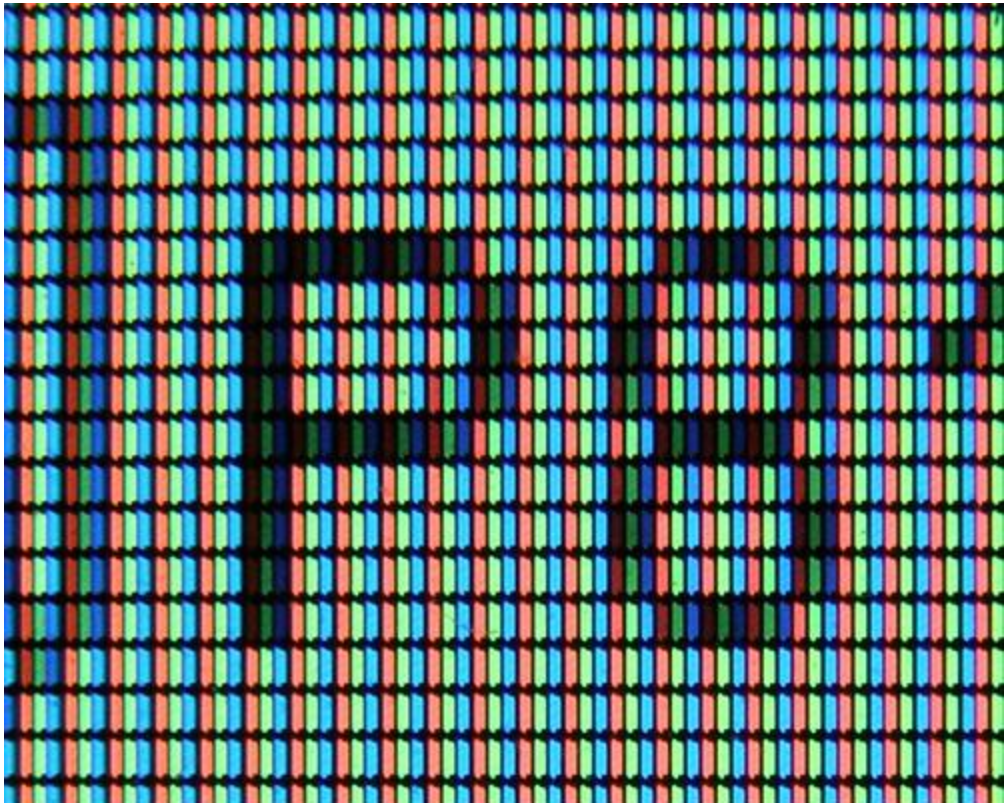
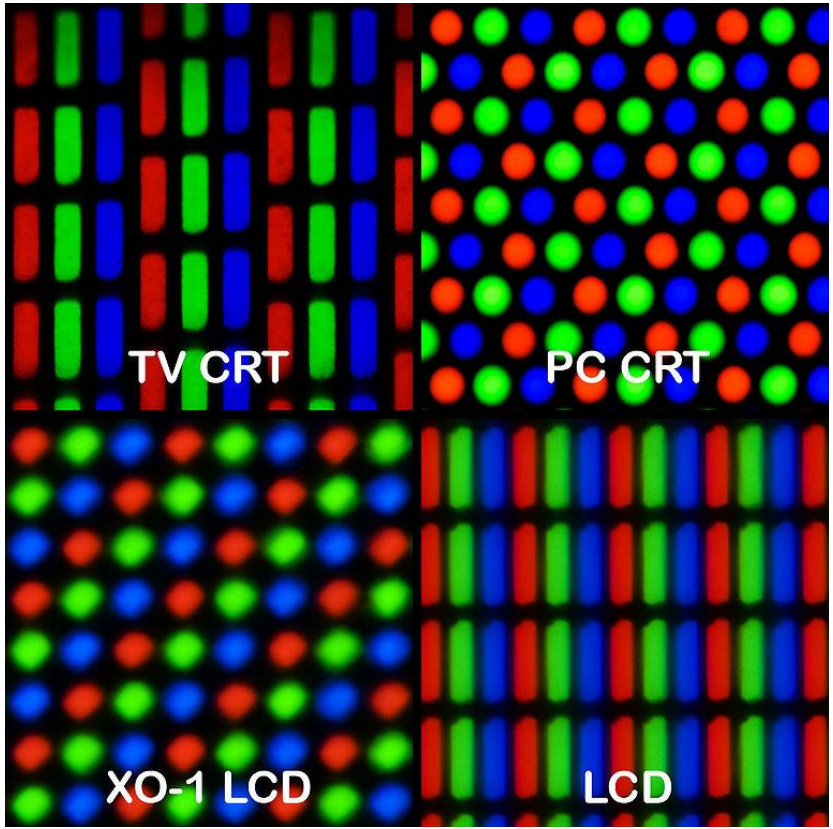
Computer Graphics labs

