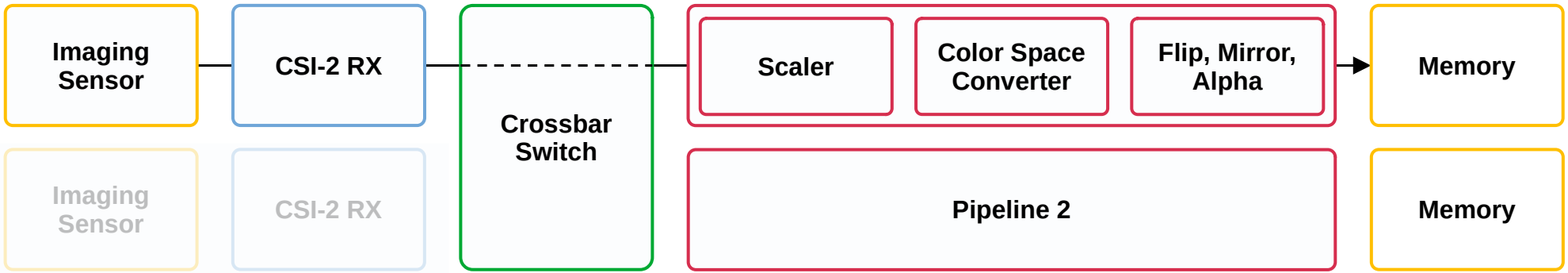
Rockchip ISP

“vimc” (Virtual Media Controller)

