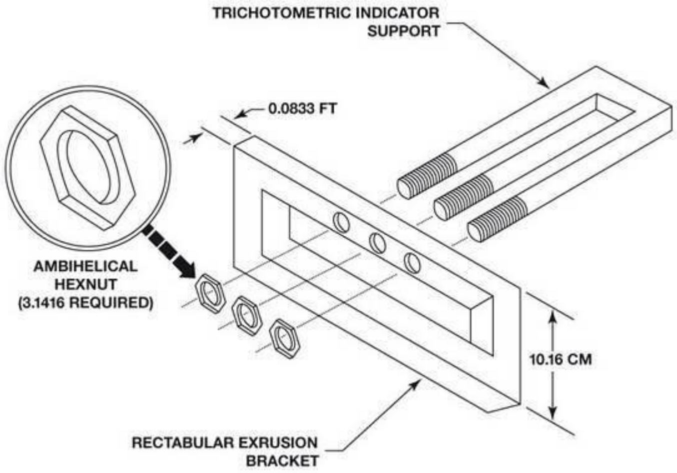
Zero-Copy Video Streaming on Embedded Systems the Easy Way


TRICHOTOMETRIC INDICATOR SUPPORT
0.0833 FT
AMBIHELICAL HEXNUT (3.1416 REQUIRED)
10.16 CM
RECTABULAR EXRUSION BRACKET

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Embedded Linux Conference-Europe
Oct 25, 2017

Examples

- Presentation capture and streaming
- Augmented Reality
- UAV video downlink
- Intercom

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Agenda

- Video and graphics on embedded devices
- Hardware acceleration units and Zero-Copy buffer sharing
- Case study: i.MX6
- The easy way
- Open Issues & Future Work

Building Blocks

- Recording / Streaming
- Receiving / Projection / Compositing
- Lens correction / Warping
- Transcoding

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Embedded System Requirements

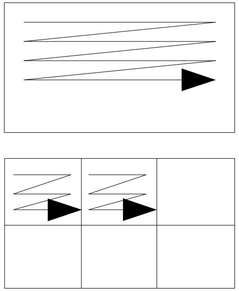
- Portable
- Energy efficient
- Lightweight

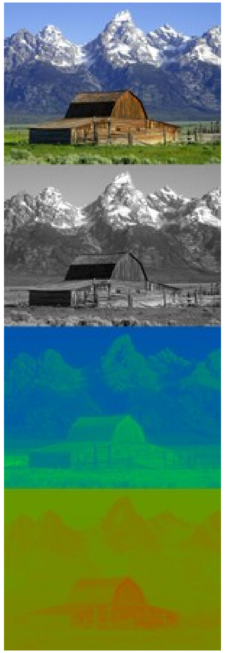
- Soft real-time
- “High” data rates

Limited processing power vs. Audio/Video use case

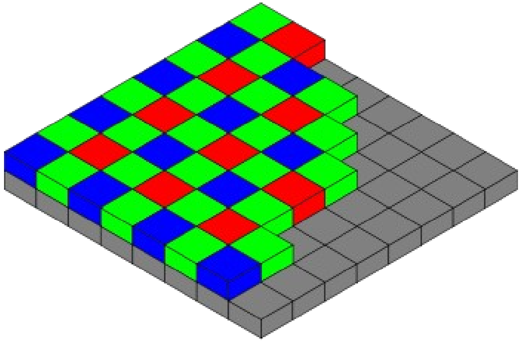
Specialized Co-processors

- Graphics Processing Unit
- Video encoder and decoder
- FPGA
- Camera
- Display Controller
- Network Controller





- Supported or preferred format in memory differ
- Copy and conversion between hardware units required



Zero-Copy

"Zero-copy" describes computer operations in which the CPU does not perform the task of copying data from one memory area to another. (Wikipedia)

- Copying in CPU is expensive
- CPU memory bandwidth smaller than hardware acceleration units
- CPU cache management

