Hardware accelerated video streaming with V4L2

on i.MX6Q

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SESSION OVERVIEW

1. Introduction
2. Simple V4L2 application
3. V4L2 application using OpenGL
4. V4L2 application using OpenGL and vendor specific features
5. Conclusion

ABOUT THE PRESENTER

- Embedded Software Engineer at **Adeneo Embedded** (Bellevue, WA)
  - Linux / Android
    - BSP Adaptation
    - Driver Development
    - System Integration
  - Former U-Boot maintainer of the Mini2440

Introduction

WHAT'S V4L2?

- Video For Linux version 2
- Common framework
- API to access video devices (/dev/videoX)
- Not only video: audio, controls (brightness/contrast/hue), output, ...

SET YOUR GOALS

- Resolution: HD, full HD, VGA, ...
- Frame rate to achieve: does it matter?
- Image processing: rotation, scaling, post processing effects, ...
- Hardware availability:
  - CPU performances
  - GPU
  - Image Processing IP (IPU, DISPC, ...)

WHY ARE WE HERE?

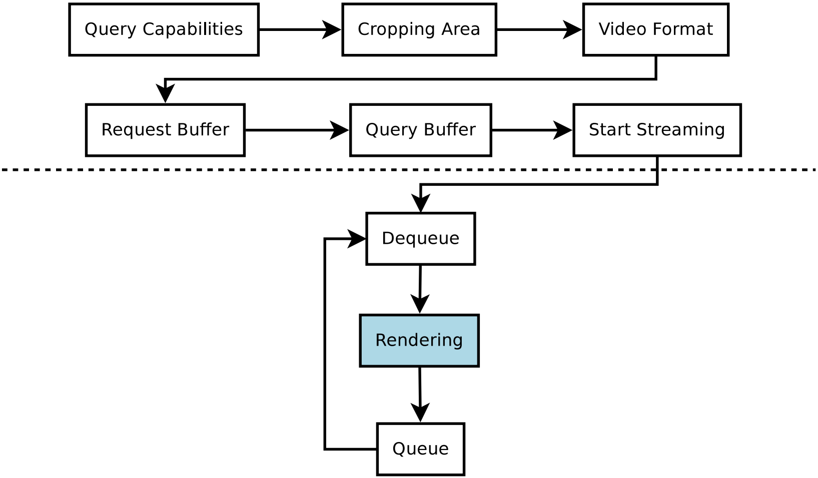
- V4L2 application development
- Optimization process and trade-offs
- Showing real customer solutions

HARDWARE SELECTION

- Freescale i.MX6Q SabreLite
- Popular platform
- Geared towards multimedia

Simple V4L2 application

ARCHITECTURE



MEMORY MANAGEMENT

Different ways to handle video capture buffers:

- V4L2_MMAP: memory mapping => allocated by the kernel
- V4L2_USERPTR: user memory => allocated the user application
- Others: DMABUF, read/write

Only MMAP will be covered in this presentation.

Warning

Drivers don't necessarily support every method

ARCHITECTURE

Query capabilities:

```
ioctl(fd, VIDIOC_QUERYCAP, &cap);

if (!(cap.capabilities & V4L2_CAP_VIDEO_CAPTURE))
        exit(EXIT_FAILURE);

if (!(cap.capabilities & V4L2_CAP_STREAMING))
        exit(EXIT_FAILURE);
```

Warning

Every V4L2 driver does not necessarily support both Streaming and Video Capture

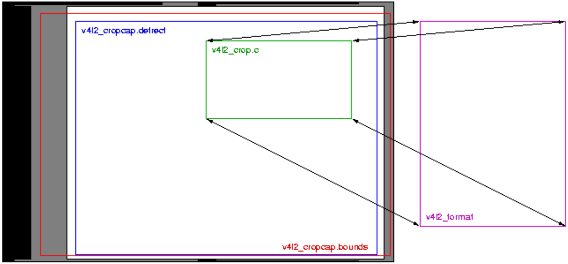
ARCHITECTURE

Reset cropping area:

```
ioctl(fd, VIDIOC_CROPCAP, &cropcap);

crop.type = V4L2_BUF_TYPE_VIDEO_CAPTURE;
crop.c = cropcap.defrect;
ioctl(fd, VIDIOC_S_CROP, &crop);
```

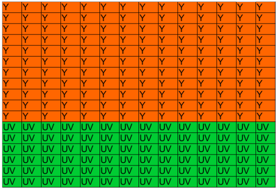
The area to capture/view needs to be defined