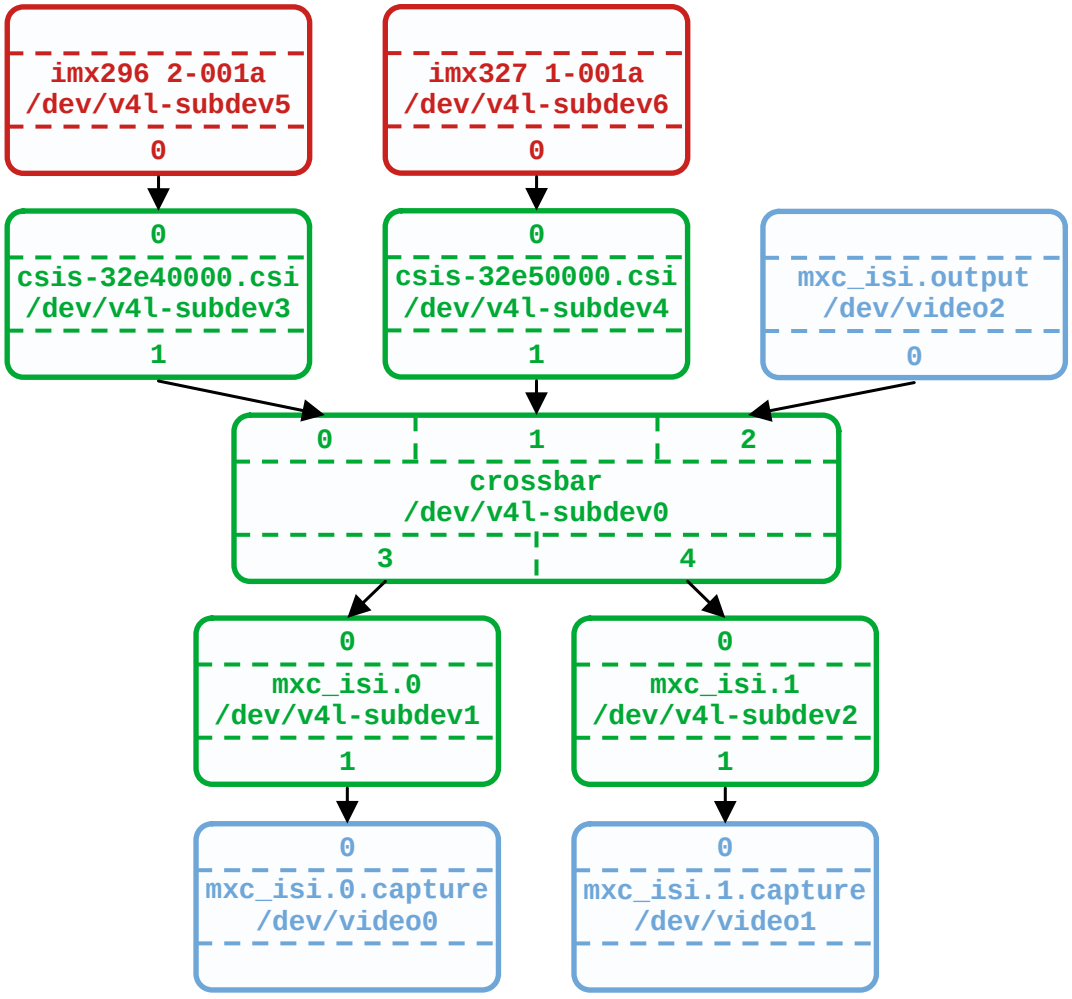
Project Structure – /src/ipa

ISI, Single Camera

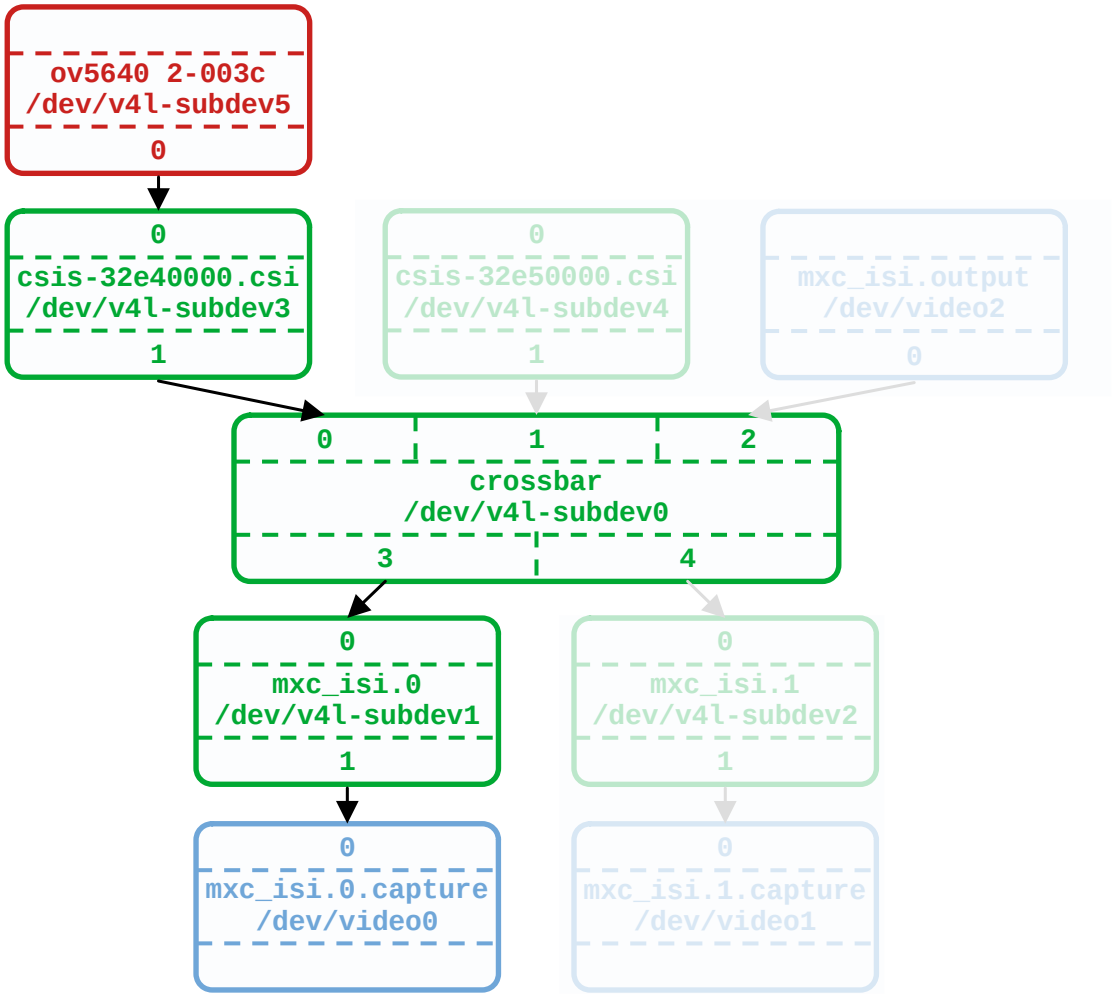
IDEAS ON BOARD



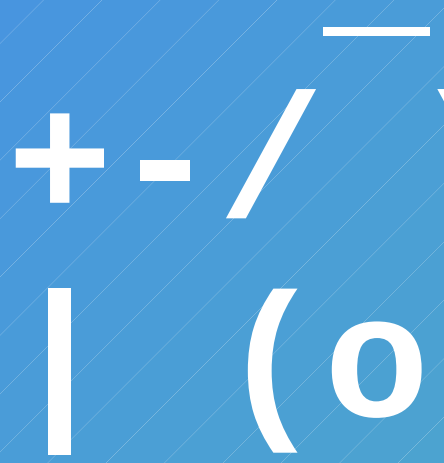
First Use Case: ISI, Single Camera



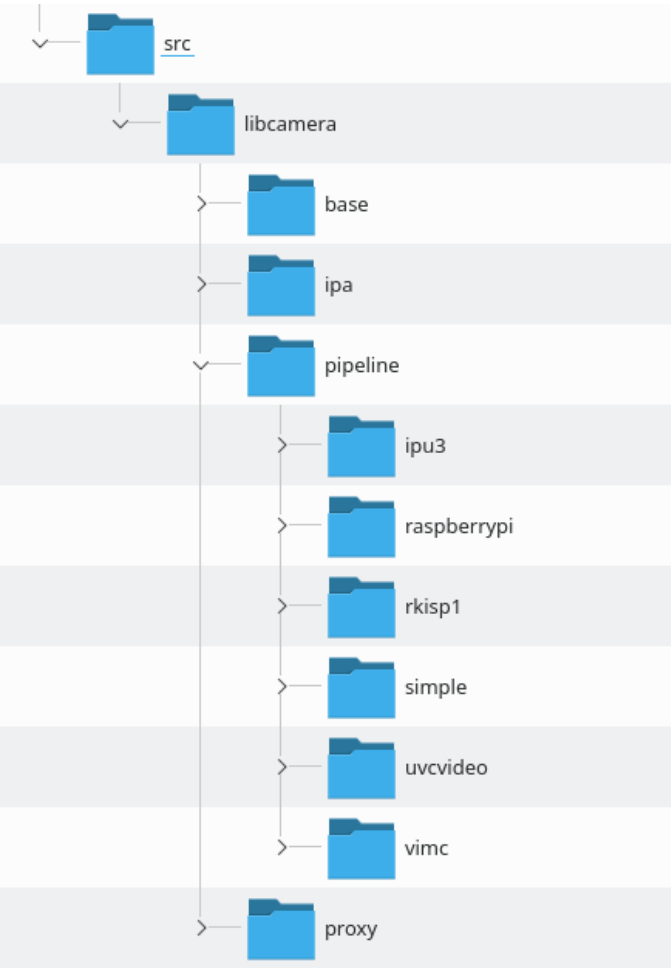
ISI Media Controller Pipeline



ISI Media Controller Pipeline



The simple pipeline handler



The “simple” pipeline handler supports simple pipelines through fully generic code. It is probably the most complicated pipeline handler implementation in libcamera.

A simple pipeline is defined as a linear pipeline without any processing block that requires specific configuration.

← here

Additionally, a generic V4L2 M2M device may be used to perform scaling and format conversion.

The Simple Pipeline Handler

```
* Overview
* --------
*
* The SimplePipelineHandler relies on generic kernel APIs to control a camera
* device, without any device-specific code and with limited device-specific
* static data.
*
* To qualify for support by the simple pipeline handler, a device shall
*
* - be supported by V4L2 drivers, exposing the Media Controller API, the V4L2
*   subdev APIs and the media bus format-based enumeration extension for the
*   VIDIOC_ENUM_FMT ioctl ;
* - not expose any device-specific API from drivers to userspace ;
* - include one or more camera sensor media entities and one or more video
*   capture devices ;
* - have a capture pipeline with linear paths from the camera sensors to the
*   video capture devices ; and
* - have an optional memory-to-memory device to perform format conversion
*   and/or scaling, exposed as a V4L2 M2M device.
```

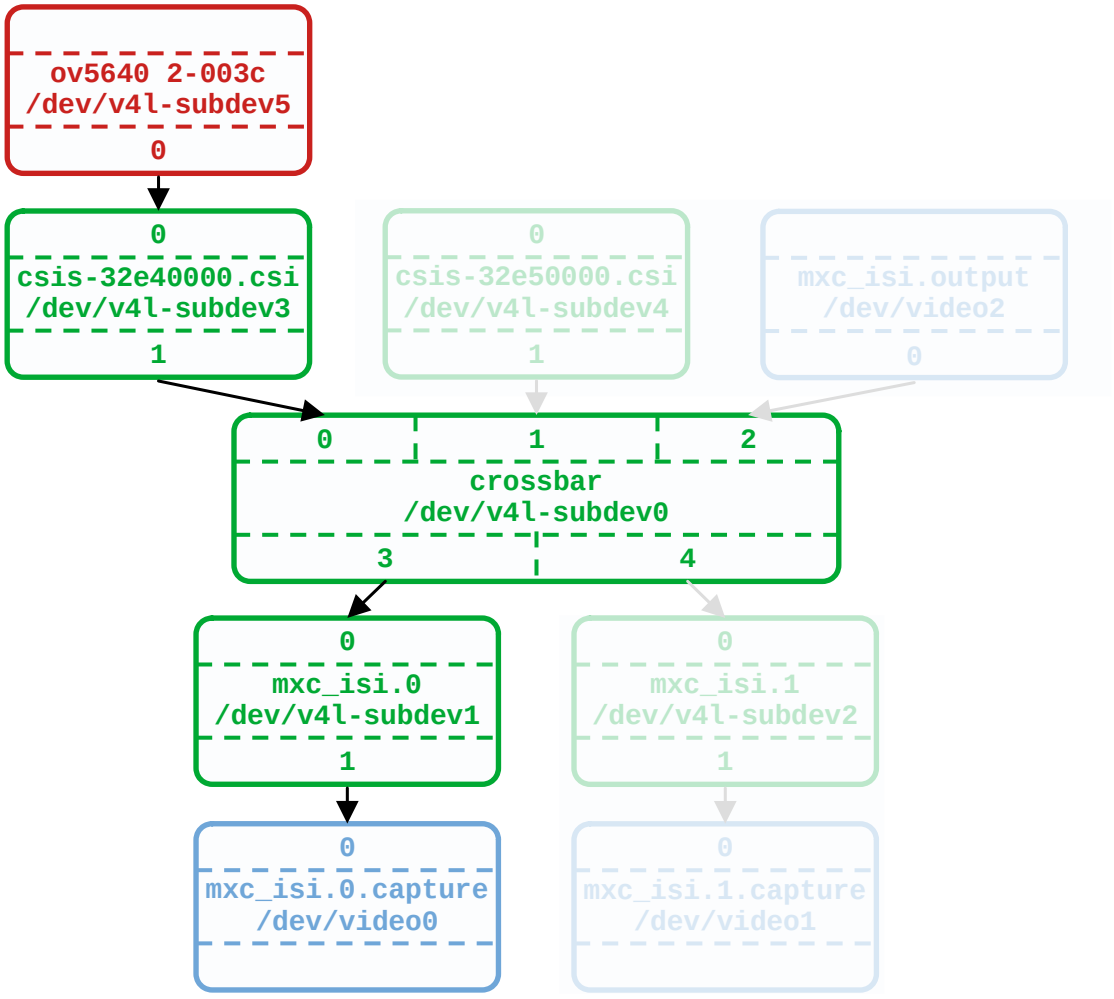
src/libcamera/pipeline/simple/simple.cpp

The Simple Pipeline Handler

```
* As devices that require a specific pipeline handler may still match the
* above characteristics, the simple pipeline handler doesn't attempt to
* automatically determine which devices it can support. It instead relies on
* an explicit list of supported devices, provided in the supportedDevices
* array.
*
* When matching a device, the pipeline handler enumerates all camera sensors
* and attempts, for each of them, to find a path to a video capture video node.
* It does so by using a breadth-first search to find the shortest path from the
* sensor device to a valid capture device. This is guaranteed to produce a
* valid path on devices with one only option and is a good heuristic on more
* complex devices to skip paths that aren't suitable for the simple pipeline
* handler. For instance, on the IPU-based i.MX6, the shortest path will skip
* encoders and image converters, and it will end in a CSI capture device.
* A more complex graph search algorithm could be implemented if a device that
* would otherwise be compatible with the pipeline handler isn't correctly
* handled by this heuristic.
```

src/libcamera/pipeline/simple/simple.cpp

The Simple Pipeline Handler



ISI Media Controller Pipeline

```
struct SimplePipelineInfo {
        const char *driver;
        /*
         * Each converter in the list contains the name
         * and the number of streams it supports.
         */
        std::vector<std::pair<const char *, unsigned int>> converters;
};

static const SimplePipelineInfo supportedDevices[] = {
        { "imx7-csi", { { "pxp", 1 } } },
        { "qcom-camss", {} },
        { "sun6i-csi", {} },
};
```

Device Support

```
 struct SimplePipelineInfo {
         const char *driver;
         /*
          * Each converter in the list contains the name
          * and the number of streams it supports.
          */
         std::vector<std::pair<const char *, unsigned int>> converters;
 };

 static const SimplePipelineInfo supportedDevices[] = {
         { "imx7-csi", { { "pxp", 1 } } },
+        { "mxc-isi", {} },
         { "qcom-camss", {} },
         { "sun6i-csi", {} },
 };
```

It’s that simple!

```
root@buildroot ~ # cam -l
[0:39:50.151292750] [317]  INFO Camera camera_manager.cpp:293 libcamera v0.0.0+3606-
123ce152
[0:39:50.336355125] [323]  WARN V4L2 v4l2_pixelformat.cpp:285 Unsupported V4L2 pixel
format YM24
Available cameras:
1: Internal front camera (/base/soc@0/bus@30800000/i2c@30a40000/camera@1a)
root@buildroot ~ # cam -c1 -C5
[0:40:46.220308875] [327]  INFO Camera camera_manager.cpp:293 libcamera v0.0.0+3606-
123ce152
[0:40:46.335423500] [328]  WARN V4L2 v4l2_pixelformat.cpp:285 Unsupported V4L2 pixel
format YM24
Using camera /base/soc@0/bus@30800000/i2c@30a40000/camera@3c as cam0
[0:40:46.343990875] [327]  INFO Camera camera.cpp:1029 configuring streams: (0) 2592x1944-
YUYV
cam0: Capture 5 frames
979.388197 (0.00 fps) cam0-stream0 seq: 000000 bytesused: 10077696
979.421517 (30.06 fps) cam0-stream0 seq: 000001 bytesused: 10077696
979.454850 (29.99 fps) cam0-stream0 seq: 000002 bytesused: 10077696
979.488182 (30.01 fps) cam0-stream0 seq: 000003 bytesused: 10077696
979.521516 (30.00 fps) cam0-stream0 seq: 000004 bytesused: 10077696
```