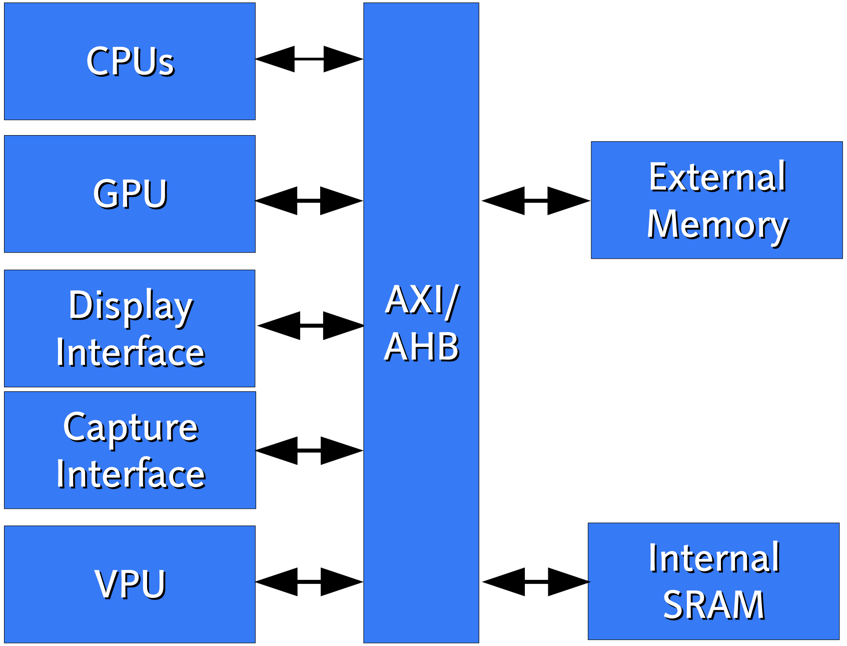
Putting it all Together, Case study: i.MX6

- Memory bandwidth
  - Up to 533 MHz DDR3 SDRAM (1066 MT/s @ 64-bit)
  - Realistically, up to 2.5 GiB/s on i.MX6Q, more on i.MX6QP

- Up to quad-core Cortex A9, 1 GHz
- CPU memcpy ~500 MiB/s
- 1080p30 YUYV: 120 MiB/s
- Cache management overhead

Putting it all Together, Case study: i.MX6

- GPU: Vivante GC2000
- Display: IPUv3 display interface
- Camera: IPUv3 capture interface
- VPU: Chips&Media CODA960