Lab 4 - Textures



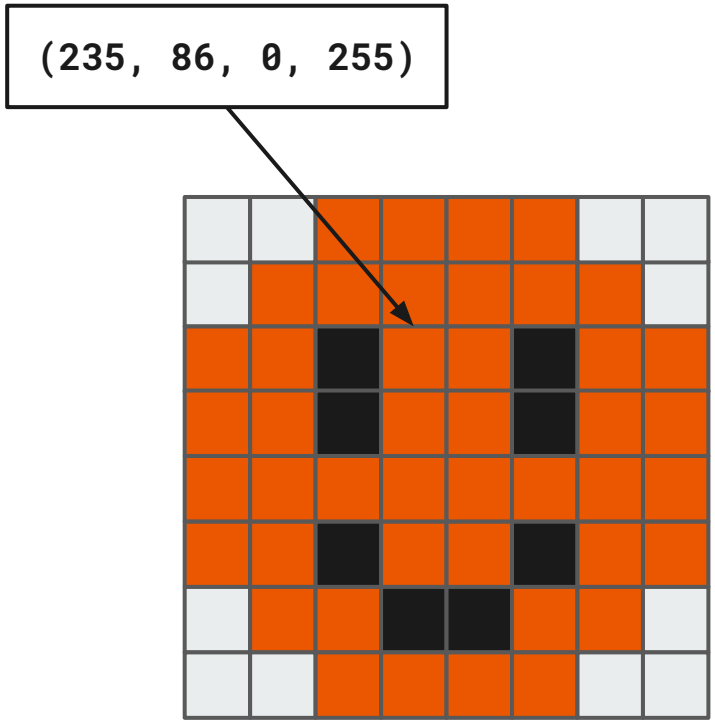

TV CRT
PC CRT
XO-1 LCD
LCD

Textures

It a 1D, 2D or 3D array of Pixels.

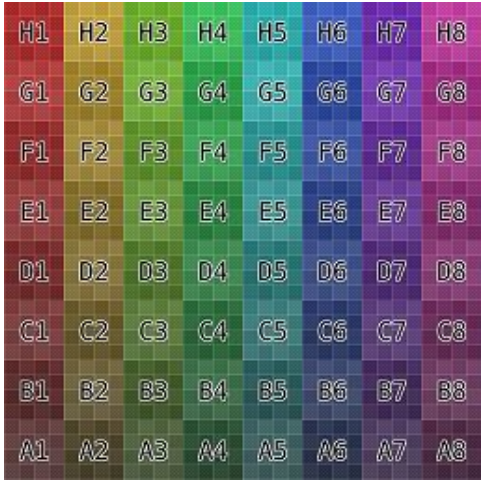
Each pixel holds a vector.

Usually the vector represents a color but not always (it is up to you to interpret it).