It’s that simple!

```
root@buildroot ~ # cam -l
[0:39:50.151292750] [317]  INFO Camera camera_manager.cpp:293 libcamera v0.0.0+3606-
123ce152 (2022-05-30T20:58:57+03:00)
[0:39:50.336355125] [323]  WARN V4L2 v4l2_pixelformat.cpp:285 Unsupported V4L2 pixel
format YM24
Available cameras:
1: Internal front camera (/base/soc@0/bus@30800000/i2c@30a40000/camera@1a)
root@buildroot ~ # cam -c1 -C5
[0:40:46.220308875] [327]  INFO Camera camera_manager.cpp:293 libcamera v0.0.0+3606-
123ce152
[0:40:46.335423500] [328]  WARN V4L2 v4l2_pixelformat.cpp:285 Unsupported V4L2 pixel
format YM24
Using camera /base/soc@0/bus@30800000/i2c@30a40000/camera@3c as cam0
[0:40:46.343990875] [327]  INFO Camera camera.cpp:1029 configuring streams: (0) 2592x1944-
YUYV
cam0: Capture 5 frames
979.388197 (0.00 fps) cam0-stream0 seq: 000000 bytesused: 10077696
979.421517 (30.06 fps) cam0-stream0 seq: 000001 bytesused: 10077696
979.454850 (29.99 fps) cam0-stream0 seq: 000002 bytesused: 10077696
979.488182 (30.01 fps) cam0-stream0 seq: 000003 bytesused: 10077696
979.521516 (30.00 fps) cam0-stream0 seq: 000004 bytesused: 10077696
```

Or is it?

```
--- a/src/libcamera/formats.yaml
+++ b/src/libcamera/formats.yaml
@@ -71,6 +71,10 @@ formats:
       fourcc: DRM_FORMAT_YUV422
   - YVU422:
       fourcc: DRM_FORMAT_YVU422
+  - YUV444:
+      fourcc: DRM_FORMAT_YUV444
+  - YVU444:
+      fourcc: DRM_FORMAT_YVU444

   - MJPEG:
       fourcc: DRM_FORMAT_MJPEG
```

Adding Missing Formats

```
--- a/src/libcamera/formats.cpp
+++ b/src/libcamera/formats.cpp
@@ -495,6 +495,32 @@ const std::map<PixelFormat, PixelFormatInfo> pixelFormatInfo{
         .pixelsPerGroup = 2,
         .planes = {{ { 2, 1 }, { 1, 1 }, { 1, 1 } }},
     } },
+    { formats::YUV444, {
+        .name = "YUV444",
+        .format = formats::YUV444,
+        .v4l2Formats = {
+            .single = V4L2PixelFormat(),
+            .multi = V4L2PixelFormat(V4L2_PIX_FMT_YUV444M),
+        },
+        .bitsPerPixel = 24,
+        .colourEncoding = PixelFormatInfo::ColourEncodingYUV,
+        .packed = false,
+        .pixelsPerGroup = 1,
+        .planes = {{ { 1, 1 }, { 1, 1 }, { 1, 1 } }},
+    } },

     /* Greyscale formats. */
     { formats::R8, {
```

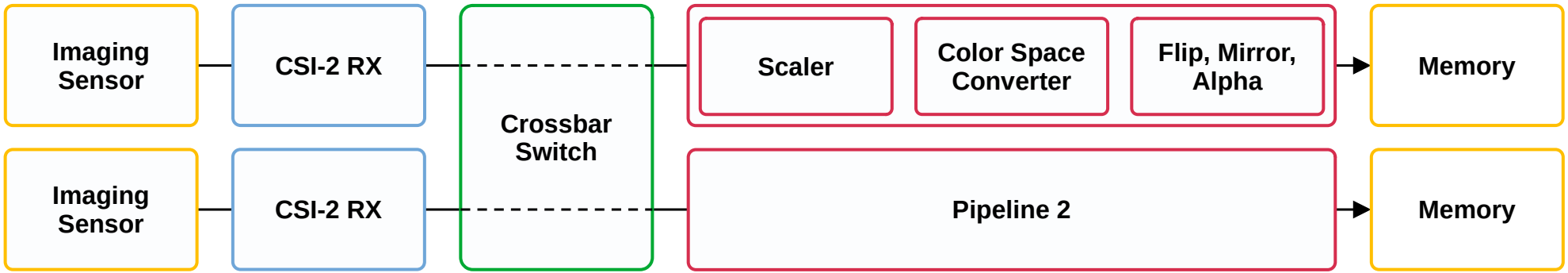
Adding Missing Formats

```
--- a/src/libcamera/v4l2_pixelformat.cpp
+++ b/src/libcamera/v4l2_pixelformat.cpp
@@ -117,6 +117,10 @@ const std::map<V4L2PixelFormat, V4L2PixelFormat::Info> vpf2pf{
         { formats::YUV422, "Planar YUV 4:2:2 (N-C)" } },
     { V4L2PixelFormat(V4L2_PIX_FMT_YVU422M),
         { formats::YVU422, "Planar YVU 4:2:2 (N-C)" } },
+    { V4L2PixelFormat(V4L2_PIX_FMT_YUV444M),
+        { formats::YUV444, "Planar YUV 4:4:4 (N-C)" } },
+    { V4L2PixelFormat(V4L2_PIX_FMT_YUV444M),
+        { formats::YVU444, "Planar YVU 4:4:4 (N-C)" } },

     /* Greyscale formats. */
     { V4L2PixelFormat(V4L2_PIX_FMT_GREY),
```