ARCHITECTURE

Set video format:

```c
fmt.fmt.pix.width = WIDTH;
fmt.fmt.pix.height = HEIGHT;
fmt.fmt.pix.pixelformat = V4L2_PIX_FMT_NV12;
fmt.fmt.pix.field = V4L2_FIELD_ANY;
ioctl(fd, VIDIOC_S_FMT, &fmt);
```



Warning

VIDIOC_ENUM_FRAMESIZES should be used to enumerate supported resolution

ARCHITECTURE

Request buffers:

```
req.count = 4;
req.type = V4L2_BUF_TYPE_VIDEO_CAPTURE;
req.memory = V4L2_MEMORY_MMAP;
ioctl(v4l2_fd, VIDIOC_REQBUFS, &req);
```

4 capture buffers need to be allocated to store video frame from the camera

ARCHITECTURE

Query buffers:

```
for (n_buffers = 0; n_buffers < req.count; n_buffers++) {
        buf.type = V4L2_BUF_TYPE_VIDEO_CAPTURE;
        buf.memory = V4L2_MEMORY_MMAP;
        buf.index = n_buffers;

        ioctl(v4l2_fd, VIDIOC_QUERYBUF, &buf);
        buffers[n_buffers].length = buf.length;
        buffers[n_buffers].start = mmap(NULL, buf.length,
                      PROT_READ | PROT_WRITE, MAP_SHARED,
                      v4l2_fd, buf.m.offset);
}
```

- Memory information such as size/adresses need to be retrieved and stored in the User Application
- Need to keep a mapping between V4L2 index buffers and memory information

ARCHITECTURE

Start capturing frames:

```
for (i = 0; i < n_buffers; ++i) {
        buf.type = V4L2_BUF_TYPE_VIDEO_CAPTURE;
        buf.memory = V4L2_MEMORY_MMAP;
        buf.index = i;

        ioctl(v4l2_fd, VIDIOC_QBUF, &buf);
}

type = V4L2_BUF_TYPE_VIDEO_CAPTURE;
ioctl(v4l2_fd, VIDIOC_STREAMON, &type);
```

Capture buffers need to be queued to be filled by the V4L2 framework

ARCHITECTURE

Rendering loop:

```
/* Dequeue */
ioctl(v4l2_fd, VIDIOC_DQBUF, &buf);

/* Conversion from NV12 to RGB */
frame = convert_nv12_to_rgb(buffers[buf.index].start);
display(frame);

/* Queue buffer for next frame */
ioctl(v4l2_fd, VIDIOC_QBUF, &buf);
```

Framebuffer pixel format is RGB

DEMONSTRATION

CONCLUSION

Advantages:

- Easy to implement

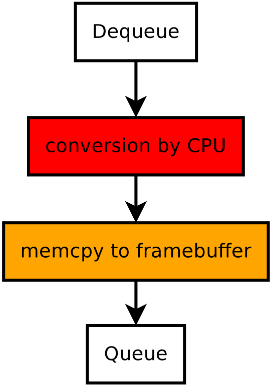
Drawbacks:

- Poor performances
- Cannot do any 'real time' geometric transformation (rotation/scaling)

V4L2 application using OpenGL

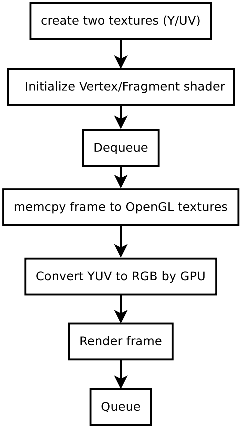
ARCHITECTURE

What we had:



ARCHITECTURE

What we are going to do:



- Using GPU with OpenGL
- Do the conversion on the GPU via shader

SHADERS

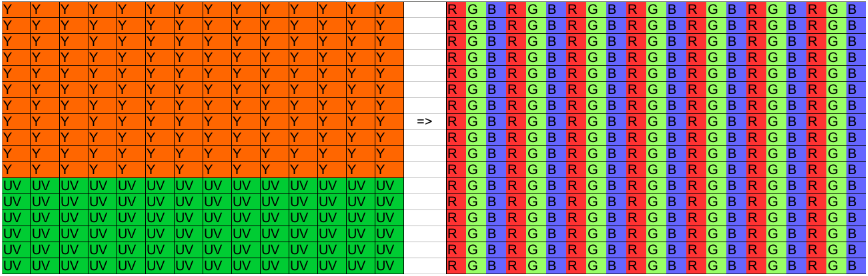
- GPU process unit
- Different types: Vertex, Fragment, Geometry
- Piece of code executed by the GPU
- Vertex shader: draw shapes (quad, triangles, ...)
- Fragment shader: transform every pixel (YUV conversion for example) => has access to OpenGL textures