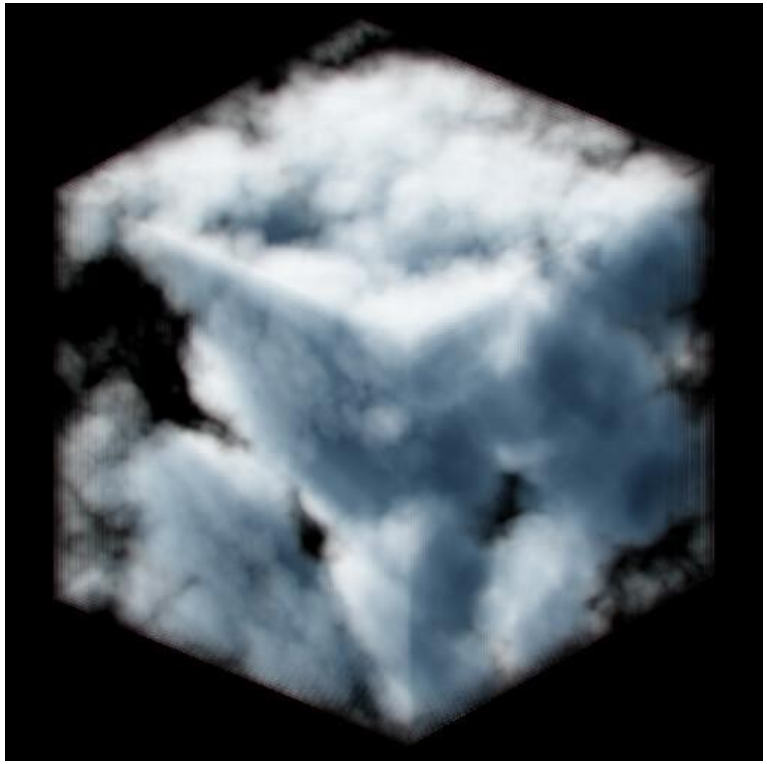


TYPES OF TEXTURES

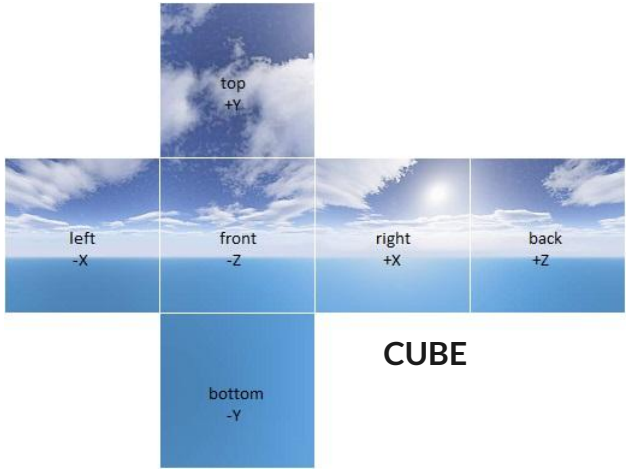
1D



2D



3D

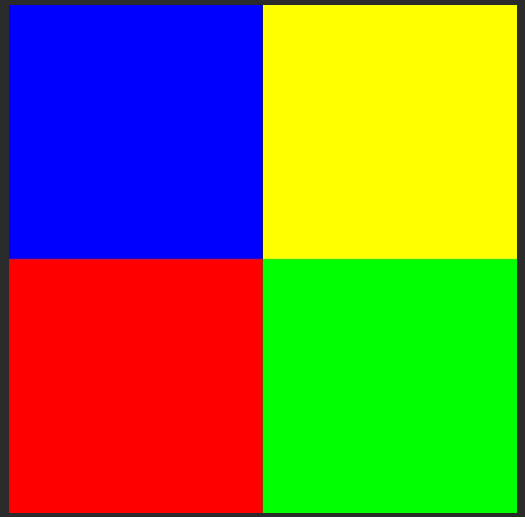


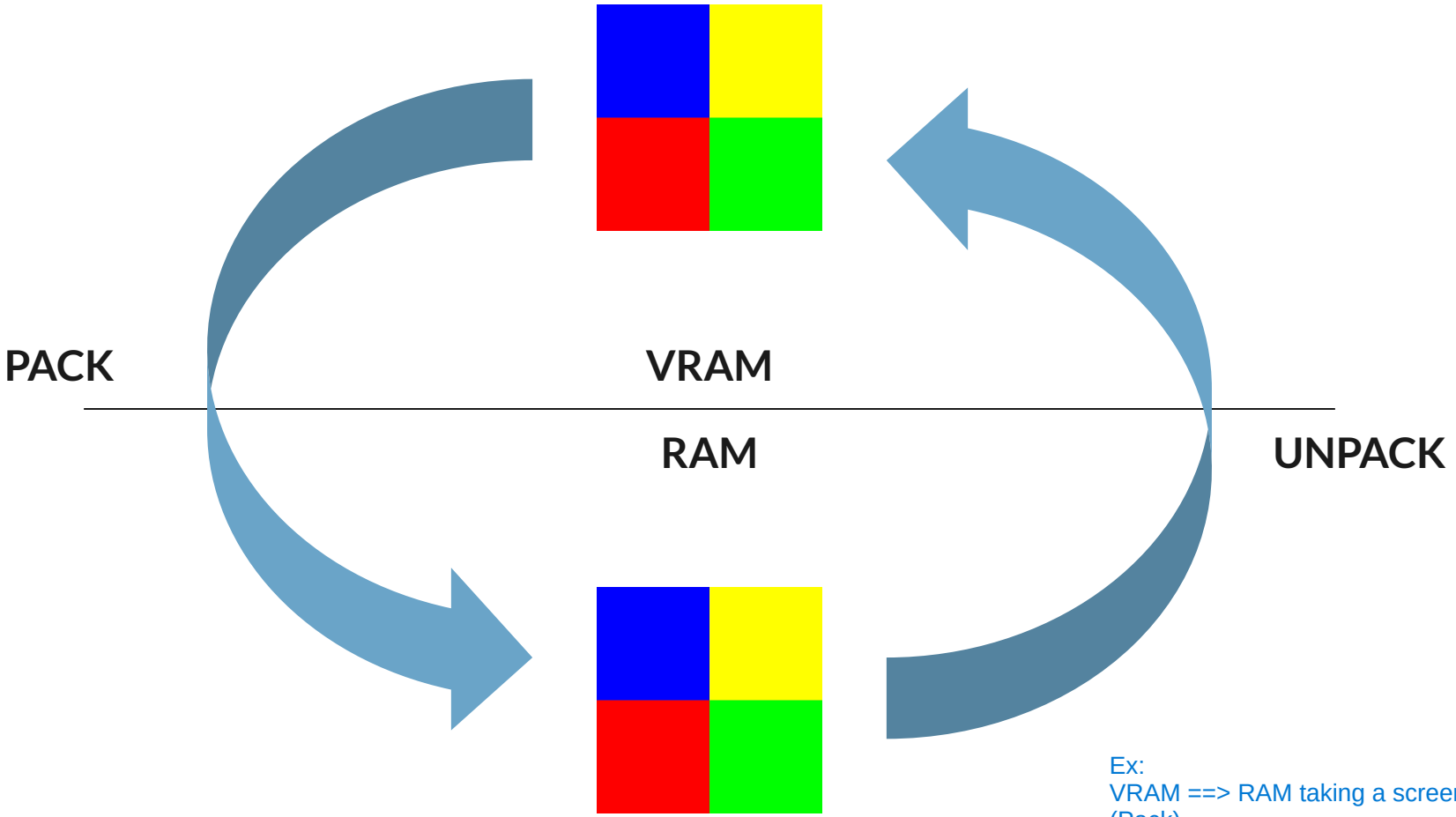
CUBE

ARRAY

AND OTHERS

```
uint8_t pixel_data[] = {
       255,   0,   0, 255,
         0, 255,   0, 255,
         0,   0, 255, 255,
       255, 255,   0, 255,
};

glGenTextures(1, &texture);
glBindTexture(GL_TEXTURE_2D, texture);

glPixelStorei(GL_UNPACK_ALIGNMENT, 4);

glTexImage2D(GL_TEXTURE_2D, 0, GL_RGBA8, 2, 2, 0, GL_RGBA,
GL_UNSIGNED_BYTE, pixel_data);

glGenerateMipmap(GL_TEXTURE_2D);
```





Ex:
VRAM ==> RAM taking a screen hot (Pack)

for pixeli_data

```
glPixelStorei(GL_UNPACK_ALIGNMENT, 4);
```

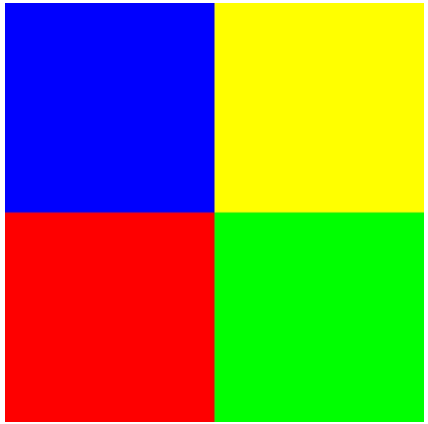
This tells OpenGL that each row starts at an offset that is multiple of 4 bytes.

The possible values are 1, 2, 4 and 8.

1 should work for every texture as long as the data is tightly packed.