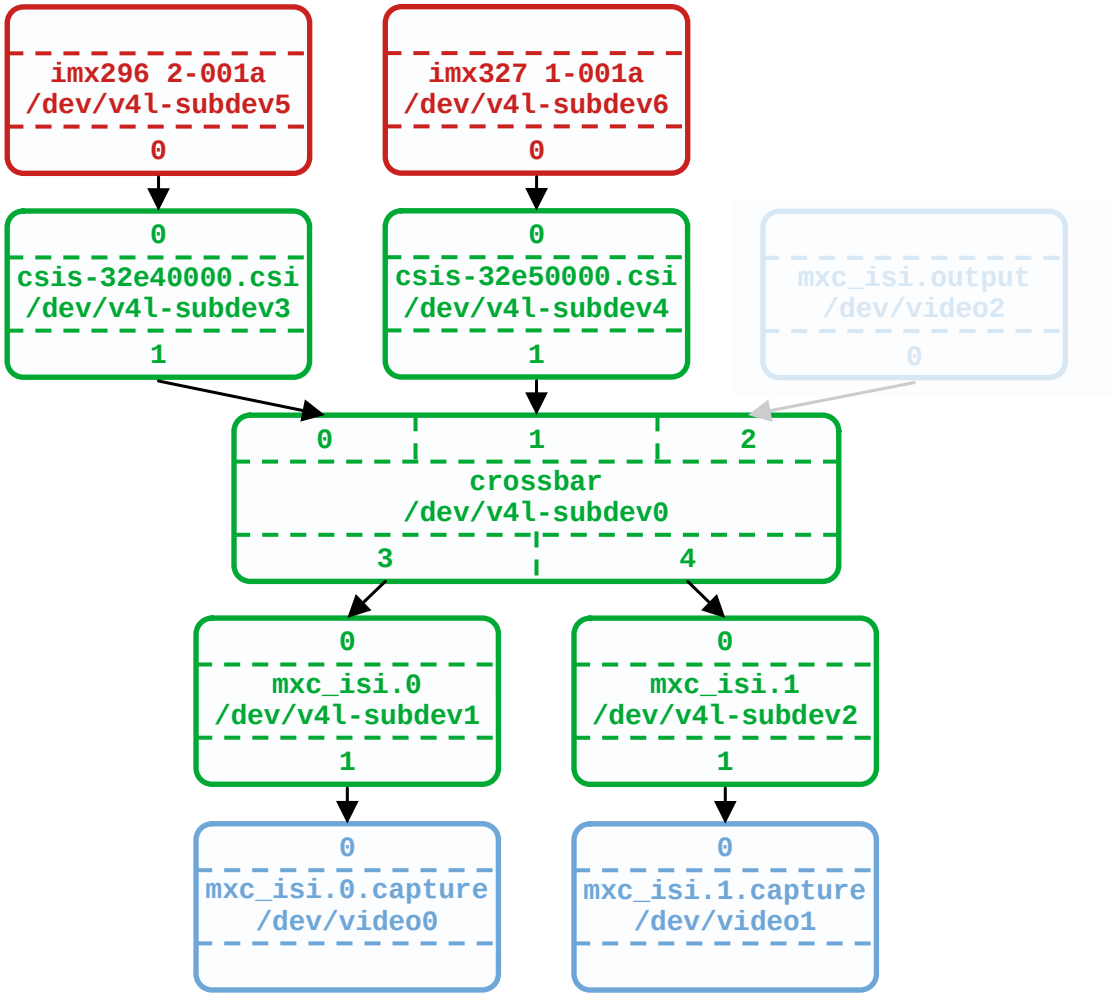
Adding Missing Formats

ISI, Dual Camera

IDEAS ON BOARD



Second Use Case – ISI, Dual Camera



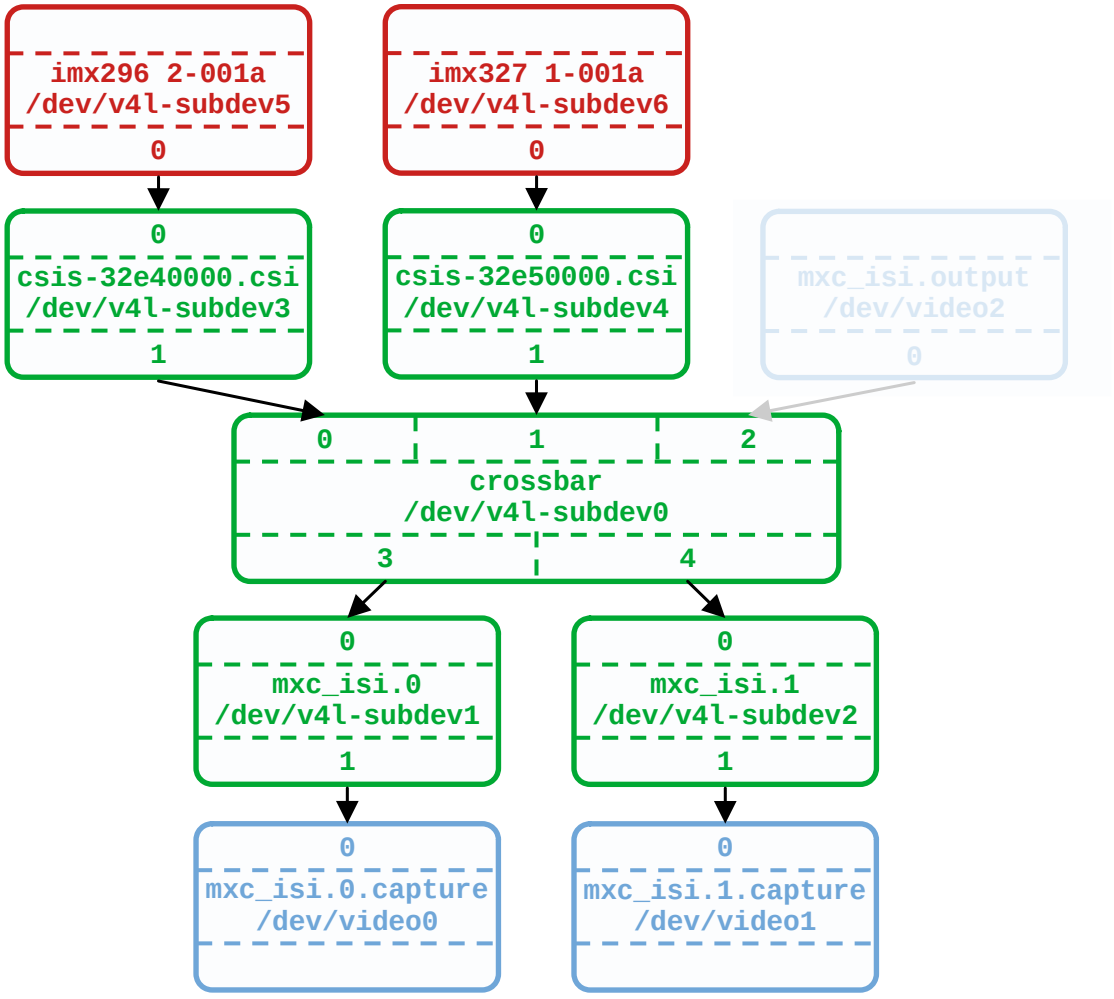
ISI Media Controller Pipeline

```
root@buildroot ~ # cam -l
[0:33:37.316170875] [262]  INFO Camera camera_manager.cpp:293 libcamera v0.0.0+3606-
e8ee3e28
Available cameras:
1: Internal front camera (/base/soc@0/bus@30800000/i2c@30a40000/camera@1a)
2: Internal back camera (/base/soc@0/bus@30800000/i2c@30a30000/camera@1a)
root@buildroot ~ # cam -c1 -C5
[0:37:09.068318375] [270]  INFO Camera camera_manager.cpp:293 libcamera v0.0.0+3606-
e8ee3e28
Using camera /base/soc@0/bus@30800000/i2c@30a40000/camera@1a as cam0
[0:37:09.216500500] [270]  INFO Camera camera.cpp:1029 configuring streams: (0) 1920x1080-
SRGGB10
cam0: Capture 5 frames
2229.820427 (0.00 fps) cam0-stream0 seq: 000000 bytesused: 4147200
2229.837072 (60.08 fps) cam0-stream0 seq: 000001 bytesused: 4147200
2229.853748 (59.97 fps) cam0-stream0 seq: 000002 bytesused: 4147200
2229.870414 (60.00 fps) cam0-stream0 seq: 000003 bytesused: 4147200
2229.887077 (60.01 fps) cam0-stream0 seq: 000004 bytesused: 4147200
```

First camera

```
root@buildroot ~ # cam -c2 -C5
[0:37:09.068318375] [270]  INFO Camera camera_manager.cpp:293 libcamera v0.0.0+3606-
e8ee3e28
Using camera /base/soc@0/bus@30800000/i2c@30a30000/camera@1a as cam0
[0:41:12.556723875] [275]  INFO Camera camera.cpp:1029 configuring streams: (0) 1920x1080-
SRGGB12
[0:41:12.626511375] [276] ERROR V4L2 v4l2_videodevice.cpp:1852 /dev/video0[19:cap]: Failed
to start streaming: Broken pipe
Failed to start capture
Failed to start camera session
```

Second camera



ISI Media Controller Pipeline

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

```
commit 63fce39a74a3156f67909fcda652166183cf6f93
Author: Jacopo Mondi <jacopo@jmondi.org>
Date:   Wed Mar 30 12:27:03 2022 +0200

    libcamera: v4l2_subdevice: Add support for the V4L2 subdev routing API

    Extend the V4L2Subdevice class to support getting and setting routing
    tables.

    Signed-off-by: Jacopo Mondi <jacopo@jmondi.org>
    Signed-off-by: Laurent Pinchart <laurent.pinchart@ideasonboard.com>
```

V4L2 Subdevice Extension

```
--- a/include/libcamera/internal/v4l2_subdevice.h
+++ b/include/libcamera/internal/v4l2_subdevice.h
@@ -61,6 +61,12 @@ public:
                ActiveFormat = V4L2_SUBDEV_FORMAT_ACTIVE,
        };

+       class Routing : public std::vector<struct v4l2_subdev_route>
+       {
+       public:
+               std::string toString() const;
+       };
+
        explicit V4L2Subdevice(const MediaEntity *entity);
        ~V4L2Subdevice();

@@ -80,6 +86,9 @@ public:
        int setFormat(unsigned int pad, V4L2SubdeviceFormat *format,
                      Whence whence = ActiveFormat);

+       int getRouting(Routing *routing, Whence whence = ActiveFormat);
+       int setRouting(Routing *routing, Whence whence = ActiveFormat);
+
```


V4L2 Subdevice Extension

```
commit ba58fbd9ac09587c06de9477c95ebbb1e20d6827
Author: Phi-Bang Nguyen <pnguyen@baylibre.com>
Date:   Fri Apr 2 17:00:49 2021 +0200

    libcamera: pipeline: simple: Walk pipeline using subdev internal routing

    When traversing the media graph to discover a pipeline from the camera
    sensor to a video node, all sink-to-source paths inside subdevs are
    considered. This can lead to invalid paths being followed, when a subdev
    has restrictions on its internal routing.

    The V4L2 API supports exposing subdev internal routing to userspace.
    Make use if this feature, when implemented by a subdev, to restrict the
    internal paths to the currently active routes. If a subdev doesn't
    implement the internal routing operations, all source pads are
    considered, as done today.

    This change is needed to properly support multiple sensors with devices
    such as the NXP i.MX8 ISI or the MediaTek i350 and i500 SENINF. Support
    for changing routes dynamically will be added later when required.

    Signed-off-by: Phi-Bang Nguyen <pnguyen@baylibre.com>
    Signed-off-by: Laurent Pinchart <laurent.pinchart@ideasonboard.com>
```

Simple Pipeline Handler Extension

```
--- a/src/libcamera/pipeline/simple/simple.cpp
+++ b/src/libcamera/pipeline/simple/simple.cpp
@@ -775,6 +798,43 @@ void SimpleCameraData::converterOutputDone(FrameBuffer *buffer)
+/* Retrieve all source pads connected to a sink pad through active routes. */
+std::vector<const MediaPad *> SimpleCameraData::routedSourcePads(MediaPad *sink)
+{
...
+       V4L2Subdevice::Routing routing = {};
+       ret = subdev->getRouting(&routing, V4L2Subdevice::ActiveFormat);
+       if (ret < 0)
+               return {};
...
+       for (const struct v4l2_subdev_route &route : routing) {
+               if (sink->index() != route.sink_pad ||
+                   !(route.flags & V4L2_SUBDEV_ROUTE_FL_ACTIVE))
+                       continue;
...
+               const MediaPad *pad = entity->getPadByIndex(route.source_pad);
+               pads.push_back(pad);
+       }
...
+       return pads;
+}
```