Device Drivers and Interfaces

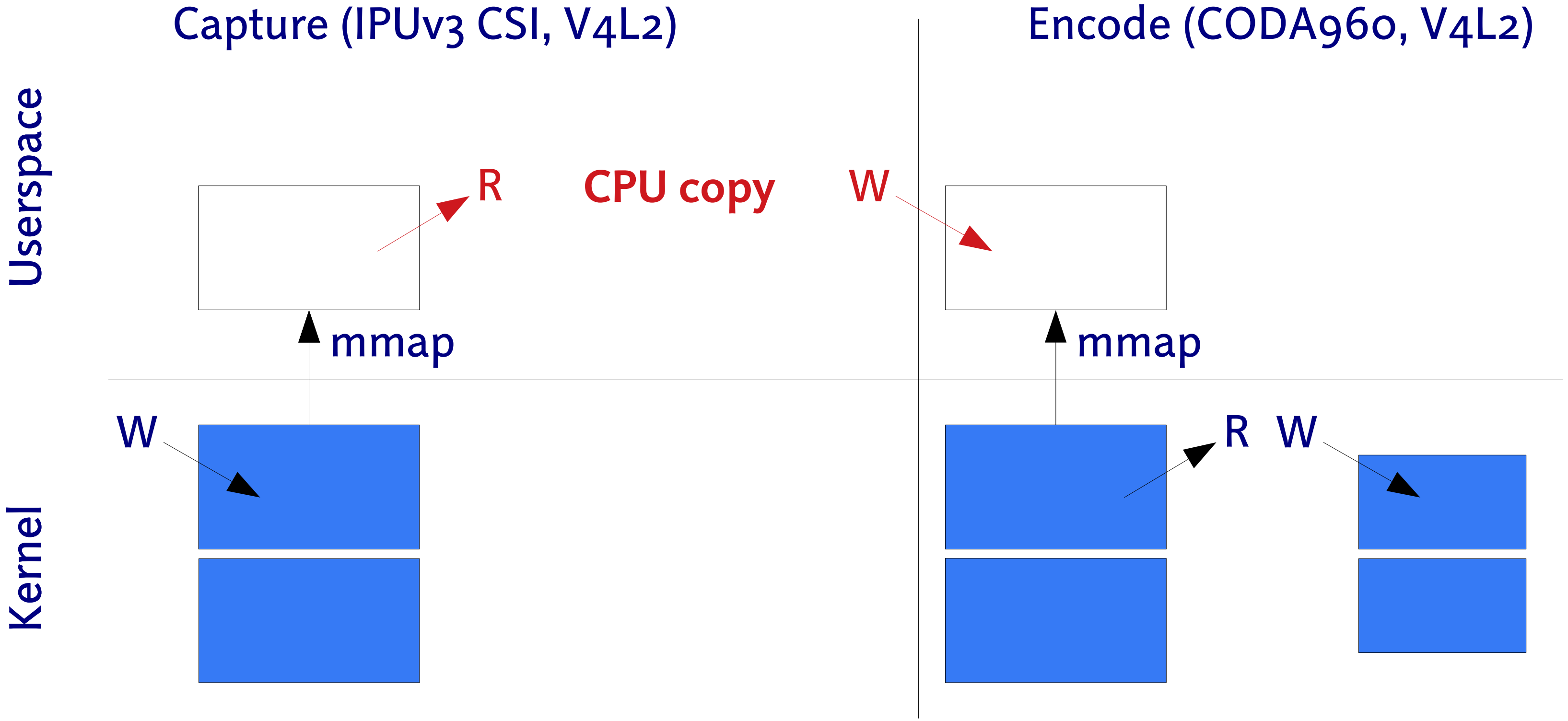
- GPU: Vivante GC2000
- Display: IPUv3 display interface
- Camera: IPUv3 capture interface
- VPU: Chips&Media CODA960

- etnaviv (DRM)
- imx-drm (DRM, KMS)
- imx-media (Video4Linux2), staging
- coda (Video4Linux)