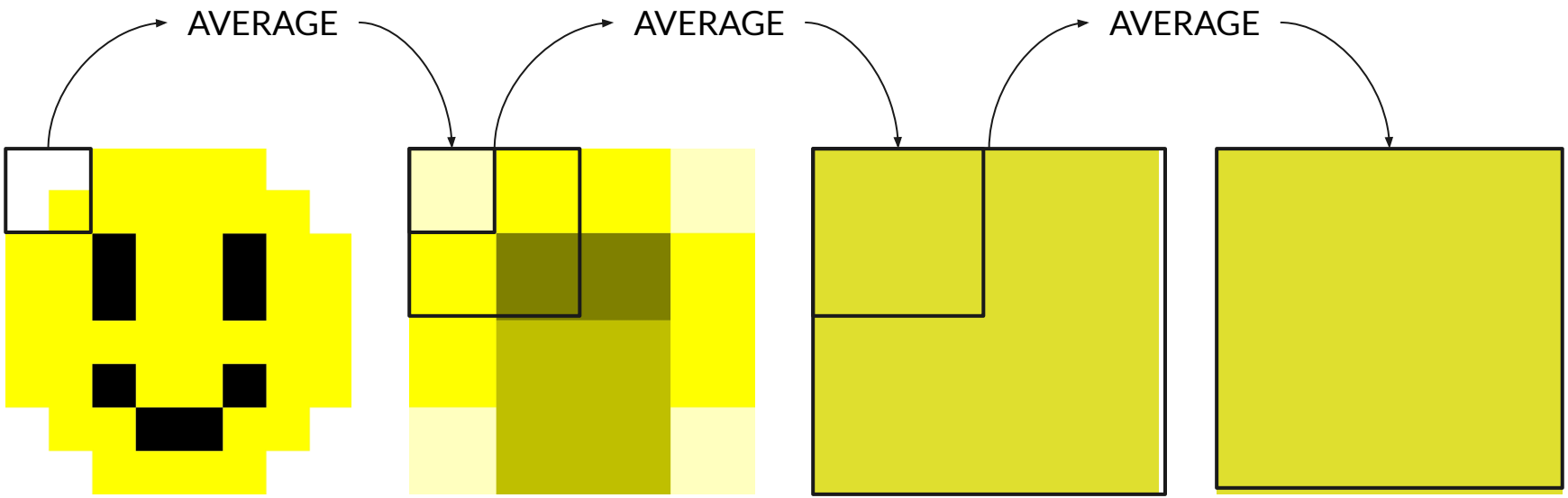
```
glGenerateMipmap(GL_TEXTURE_2D);
```

A Mip level is a smaller version of the texture.



Level 0 (2x2)

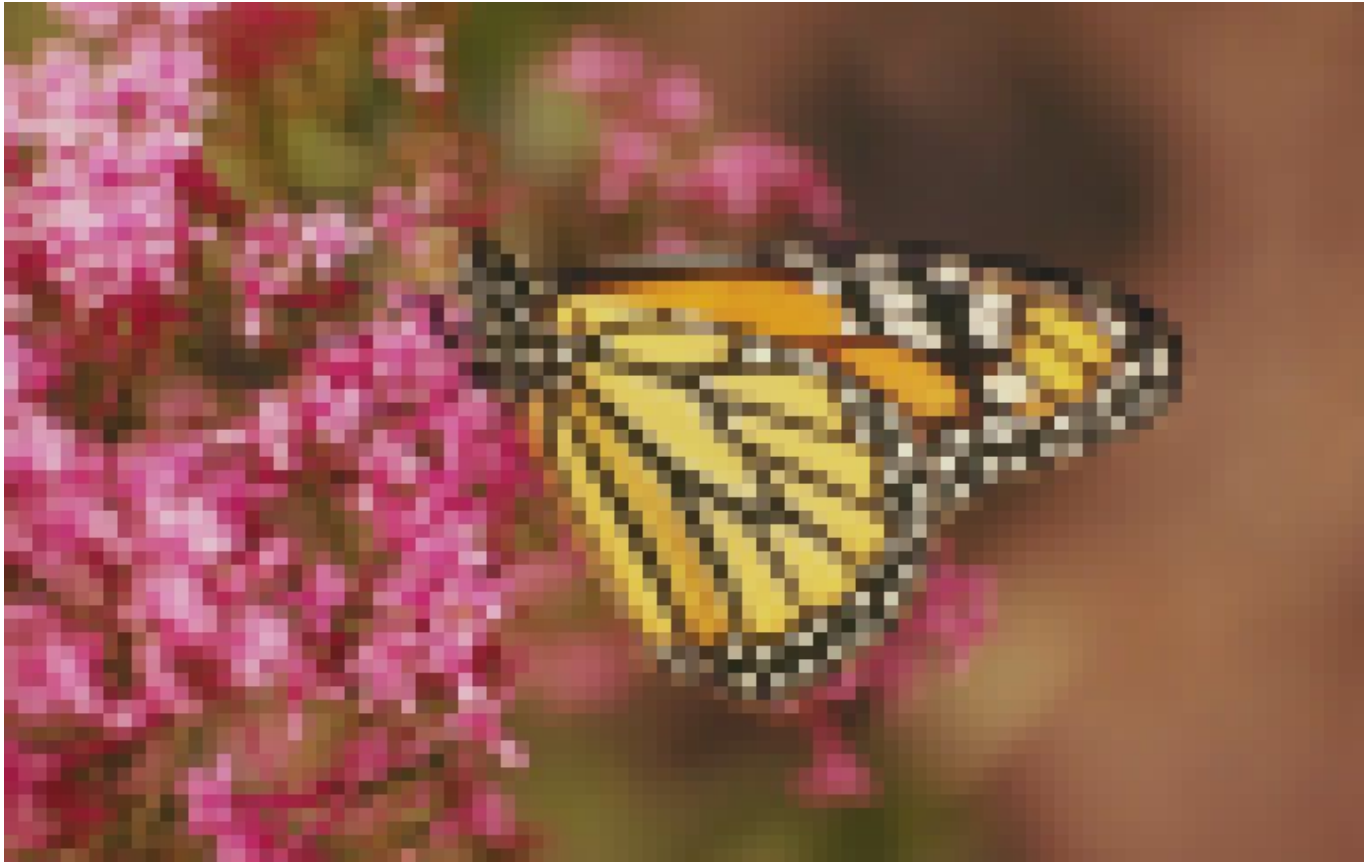
Level 1 (1x1)