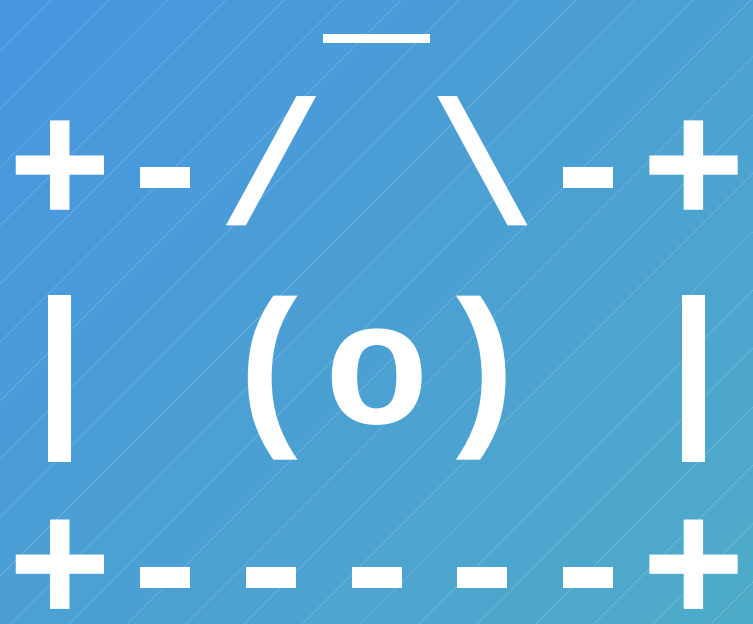
Simple Pipeline Handler Extension

```
$ git log –oneline
...
53fd21f1798b libcamera: pipeline: simple: Don't disable links carrying other streams
ba58fbd9ac09 libcamera: pipeline: simple: Walk pipeline using subdev internal routing
4756da675dc6 libcamera: pipeline: simple: Setup links in the context of sink entities
da168e5bf4fc libcamera: pipeline: simple: Reset routing table of subdevs
63fce39a74a3 libcamera: v4l2_subdevice: Add support for the V4L2 subdev routing API
06da6ea33b69 libcamera: v4l2_subdevice: Collect subdev capabilities
2b87018140fd libcamera: v4l2_subdevice: Change V4L2Subdevice::Whence
ff965168f965 include: linux: Add V4L2 subdev internal routing API
...
```

Simple Pipeline Handler Extension

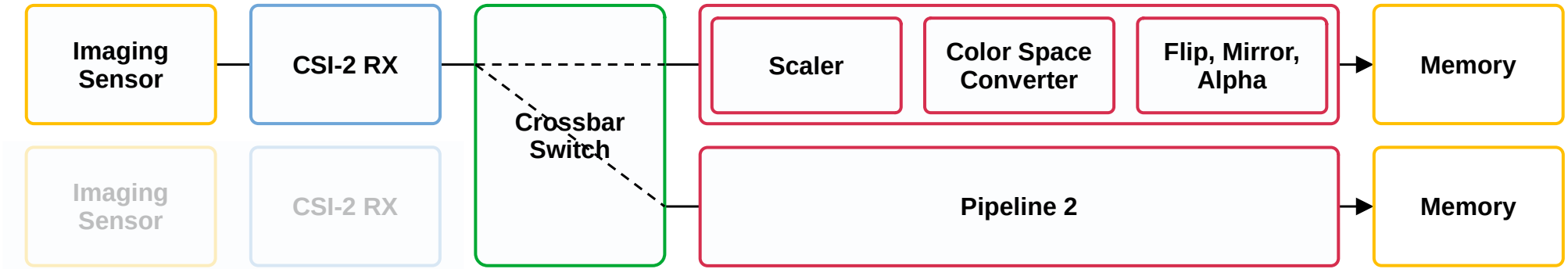
```
root@buildroot ~ # cam -c2 -C5
[0:02:12.088659000] [258]  INFO Camera camera_manager.cpp:293 libcamera v0.0.0+3627-
53fd21f1
Using camera /base/soc@0/bus@30800000/i2c@30a30000/camera@1a as cam0
[0:02:12.239059000] [258]  INFO Camera camera.cpp:1029 configuring streams: (0) 1456x1088-
SBGGR10
cam0: Capture 5 frames
132.712521 (0.00 fps) cam0-stream0 seq: 000000 bytesused: 3168256
132.729069 (60.43 fps) cam0-stream0 seq: 000001 bytesused: 3168256
132.745629 (60.39 fps) cam0-stream0 seq: 000002 bytesused: 3168256
132.762192 (60.38 fps) cam0-stream0 seq: 000003 bytesused: 3168256
132.778753 (60.38 fps) cam0-stream0 seq: 000004 bytesused: 3168256
```

Second camera



ISI, Single Camera, Dual Stream

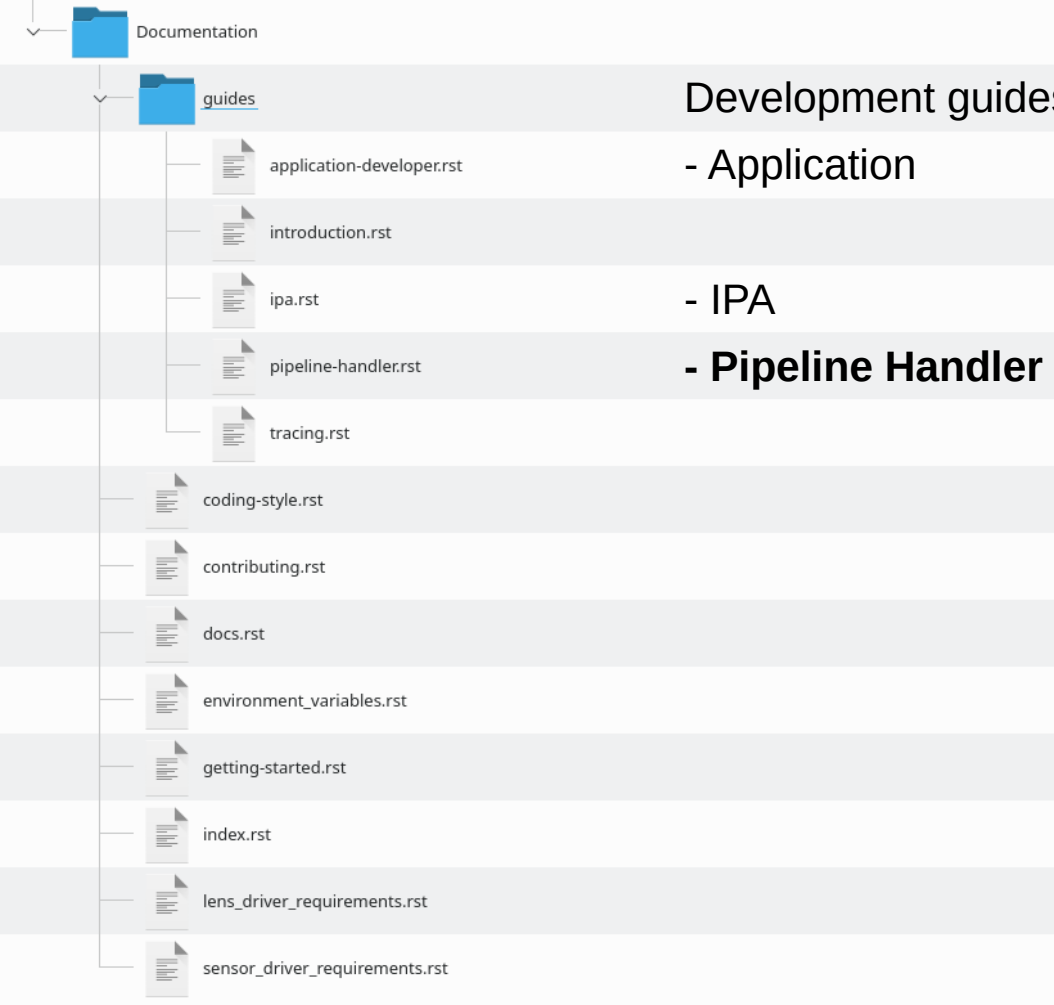
IDEAS ON BOARD



Third Use Case: ISI, Dual Stream

ISI Pipeline Handler

IDEAS ON BOARD



Pipeline Handler Writer’s Guide

Pipeline Handler Writers Guide

Pipeline handlers are the abstraction layer for device-specific hardware configuration. They access and control hardware through the V4L2 and Media Controller kernel interfaces, and implement an internal API to control the ISP and capture components of a pipeline directly.

Prerequisite knowledge: system architecture

A pipeline handler configures and manages the image acquisition and transformation pipeline realized by specialized system peripherals combined with an image source connected to the system through a data and control bus. The presence, number and characteristics of them vary depending on the system design and the product integration of the target platform.

System components can be classified in three macro-categories:

- Input ports: Interfaces to external devices, usually image sensors, which transfer data from the physical bus to locations accessible by other system peripherals. An input port needs to be configured according to the input image format and size and could optionally apply basic transformations on the received images, most typically cropping/scaling and some formats conversion. The industry standard for the system typically targeted by libcamera is to have receivers compliant with the MIPI CSI-2 specifications, implemented on a compatible physical layer such as MIPI D-PHY or MIPI C-PHY. Other design are possible but less common, such as LVDS or the legacy BT.601 and BT.656

Pipeline Handler Writer’s Guide

1. The Skeleton
2. The Matching
3. The Configuration
4. The Buffers
5. The Capture

1. The Skeleton
2. The Matching
3. The Configuration
4. The Buffers
5. The Capture

- Wire up the build system
- Create the pipeline handler

The Skeleton

```
--- a/meson_options.txt
+++ b/meson_options.txt
@@ -37,7 +37,10 @@ option('lc-compliance',

 option('pipelines',
         type : 'array',
-        choices : ['ipu3', 'raspberrypi', 'rkisp1', 'simple', 'uvcvideo', 'vimc'],
+        choices : [
+            'imx8mp', 'ipu3', 'raspberrypi', 'rkisp1',
+            'simple', 'uvcvideo', 'vimc'
+        ],
         description : 'Select which pipeline handlers to include')
```