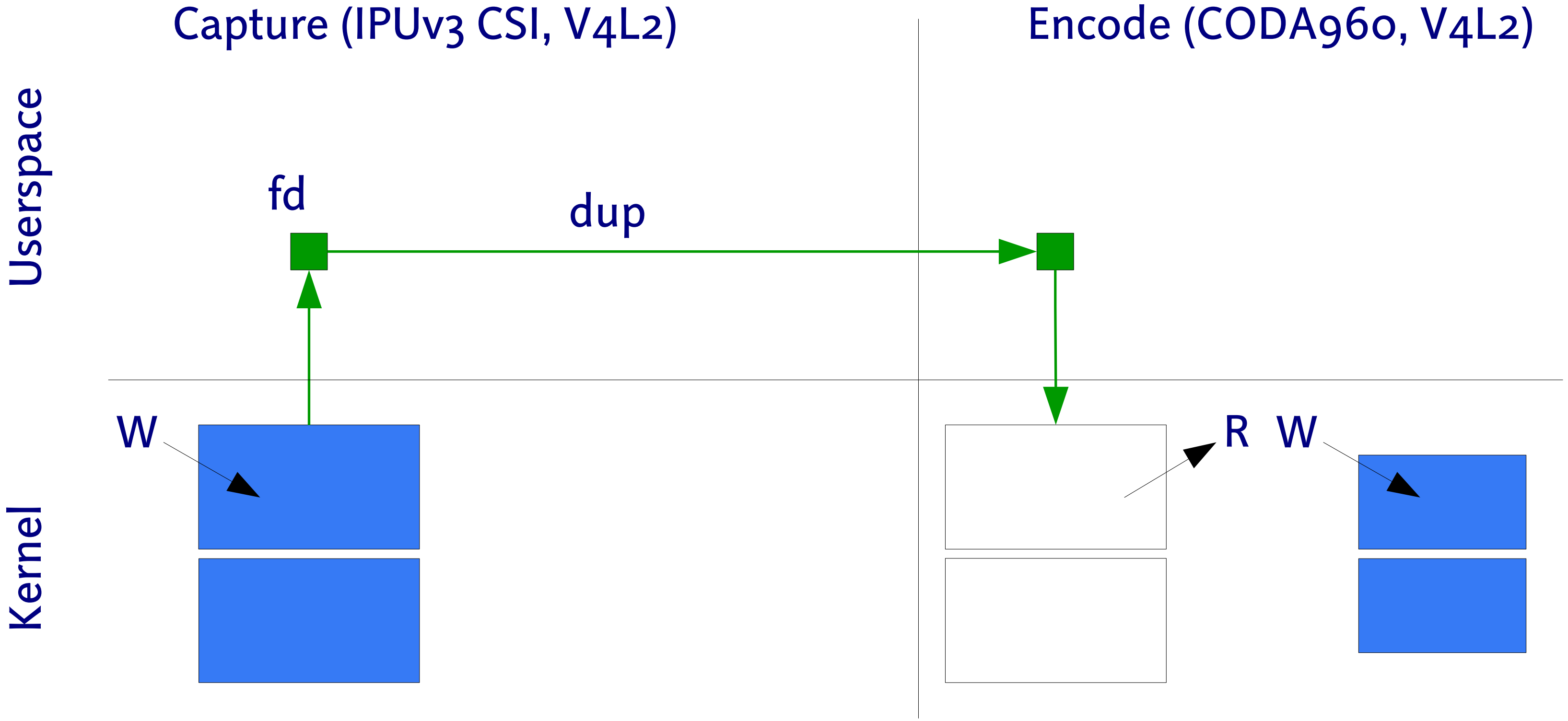
- Userspace: Mesa/etnaviv (OpenGL)