TEXTURES

Generate two textures for planar Y and UV:

```
glGenTextures (2, textures);
```

- A Texture is an image container for the GPU
- No 'standard' support in OpenGL for YUV texture



RENDERING LOOP

```
/* Dequeue */

glActiveTexture(GL_TEXTURE0);
/* Y planar */
glBindTexture(GL_TEXTURE_2D, textures[0]);
glTexImage2D(GL_TEXTURE_2D, 0, GL_LUMINANCE, width, height, 0,
    GL_LUMINANCE, GL_UNSIGNED_BYTE, in);

/* Queue */
```

- Map the first texture (Y planar) to an OpenGL internal format => GL_LUMINANCE
- GL_LUMINANCE has a size of 8 bits, exactly as the Y planar!

RENDERING LOOP

```
/* Dequeue */

glActiveTexture(GL_TEXTURE1);
/* UV planar */
in += (width*height);
glBindTexture(GL_TEXTURE_2D, textures[1]);
glTexImage2D(GL_TEXTURE_2D, 0, GL_LUMINANCE_ALPHA, width/2,
    height/2, 0, GL_LUMINANCE_ALPHA, GL_UNSIGNED_BYTE, in);

/* Queue */
```

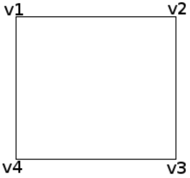
- Map the second texture (UV planar) to an OpenGL internal format => GL_LUMINANCE_ALPHA
- GL_LUMINANCE_ALPHA has a size of 16 bits, exactly as the UV planar!
- Shaders have everything now!

SHADERS

Example of vertex shader:

```
void main(void) {
        opos = texpos;
        gl_Position = vec4(position, 1.0);
}
```

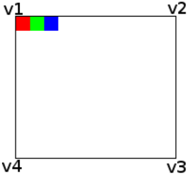
- *opos* is the texture position => pass to the Fragment Shader for color conversion.
- gl_Position is the vertex position.



ARCHITECTURE

Example of fragment shader:

```
void main(void) {
        yuv.x=texture2D(Ytex, opos).r;
        yuv.yz=texture2D(UVtex, opos).ra;
        yuv += offset;
        r = dot(yuv, rcoeff);
        g = dot(yuv, gcoeff);
        b = dot(yuv, bcoeff);
        gl_FragColor=vec4(r,g,b,1);
}
```



- texture2D(Ytex, opos).r => GL_LUMINANCE texture
- texture2D(Ytex, opos).ra => GL_LUMINANCE_ALPHA texture
- Do the conversion using the GPU

ARCHITECTURE

To summarize:

- Copy V4L2 buffer to OpenGL textures
- Vertex Shader: draw a quad => the viewport
- Fragment Shader: convert and fill the quad/triangles => the video
- Display the frame

DEMONSTRATION

CONCLUSION

Advantages:

- Decent performances
- Can handle geometric transformation (rotation/scaling)
- Relax the CPU load
- Generic solution (if your board has a GPU ...)

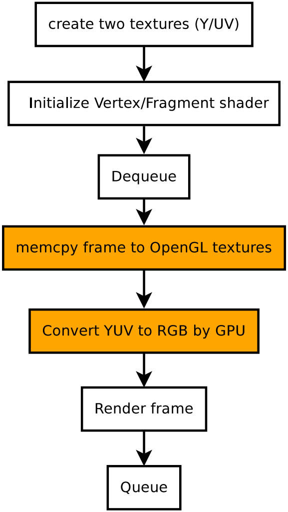
Drawbacks:

- Need some OpenGL skills

V4L2 application using OpenGL and vendor specific features

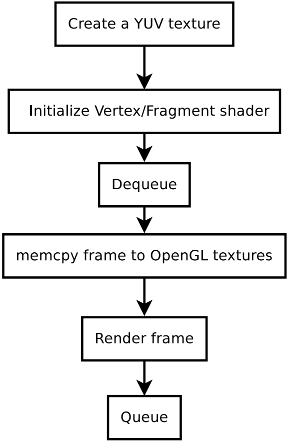
ARCHITECTURE

What we had:



ARCHITECTURE

What we are going to do:



- Handle YUV OpenGL Texture directly => no need the conversion by shader anymore!