The Skeleton – Wire Up The Build System

```
# SPDX-License-Identifier: CC0-1.0

libcamera_sources += files([
    'imx8mp.cpp',
])
```

src/libcamera/pipeline/imx8mp/meson.build

The Skeleton – Wire Up The Build System

```
#include "libcamera/internal/pipeline_handler.h"

namespace libcamera {

class PipelineHandlerIMX8MP : public PipelineHandler
{
Public:
     PipelineHandlerIMX8MP(CameraManager *manager);

     bool match(DeviceEnumerator *enumerator) override;
     CameraConfiguration *generateConfiguration(Camera *camera,
                                                const StreamRoles &roles) override;
     int configure(Camera *camera, CameraConfiguration *config) override;
     int exportFrameBuffers(Camera *camera, Stream *stream,
                            std::vector<std::unique_ptr<FrameBuffer>> *buffers) override;
     int start(Camera *camera, const ControlList *controls) override;

protected:
     int queueRequestDevice(Camera *camera, Request *request) override;
     void stopDevice(Camera *camera) override;
};

REGISTER_PIPELINE_HANDLER(PipelineHandlerIMX8MP)

} /* namespace libcamera */
```

src/libcamera/pipeline/imx8mp/imx8mp.cpp

The Skeleton – Create The Pipeline Handle

1. The Skeleton
2. The Matching
3. The Configuration
4. The Buffers
5. The Capture

- Match media devices
- Discover the pipeline
- Create the camera data
- Register the cameras

The Matching

```
PipelineHandlerIMX8MP::PipelineHandlerIMX8MP(CameraManager *manager)
        : PipelineHandler(manager)
{
}

bool PipelineHandlerIMX8MP::match(DeviceEnumerator *enumerator)
{
        DeviceMatch dm("mxc-isi");
        dm.add("crossbar");
        dm.add("mxc_isi.0");
        dm.add("mxc_isi.0.capture");

        isiDev_ = acquireMediaDevice(enumerator, dm);
        if (!isiDev_)
                return false;

        return false;
}
```

src/libcamera/pipeline/imx8mp/imx8mp.cpp

The Matching – Match Media Devices

```
#include <memory>
#include <vector>

#include "libcamera/internal/media_device.h"
#include "libcamera/internal/v4l2_subdevice.h"
#include "libcamera/internal/v4l2_videodevice.h"

...

class PipelineHandlerIMX8MP : public PipelineHandler
{
...
private:
        struct Pipe {
                std::unique_ptr<V4L2Subdevice> isi;
                std::unique_ptr<V4L2VideoDevice> video;
        };

        MediaDevice *isiDev_;

        std::unique_ptr<V4L2Subdevice> crossbar_;
        std::vector<Pipe> pipes_;
};
```

src/libcamera/pipeline/imx8mp/imx8mp.cpp

The Matching – Discover The Pipeline

```
bool PipelineHandlerIMX8MP::match(DeviceEnumerator *enumerator)
{
...
        /*
         * Acquire the subdevs and video nodes for the crossbar switch and the
         * processing pipelines.
         */
        crossbar_ = V4L2Subdevice::fromEntityName(isiDev_, "crossbar");
        if (!crossbar_)
                return false;

        return false;
}
```

src/libcamera/pipeline/imx8mp/imx8mp.cpp

The Matching – Discover The Pipeline

```
bool PipelineHandlerIMX8MP::match(DeviceEnumerator *enumerator)
{
...
        for (unsigned int i = 0; ; ++i) {
                std::string entityName = "mxc_isi." + std::to_string(i);
                std::unique_ptr<V4L2Subdevice> isi =
                        V4L2Subdevice::fromEntityName(isiDev_, entityName);
                if (!isi)
                        break;

                entityName += ".capture";
                std::unique_ptr<V4L2VideoDevice> video =
                        V4L2VideoDevice::fromEntityName(isiDev_, entityName);
                if (!video)
                        break;

                pipes_.push_back({ std::move(isi), std::move(video) });
        }

        if (pipes_.empty())
                return false;

        return false;
}
```

src/libcamera/pipeline/imx8mp/imx8mp.cpp

The Matching – Discover The Pipeline

```
bool PipelineHandlerIMX8MP::match(DeviceEnumerator *enumerator)
{
...
        /*
         * Loop over all the crossbar switch sink pads to find connected CSI-2
         * receivers and camera sensors.
         */
        unsigned int numCameras = 0;
        for (MediaPad *pad : crossbar_->entity()->pads()) {
                if (!(pad->flags() & MEDIA_PAD_FL_SINK) || pad->links().empty())
                        continue;

                MediaEntity *csi = pad->links()[0]->source()->entity();
                if (csi->pads().size() != 2)
                        continue;

                pad = csi->pads()[0];
                if (!(pad->flags() & MEDIA_PAD_FL_SINK) || pad->links().empty())
                        continue;

                MediaEntity *sensor = pad->links()[0]->source()->entity();
                if (sensor->function() != MEDIA_ENT_F_CAM_SENSOR)
                        continue;
        }

        return false;
}
```

src/libcamera/pipeline/imx8mp/imx8mp.cpp

The Matching – Discover The Pipeline

```
class IMX8MPCameraData : public Camera::Private
{
public:
        IMX8MPCameraData(PipelineHandler *ph)
                : Camera::Private(ph)
        {
        }

        PipelineHandlerIMX8MP *pipe()
        {
                return static_cast<PipelineHandlerIMX8MP *>(Camera::Private::pipe());
        }

        struct {
                std::unique_ptr<V4L2VideoDevice> capture;
                std::unique_ptr<V4L2Subdevice> csis;
                V4L2Subdevice *isi;
                CameraSensor *sensor;
        } pipe_;

        Stream stream_;
};
```

src/libcamera/pipeline/imx8mp/imx8mp.cpp

The Matching – Create The Camera Data

```
bool PipelineHandlerIMX8MP::match(DeviceEnumerator *enumerator)
{
...
        /*
         * Loop over all the crossbar switch sink pads to find connected CSI-2
         * receivers and camera sensors.
         */
        unsigned int numCameras = 0;
        for (MediaPad *pad : crossbar_->entity()->pads()) {
                ...
                /* Create the camera data. */
                std::unique_ptr<IMX8MPCameraData> data =
                        std::make_unique<IMX8MPCameraData>(this);

                data->pipe_.sensor = std::make_unique<CameraSensor>(sensor);
                data->pipe_.csis = std::make_unique<V4L2Subdevice>(csi);
                data->pipe_.isi = pipes_[numCameras].isi.get();
                data->pipe_.capture = pipes_[numCameras].video.get();
        }

        return false;
}
```

src/libcamera/pipeline/imx8mp/imx8mp.cpp

The Matching – Create The Camera Data

```
class IMX8MPCameraData : public Camera::Private
{
public:
        ...
        int init();
};

int IMX8MPCameraData::init()
{
        int ret = pipe_.sensor->init();
        if (ret)
                return ret;

        ret = pipe_.csis->open();
        if (ret)
                return ret;

        ret = pipe_.isi->open();
        if (ret)
                return ret;

        ret = pipe_.capture->open();
        if (ret)
                return ret;

        return 0;
}
```

src/libcamera/pipeline/imx8mp/imx8mp.cpp

The Matching – Create The Camera Data

```
bool PipelineHandlerIMX8MP::match(DeviceEnumerator *enumerator)
{
...
        /*
         * Loop over all the crossbar switch sink pads to find connected CSI-2
         * receivers and camera sensors.
         */
        unsigned int numCameras = 0;
        for (MediaPad *pad : crossbar_->entity()->pads()) {
                ...
                int ret = data->init();
                if (ret)
                        return false;

                /* Register the camera. */
                const std::string &id = data->pipe_.sensor->id();
                std::set<Stream *> streams = { &data->stream_ };
                std::shared_ptr<Camera> camera =
                        Camera::create(std::move(data), id, streams);

                registerCamera(std::move(camera));
                numCameras++;
        }

        return numCameras > 0;
}
```

src/libcamera/pipeline/imx8mp/imx8mp.cpp

The Matching – Register The Cameras

```
root@buildroot ~ # cam -l
[0:01:28.355935500] [257]  INFO Camera camera_manager.cpp:293 libcamera v0.0.0+3610-
ace9e0a1
Available cameras:
1: (/base/soc@0/bus@30800000/i2c@30a40000/camera@1a)
2: (/base/soc@0/bus@30800000/i2c@30a30000/camera@1a)
```

Intermezzo: First Test

```
int IMX8MPCameraData::init()
{
...
        properties_ = pipe_.sensor->properties();

        return 0;
}
```

src/libcamera/pipeline/imx8mp/imx8mp.cpp

Intermezzo: Add Camera Properties

```
root@buildroot ~ # cam -l
[0:03:42.037213125] [260]  INFO Camera camera_manager.cpp:293 libcamera v0.0.0+3610-
ace9e0a1
Available cameras:
1: Internal front camera (/base/soc@0/bus@30800000/i2c@30a40000/camera@1a)
2: Internal back camera (/base/soc@0/bus@30800000/i2c@30a30000/camera@1a)
```