AVERAGE
AVERAGE
AVERAGE
Level 0 (8x8)
Level 1 (4x4)
Level 2 (2x2)
Level 3 (1x1)

Level 0 (768x512)

Level 1 (384x256)

Level 2 (192x128)



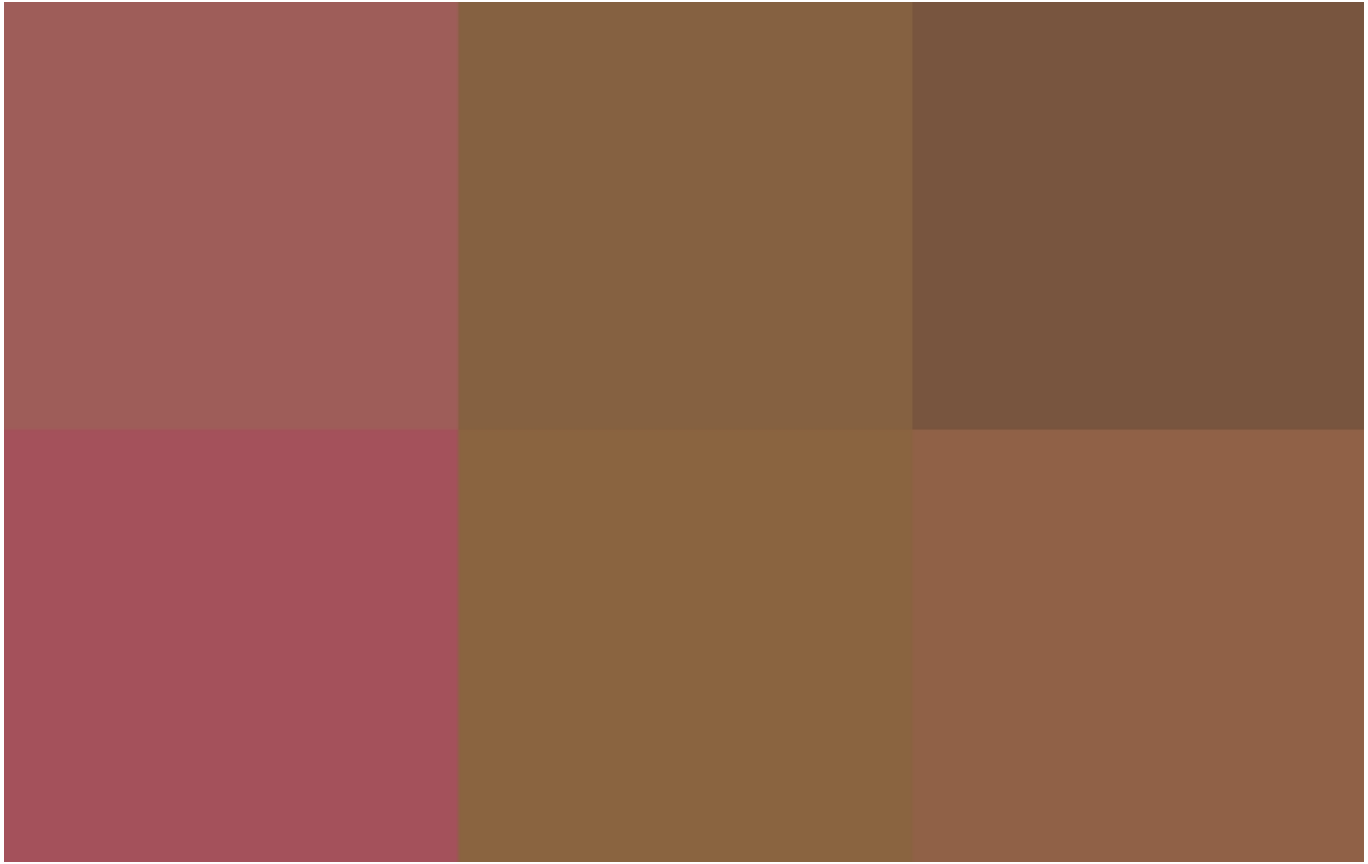
Level 3 (96x64)

Level 4 (48x32)

Level 5 (24x16)