- DMABuf

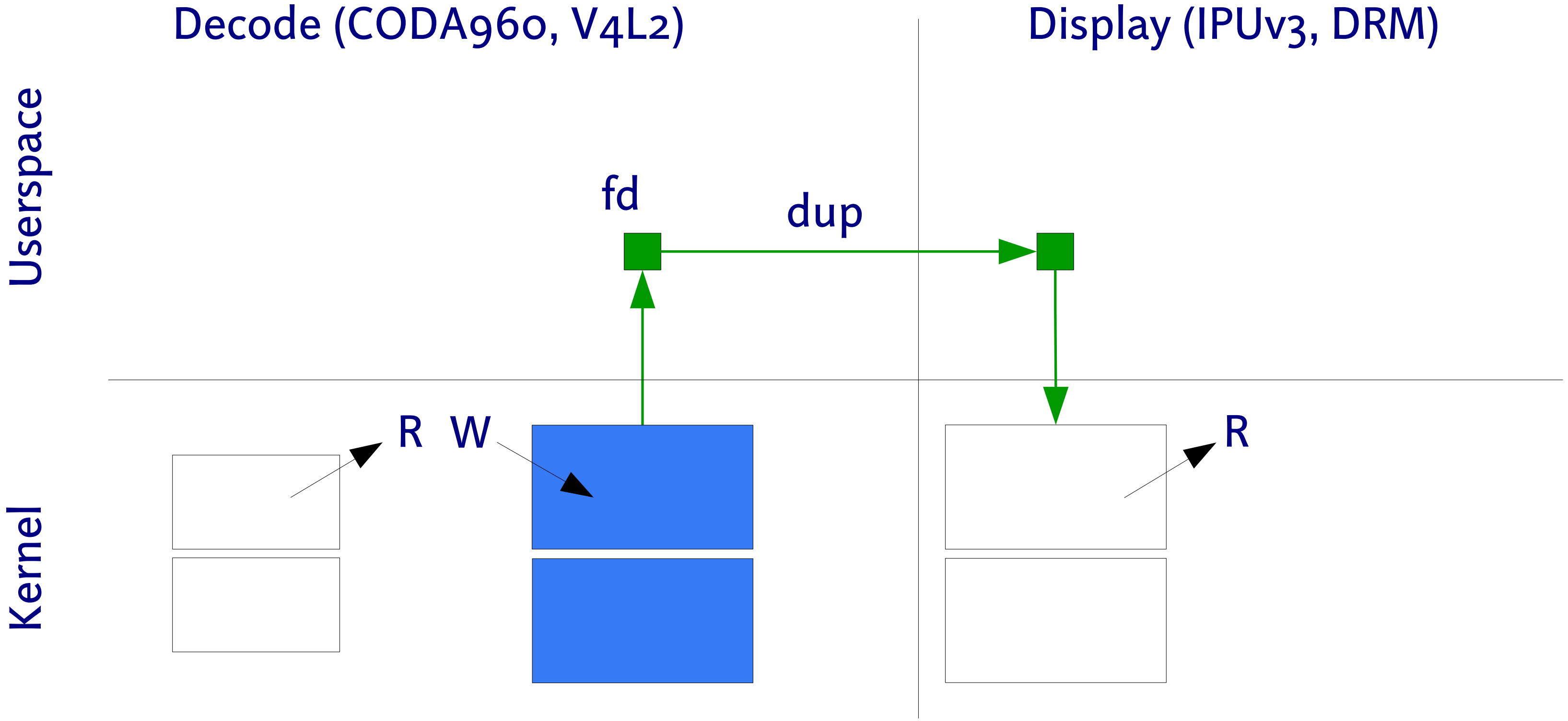
Before DMABuf



DMABuf


Capture (IPUv3 CSI, V4L2)
Encode (CODA960, V4L2)
Userspace
Kernel
fd
dup
W
R
W

DMABuf


Decode (CODA960, V4L2)
Display (IPUv3, DRM)
Userspace
Kernel
fd
dup
R
W
R

Device Drivers and Interfaces (API)

- V4L2 ioctls:

  ```
  VIDIOC_EXPBUF
  VIDIOC_QBUF
  ```

Import/export DMABuf handles from/into video devices

- DRM ioctls:

  ```
  DRM_IOCTL_PRIME_HANDLE_TO_FD
  DRM_IOCTL_PRIME_FD_TO_HANDLE
  ```

Import/export DMABuf handles from/into GPU or display contoller devices, used by libdrm/Mesa

- EGL extensions:

  ```
  EGL_EXT_image_dma_buf_import
  EGL_EXT_image_dma_buf_import_modifiers
  EGL_MESA_image_dma_buf_export
  ```

These sit on top of DRM_IOCTL_PRIME_*

Device Drivers and Interfaces: V4L2

```
/* V4L2 DMABuf export */

int video_fd = open("/dev/v4l/by-name/csi",
                    O_RDWR);

struct v4l2_requestbuffers reqbuf = {
    .count = 1,
    .type = V4L2_BUF_TYPE_VIDEO_CAPTURE,
    .memory = V4L2_MEMORY_MMAP,
};
ioctl(video_fd, VIDIOC_REQBUFS, &reqbuf);

struct v4l2_exportbuffer expbuf = {
    .type = V4L2_BUF_TYPE_VIDEO_CAPTURE,
    .index = 0,
};
ioctl(video_fd, VIDIOC_EXPBUF, &expbuf);

int dmabuf_fd = expbuf.fd;
```

```
/* V4L2 DMABuf import */

int dmabuf_fd;
int video_fd = open("/dev/v4l/by-name/coda",
                    O_RDWR);

struct v4l2_requestbuffers reqbuf = {
    .count = 1,
    .type = V4L2_BUF_TYPE_VIDEO_OUTPUT,
    .memory = V4L2_MEMORY_DMABUF,
};
ioctl(video_fd, VIDIOC_REQBUFS, &reqbuf);

struct v4l2_buffer buf = {
    .type = V4L2_BUF_TYPE_VIDEO_OUTPUT,
    .memory = V4L2_MEMORY_DMABUF,
    .index = 0,
    .m.fd = dmabuf_fd,
};
ioctl(video_fd, VIDIOC_QBUF, &buf);
```

https://linuxtv.org/downloads/v4l-dvb-apis-new/uapi/v4l/vidioc-expbuf.html
https://linuxtv.org/downloads/v4l-dvb-apis-new/uapi/v4l/dmabuf.html