Intermezzo: Second Test

1. The Skeleton
2. The Matching
3. The Configuration
4. The Buffers
5. The Capture

- Generate a configuration
- Validate the configuration
- Configure the camera

The Configuration

```
CameraConfiguration *
PipelineHandlerIMX8MP::generateConfiguration(Camera *camera,
                                             const StreamRoles &roles)
{
        IMX8MPCameraData *data = cameraData(camera);
        CameraConfiguration *config = new IMX8MPCameraConfiguration(data);

        if (roles.empty())
                return config;

        /* \todo Customize the configuration based on hardware capabilities. */
        StreamConfiguration cfg;
        cfg.size = { 1920, 1080 };
        cfg.pixelFormat = formats::YUYV;
        cfg.bufferCount = 4;

        config->addConfiguration(cfg);
        config->validate();

        return config;
}
```

src/libcamera/pipeline/imx8mp/imx8mp.cpp

The Configuration – Generate

```
class IMX8MPCameraConfiguration : public CameraConfiguration
{
public:
        IMX8MPCameraConfiguration(IMX8MPCameraData *data)
                : data_(data)
        {
        }

        Status validate() override;

private:
        const IMX8MPCameraData *data_;
};
```

src/libcamera/pipeline/imx8mp/imx8mp.cpp

The Configuration – Generate

```
CameraConfiguration::Status IMX8MPCameraConfiguration::validate()
{
        Status status = Valid;

        if (config_.empty())
                return Invalid;

        if (config_.size() > 1) {
                config_.resize(1);
                status = Adjusted;
        }

        StreamConfiguration &cfg = config_[0];

        /* \todo Validate the configuration. */

        return status;
}
```

src/libcamera/pipeline/imx8mp/imx8mp.cpp

The Configuration – Validate

```
int PipelineHandlerIMX8MP::configure(Camera *camera, CameraConfiguration *c)
{
        IMX8MPCameraConfiguration *camConfig = static_cast<IMX8MPCameraConfiguration *>(c);

        IMX8MPCameraData *data = cameraData(camera);
        CameraSensor *sensor = data->pipe_.sensor.get();

        /* All links are immutable except the sensor -> csis link. */
        const MediaPad *sensorSrc = sensor->entity()->getPadByIndex(0);
        SensorSrc->links()[0]->setEnabled(true);

...

        return 0;
}
```

src/libcamera/pipeline/imx8mp/imx8mp.cpp

The Configuration – Configure

```
int PipelineHandlerIMX8MP::configure(Camera *camera, CameraConfiguration *c)
{
...
        /* Apply formats to the capture pipeline. */
        StreamConfiguration &config = camConfig->at(0);

...

        V4L2SubdeviceFormat sensorFmt{};
        sensorFmt.mbus_code = pipeFormat.mbusCode;
        sensorFmt.size = config.size;
        int ret = sensor->setFormat(&sensorFmt);
        if (ret)
                return ret;

        ret = data->pipe_.csis->setFormat(0, &sensorFmt);
        if (ret)
                return ret;

        ret = data->pipe_.csis->setFormat(1, &sensorFmt);
        if (ret)
                return ret;

...

        return 0;
}
```

src/libcamera/pipeline/imx8mp/imx8mp.cpp

The Configuration – Configure

1. The Skeleton
2. The Matching
3. The Configuration
4. The Buffers
5. The Capture

- Export frame buffers

The Buffers

```
int PipelineHandlerIMX8MP::exportFrameBuffers(Camera *camera, Stream *stream,
                                              std::vector<std::unique_ptr<FrameBuffer>> *buffers)
{
        IMX8MPCameraData *data = cameraData(camera);
        unsigned int count = stream->configuration().bufferCount;

        return data->pipe_.capture->exportBuffers(count, buffers);
}
```

src/libcamera/pipeline/imx8mp/imx8mp.cpp

The Buffers – Export Frame Buffers

1. The Skeleton
2. The Matching
3. The Configuration
4. The Buffers
5. The Capture

- Start the device
- Queue capture requests
- Stop the device

```
int PipelineHandlerIMX8MP::start(Camera *camera,
                                 [[maybe_unused]] const ControlList *controls)
{
        IMX8MPCameraData *data = cameraData(camera);
        V4L2VideoDevice *capture = data->pipe_.capture;
        const Stream *stream = &data->stream_;
        const StreamConfiguration &config = stream->configuration();

        int ret = capture->importBuffers(config.bufferCount);
        if (ret)
                return ret;

        return capture->streamOn();
}
```

src/libcamera/pipeline/imx8mp/imx8mp.cpp

The Capture – Start The Device

```
int PipelineHandlerIMX8MP::queueRequestDevice(Camera *camera, Request *request)
{
        IMX8MPCameraData *data = cameraData(camera);
        V4L2VideoDevice *capture = data->pipe_.capture;

        for (auto &[stream, buffer] : request->buffers()) {
                int ret = capture->queueBuffer(buffer);
                if (ret)
                        return ret;
        }

        return 0;
}
```

src/libcamera/pipeline/imx8mp/imx8mp.cpp

The Capture – Queue Capture Requests

```
void PipelineHandlerIMX8MP::stopDevice(Camera *camera)
{
        IMX8MPCameraData *data = cameraData(camera);
        V4L2VideoDevice *capture = data->pipe_.capture;

        capture->streamOff();
        capture->releaseBuffers();
}
```

src/libcamera/pipeline/imx8mp/imx8mp.cpp

The Capture – Stop The Device

```
root@buildroot ~ # cam -c1 -C5
[1:33:46.502527375] [298]  INFO Camera camera_manager.cpp:293 libcamera v0.0.0+3615-
3b4bb215
Using camera /base/soc@0/bus@30800000/i2c@30a40000/camera@1a as cam0
[1:33:46.674367625] [298]  INFO Camera camera.cpp:1029 configuring streams: (0) 1920x1080-
SRGGB10
cam0: Capture 5 frames
```

Final Test

```
root@buildroot ~ # cam -c1 -C5
[1:33:46.502527375] [298]  INFO Camera camera_manager.cpp:293 libcamera v0.0.0+3615-
3b4bb215
Using camera /base/soc@0/bus@30800000/i2c@30a40000/camera@1a as cam0
[1:33:46.674367625] [298]  INFO Camera camera.cpp:1029 configuring streams: (0) 1920x1080-
SRGGB10
cam0: Capture 5 frames
<wait>
```

Final Test

```
root@buildroot ~ # cam -c1 -C5
[1:33:46.502527375] [298]  INFO Camera camera_manager.cpp:293 libcamera v0.0.0+3615-
3b4bb215
Using camera /base/soc@0/bus@30800000/i2c@30a40000/camera@1a as cam0
[1:33:46.674367625] [298]  INFO Camera camera.cpp:1029 configuring streams: (0) 1920x1080-
SRGGB10
cam0: Capture 5 frames
<wait>
<wait some more>
```

Final Test

```
root@buildroot ~ # cam -c1 -C5
[1:33:46.502527375] [298]  INFO Camera camera_manager.cpp:293 libcamera v0.0.0+3615-
3b4bb215
Using camera /base/soc@0/bus@30800000/i2c@30a40000/camera@1a as cam0
[1:33:46.674367625] [298]  INFO Camera camera.cpp:1029 configuring streams: (0) 1920x1080-
SRGGB10
cam0: Capture 5 frames
<wait>
<wait some more>
<get a cup of tea>
```

Final Test

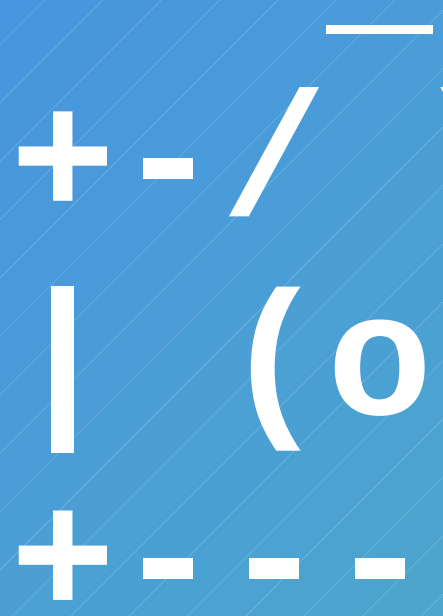
```
bool PipelineHandlerIMX8MP::match(DeviceEnumerator *enumerator)
{
...
        for (unsigned int i = 0; ; ++i) {
...
                std::unique_ptr<V4L2VideoDevice> video =
                        V4L2VideoDevice::fromEntityName(isiDev_, entityName);
                if (!video)
                        Break;

                video->bufferReady.connect(this, &PipelineHandlerIMX8MP::bufferReady);

                pipes_.push_back({ std::move(isi), std::move(video) });
        }

...
}

void PipelineHandlerIMX8MP::bufferReady(FrameBuffer *buffer)
{
        Request *request = buffer->request();

        completeBuffer(request, buffer);
        completeRequest(request);
}
```

src/libcamera/pipeline/imx8mp/imx8mp.cpp

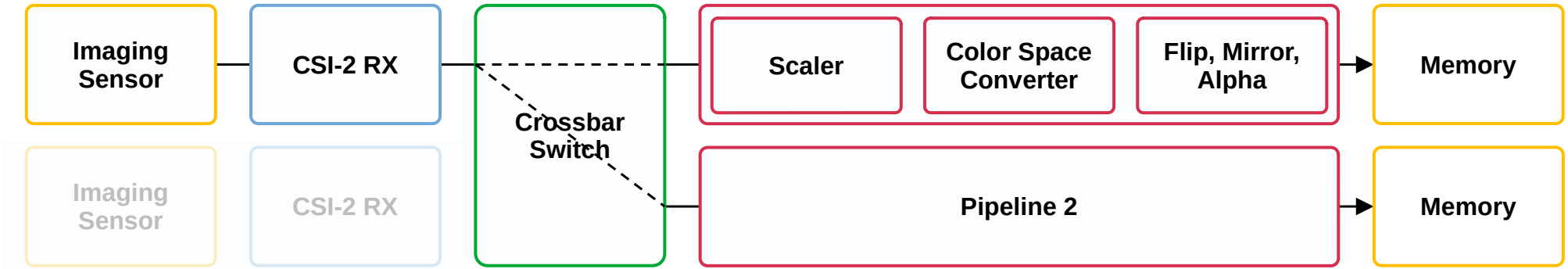
The Capture – Handle Events

```
root@buildroot ~ # cam -c1 -C5
[1:35:17.092654500] [300]  INFO Camera camera_manager.cpp:293 libcamera v0.0.0+3615-
3b4bb215
Using camera /base/soc@0/bus@30800000/i2c@30a40000/camera@1a as cam0
[1:35:17.263601750] [300]  INFO Camera camera.cpp:1029 configuring streams: (0) 1920x1080-
SRGGB10
cam0: Capture 5 frames
5717.881212 (0.00 fps) cam0-stream0 seq: 000000 bytesused: 4147200
5717.897881 (59.99 fps) cam0-stream0 seq: 000001 bytesused: 4147200
5717.914544 (60.01 fps) cam0-stream0 seq: 000002 bytesused: 4147200
5717.931211 (60.00 fps) cam0-stream0 seq: 000003 bytesused: 4147200
5717.947879 (60.00 fps) cam0-stream0 seq: 000004 bytesused: 4147200
```