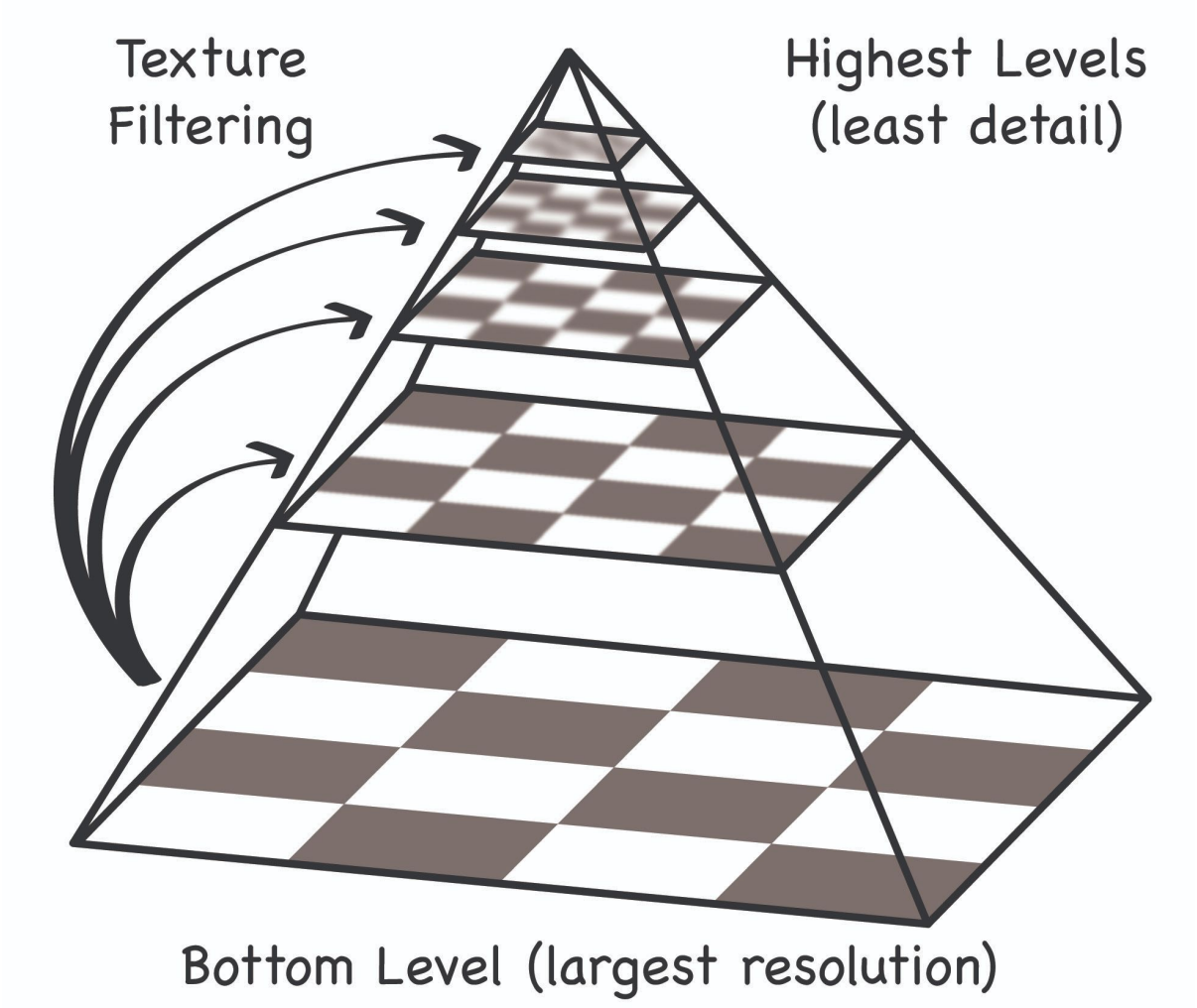
Level 6 (12x8)

Level 7 (6x4)



Level 8 (3x2)

Level 9 (1x1)


Texture
Filtering
Highest Levels
(least detail)
Bottom Level (largest resolution)

```
glTexImage2D(GL_TEXTURE_2D, 0, GL_RGBA8, 2, 2, 0, GL_RGBA, GL_UNSIGNED_BYTE, data);
```

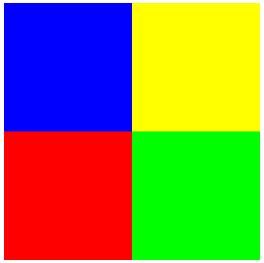
Mip Level = 0

Internal Format

Width & Height

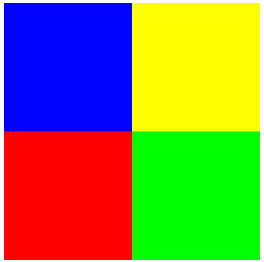
Border (must be 0)