Device Drivers and Interfaces: EGL/OpenGL ES

```
EGLint attrib_list[] = {
    EGL_WIDTH, 1920,
    EGL_HEIGHT, 1280,
    EGL_LINUX_DRM_FOURCC_EXT,
        DRM_FORMAT_YUYV,
    EGL_DMA_BUF_PLANE0_FD_EXT, dmabuf_fd,
    EGL_DMA_BUF_PLANE0_FD_OFFSET_EXT, 0,
    EGL_DMA_BUF_PLANE0_FD_PITCH_EXT, 3840,
    EGL_NONE,
};
EGLImageKHR egl_image = eglCreateImageKHR(
            egl_display,
            EGL_NO_CONTEXT,
            EGL_LINUX_DMA_BUF_EXT,
            NULL,
            attrib_list);

glEGLImageTargetTexture2DOES(
            GL_TEXTURE_EXTERNAL_OES,
            egl_image);
```

```
int dmabuf_fd;
int stride;

eglExportDMABUFImageMESA(
            egl_display,
            egl_image,
            &dmabuf_fd,
            &stride);
```

https://www.khronos.org/registry/EGL/extensions/EXT/EGL_EXT_image_dma_buf_import.txt
https://www.khronos.org/registry/EGL/extensions/MESA/EGL_MESA_image_dma_buf_export.txt