RENDERING LOOP

```
/* Get a GPU pointer */
glTexDirectVIV (GL_TEXTURE_2D, WIDTH, HEIGHT, GL_VIV_NV12, &
     pTexel);

/* Dequeue */
...

glBindTexture(GL_TEXTURE_2D, textures[0]);
memcpy(pTexel, buffers[buf.index].start, width * height * 3/2);
glTexDirectInvalidateVIV(GL_TEXTURE_2D);

/* Queue */
...
```

- pTexel is a pointer directly to a GPU memory
- Conversion is done by the GPU before processing shaders
- Handle different YUV formats

SHADERS UPDATE

Vertex shader:

```
void main(void) {
        opos = texpos;
        gl_Position = vec4(position, 1.0);
}
```

Fragment shader:

```
void main(void) {
        yuv=texture2D(YUVtex, opos);
        gl_FragColor=vec4(yuv,1);
}
```

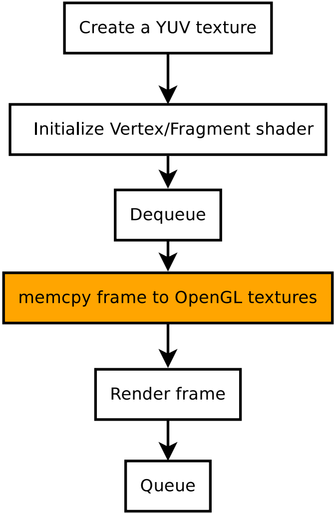
ARCHITECTURE

To summarize:

- Copy V4L2 buffer to OpenGL textures
- Vertex Shader: draw a quad => the viewport
- Fragment Shader: fill the quad => the video
- Display the frame

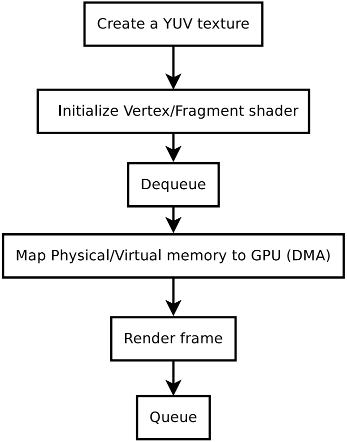
ARCHITECTURE

What we had:



ARCHITECTURE

What we are going to do:



- Remove memcpy by using DMA

RENDERING LOOP

```
/* Dequeue */
...

glBindTexture (GL_TEXTURE_2D, textures[0]);
/* Physical and Virtual addresses */
glTexDirectVIVMap(GL_TEXTURE_2D, width, height, GL_VIV_NV12, &
    buffers[buf.index].start, &(buffers[buf.index].offset));
glTexDirectInvalidateVIV(GL_TEXTURE_2D);

/* Queue */
...
```

- No more memcpy()
- GPU knows the physical address in RAM

ARCHITECTURE

To summarize:

- Copy V4L2 buffer to OpenGL textures by using the DMA
- Vertex Shader: draw a quad => the viewport
- Fragment Shader: fill the quad => the video
- Display the frame

DEMONSTRATION

CONCLUSION

Advantages:

- No more memory copy (memcpy)
- Good performances: can handle fullHD (1080p) at 60FPS
- Handle geometric transformation (rotation/scaling)
- Application is less complex => no conversion code needed anymore

Drawbacks:

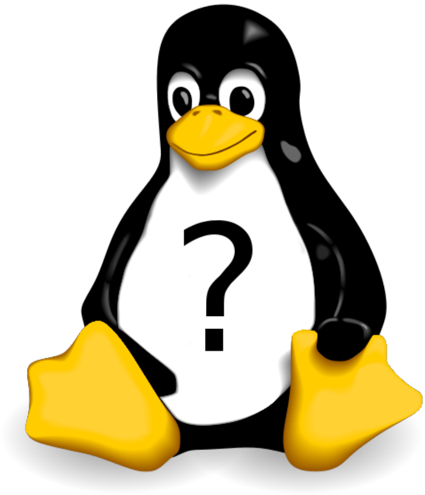
- Need some OpenGL skills and GPU API

Conclusion

CONCLUSION

- Highly hardware dependent
- Other hardware solutions: IPU (Image Processing Unit), DISPC (Display Controller), ...
- GStreamer support and features

QUESTIONS?



REFERENCES

- Fourcc: http://www.fourcc.org/
- Kernel Documentation: https://www.kernel.org/ v4l2-framework.txt
- Freescale GPU VDK
- GStreamer for i.MX: https://github.com/Freescale/gstreamer-imx.git