Format & Data type of Data pointer



VRAM

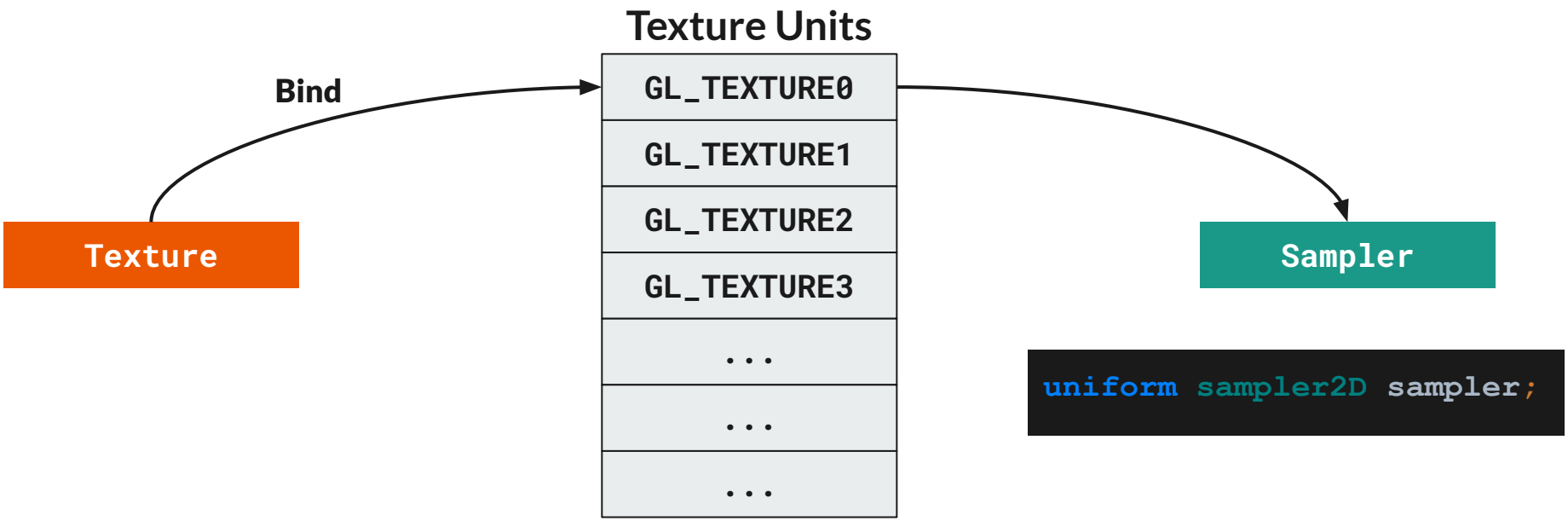
RAM



each number is 0-255 unsigned byte

```
uint8_t data[] = {
        255,   0,   0, 255,
          0, 255,   0, 255,
          0,   0, 255, 255,
        255, 255,   0, 255,
};
```

```
glActiveTexture(GL_TEXTURE0);
glBindTexture(GL_TEXTURE_2D, texture);
GLuint sampler_loc = glGetUniformLocation(program, "sampler");
glUniform1i(sampler_loc , 0);
```




```
uniform sampler2D sampler;
```

```
vec4 frag_color = texelFetch(sampler, pixel_coord, lod);
```

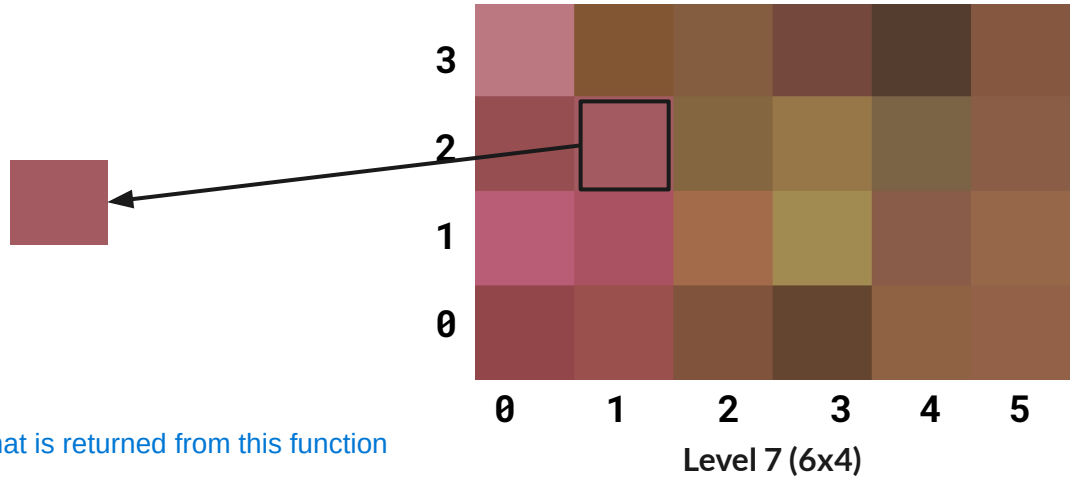
Texture Sampler

2D Index of Pixel

Mip level

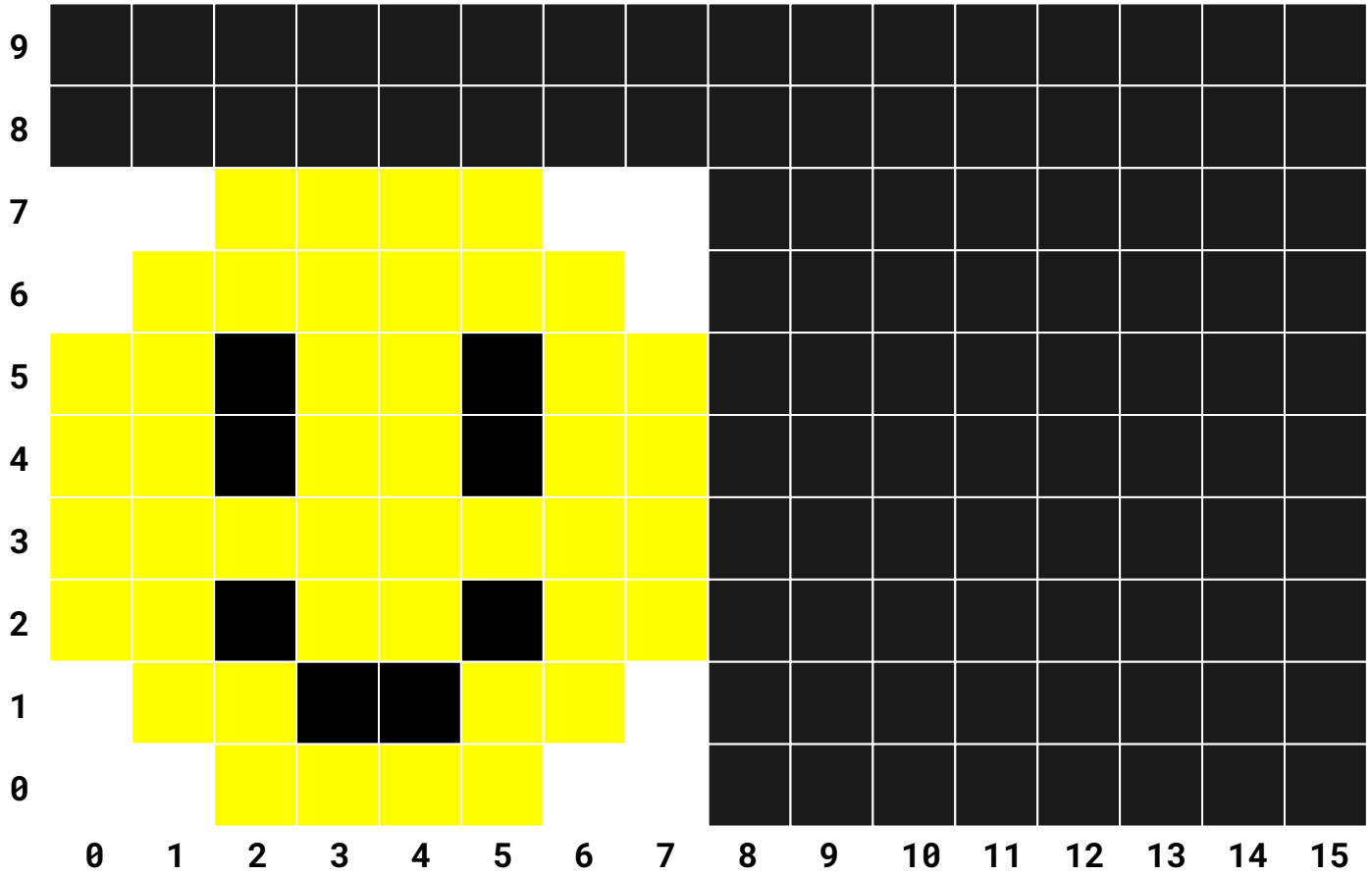
texel building unit of texture so here this code id getting value of one texture ro pixel

```
vec4 frag_color = texelFetch(sampler, ivec2(1,2), 7);
```