The Easy Way

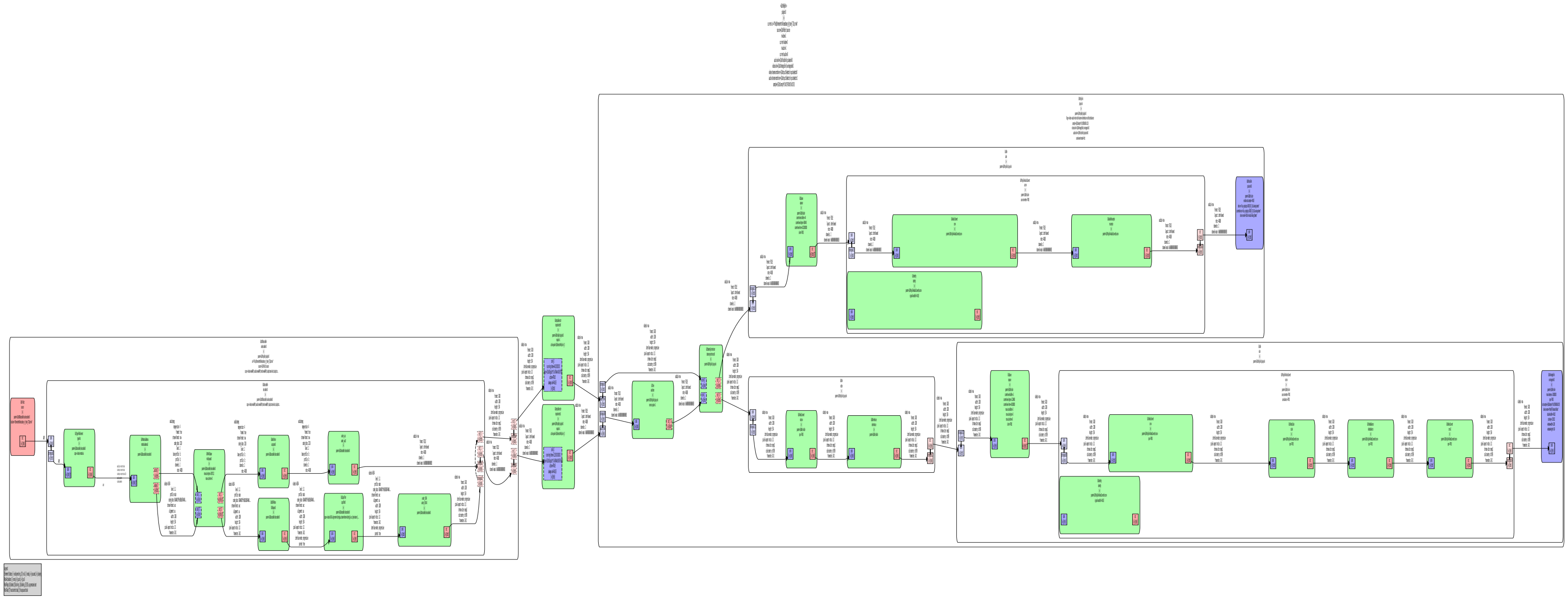
GStreamer

“GStreamer is a library for constructing graphs of media-handling components. The applications it supports range from simple Ogg/Vorbis playback, audio/video streaming to complex audio (mixing) and video (non-linear editing) processing.

Applications can take advantage of advances in codec and filter technology transparently. Developers can add new codecs and filters by writing a simple plugin with a clean, generic interface.”

GStreamer

```
gst-launch-1.0 playbin uri=file:///home/mtr/Videos/tears_of_steel_720p.mkv
```



GStreamer

- Sink support
  - Wayland
  - WebRTC
  - QML
  - ...
- Plugins
  - V4L2
  - OpenGL
  - Third party
  - ...
- Language bindings
  - C++
  - Python
  - Rust
  - ...
- Autoplugging
  - decodebin
  - encodebin
  - playsink
  - ...

Video4Linux2

- Elements: v4l2sink, v4l2videodec, v4l2videoenc, ...
- Support DMABuf import and export
- Recent feature: stable element names

- Nicolas Dufresne - Implementing Zero-Copy pipelines in GStreamer
- GStreamer Conference 2017
- https://gstconf.ubicast.tv/videos/zero-copy-pipelines-in-gstreamer/

Direct Rendering Manager / Kernel Mode Setting

- Kernel subsystem for video cards
- API and user space library

- Element: kmssink
- Import DMABuf automatically
- Output via video card
- Depends on features of kms driver (e.g., no scaling on i.MX6)

Simple tool for testing

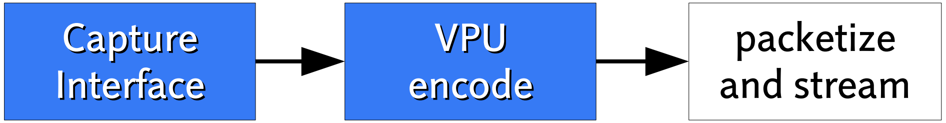
Wayland

- Display server protocol
- DMABuf: linux_dmabuf_unstable_v1
- Compositor decides
  - OpenGL upload for compositing
  - Display as overlay

- Element: waylandsink
- Your mileage may vary
- Depends on compositor
- Imported format might not be supported

GStreamer on i.MX6: Sender

- Camera: v4l2src
- CODA encode: v4l2h264enc



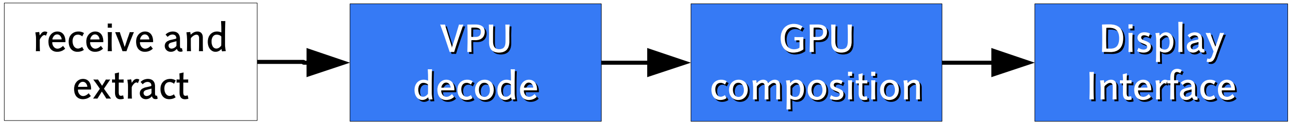
```
gst-launch-1.0 v4l2src io-mode=dmabuf[1] device=/dev/v4l/by-name/csi ! \
               v4l2h264enc output-io-mode=dmabuf-import[2] ! \
               rtph264pay ! \
               udpsink
```