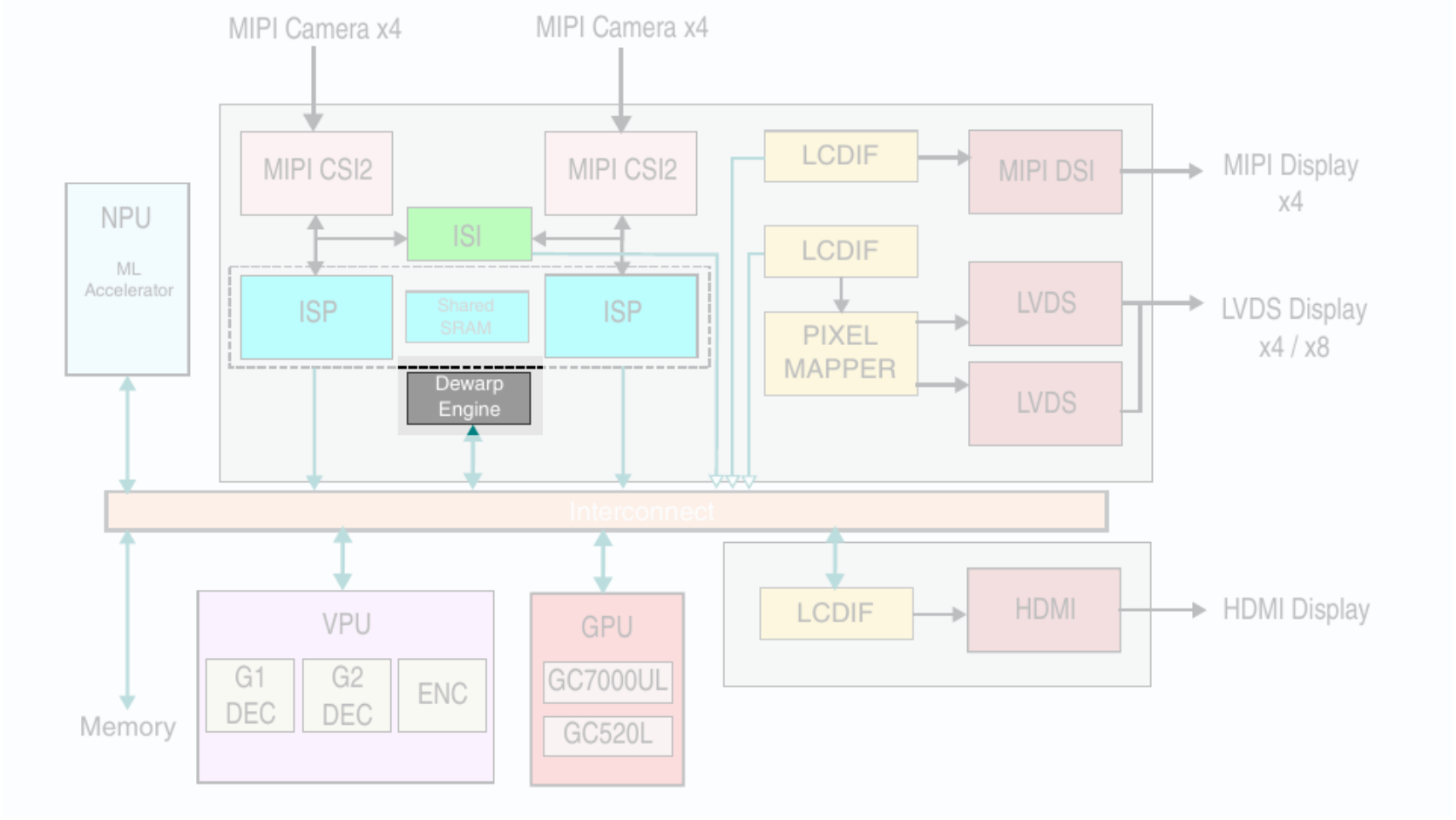
Final Test, For Real



Exercises For The Reader



Next Steps – Multi-Stream



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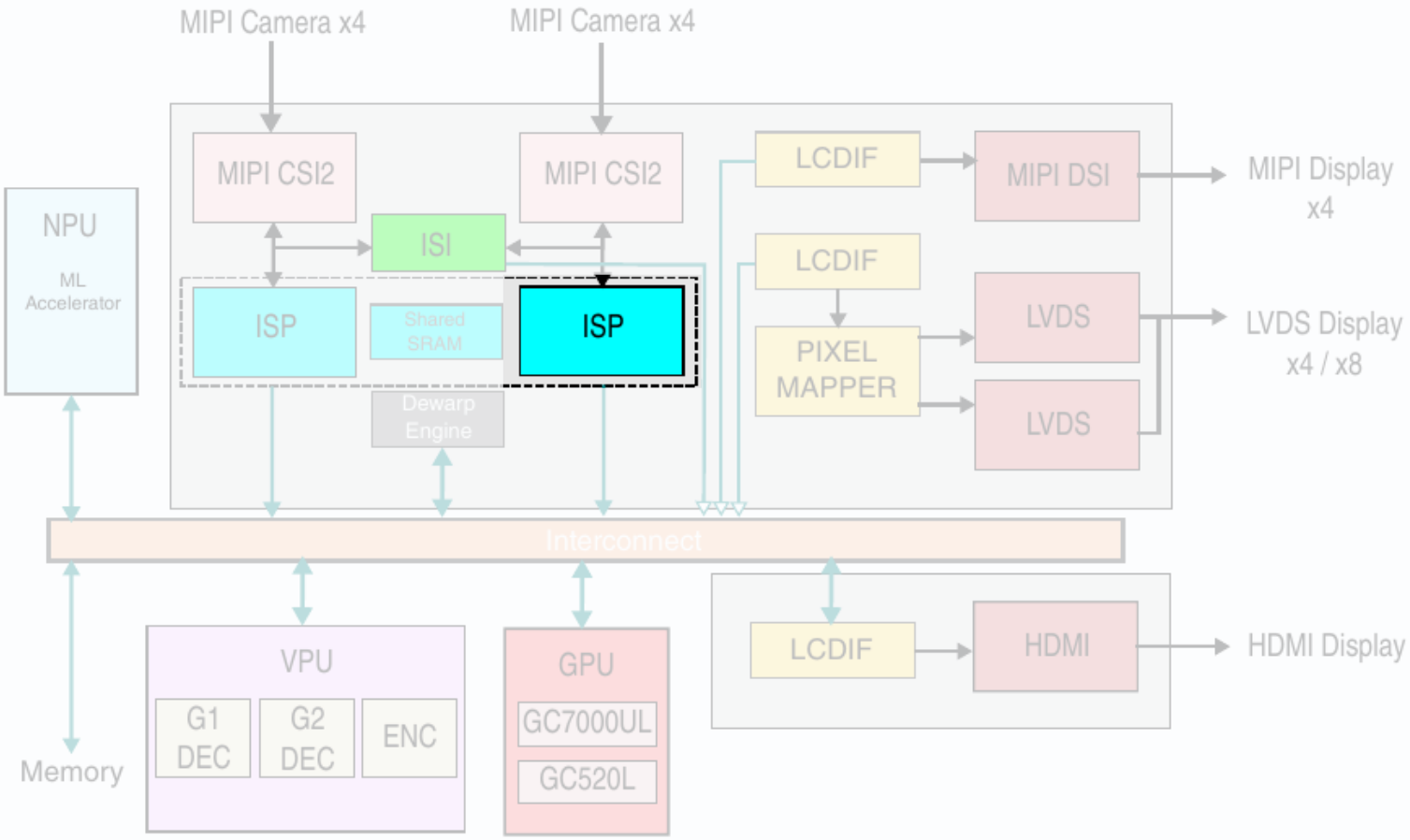
Next Steps – Dewarper



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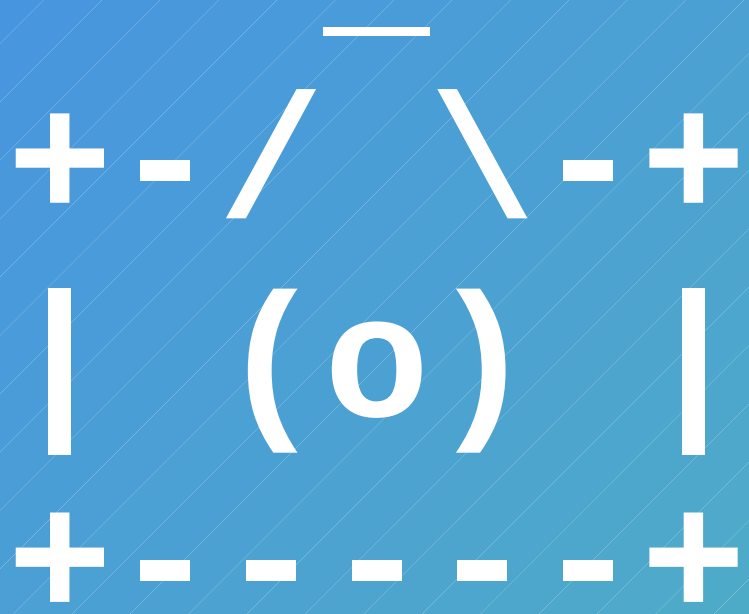
Next Steps – ISP



libcamera

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Contact

Merci.