[1] Still necessary in GStreamer 1.12, automatic in master

[2] Still necessary, will be auto-negotiated in the future

GStreamer on i.MX6: Receiver

- CODA decode: v4l2h264dec
- GPU, display: waylandsink



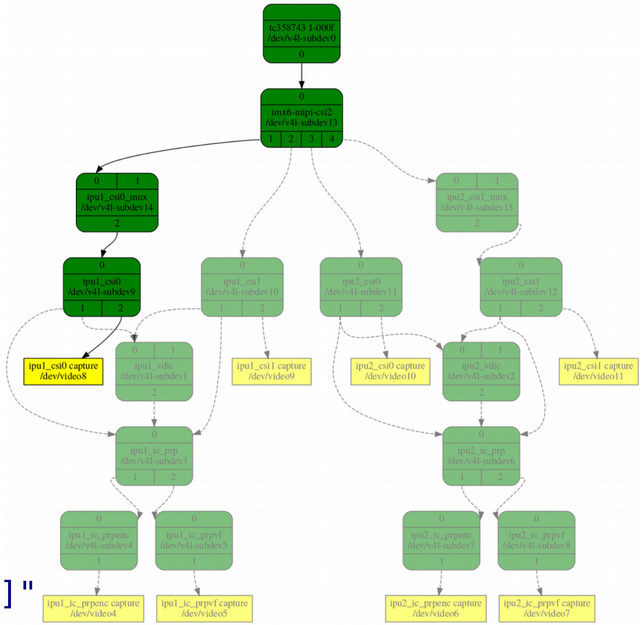
```
gst-launch-1.0 udpsrc ! application/x-rtp,payload=96 ! \
               rtph264depay ! \
               h264parse ! \
               v4l2h264dec[1] io-mode=dmabuf[2] ! \
               waylandsink
```

[1] Stable element names in master, for 1.12: **v4l2videodec** device=/dev/videoX

[2] Still necessary in GStreamer 1.12, automatic in master

Camera Input Pipeline

- Media input pipeline
- Currently needs manual configuration: media-ctl
- Pavel Machek: Cheap Complex Cameras (http://sched.co/ByYH)



```
media-ctl --links "'tc358743 1-000f':0->'imx6-mipi-csi2':0[1]"
media-ctl --links "'imx6-mipi-csi2':1->'ipu1_csi0_mux':0[1]"
media-ctl --links "'ipu1_csi0_mux':2->'ipu1_csi0':0[1]"
media-ctl --links "'ipu1_csi0':2->'ipu1_csi0 capture':0[1]"

media-ctl --set-dv "'tc358743 1-000f':0"

media-ctl --set-v4l2 "'tc358743 1-000f':0[fmt:UYVY8_1X16/1920x1080]"
media-ctl --set-v4l2 "'imx6-mipi-csi2':1[fmt:UYVY8_1X16/1920x1080]"
media-ctl --set-v4l2 "'ipu1_csi0_mux':2[fmt:UYVY8_1X16/1920x1080]"
media-ctl --set-v4l2 "'ipu1_csi0':0[fmt:UYVY8_1X16/1920x1080@1/60]"
media-ctl --set-v4l2 "'ipu1_csi0':2[fmt:AYUV32/1920x1080@1/30]"
```

Future Work

- Useful default media-controller configuration
- Mesa/etnaviv
  - NV12 and YUYV texture import (GL_TEXTURE_2D)
  - Direct sampling from linear buffers
  - OpenCL support
- Weston: Atomic modesetting patchset for overlay plane support

Open Questions

- Camera pipeline configuration → Autoconfiguration? Device-tree default?
- Remaining proprietay blob: CODA VPU firmware
- V4l2 access as root → Pipewire?

Conclusion

- Modern embedded system use various coprocessors
- DMABuf is usable abstraction for zero-copy on Linux
- Let GStreamer manage all the ugly details

- Know your hardware
- Be aware of corner cases
- Check resulting GStreamer pipeline
- Zero-copy between driver blobs problematic or impossible → Avoid blobs!

Thank You!

- Questions?