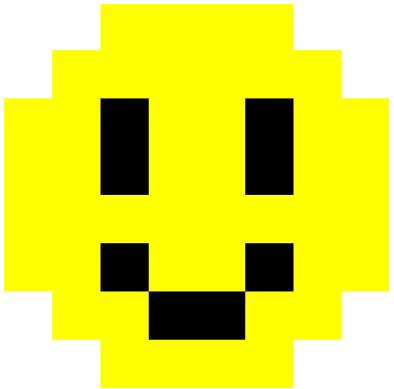


Thus is what is returned from this function

WINDOW



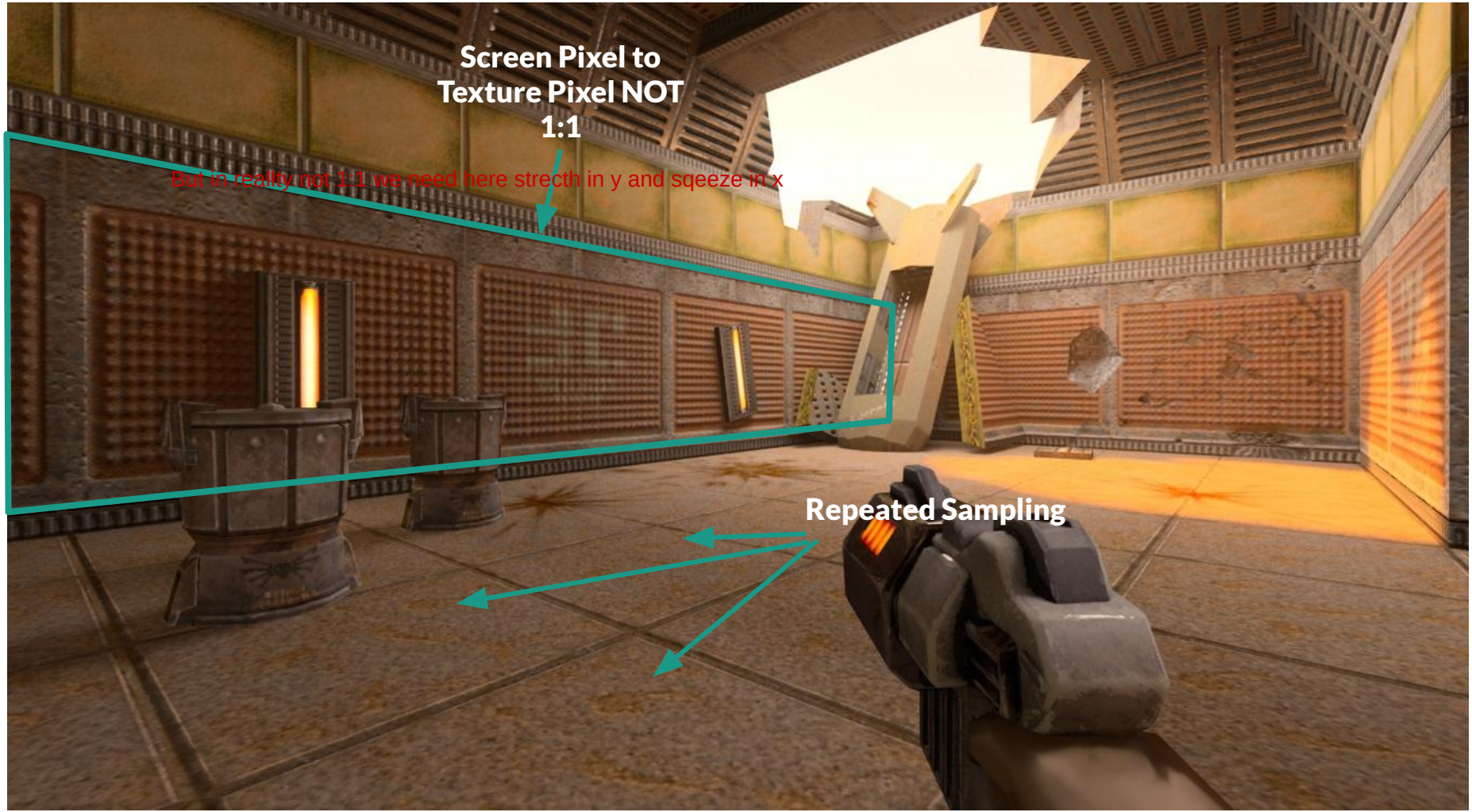

```
texelFetch(sampler,
gl_FragCoord.xy,
0);
```



Sampler
(Texture 2D)

1:1 Screen Pixel to Texture Pixel

one-to-one mapping


Screen Pixel to
Texture Pixel NOT
1:1
But in reality not 1:1 we need here strecth in y and sqeeze in x
Repeated Sampling

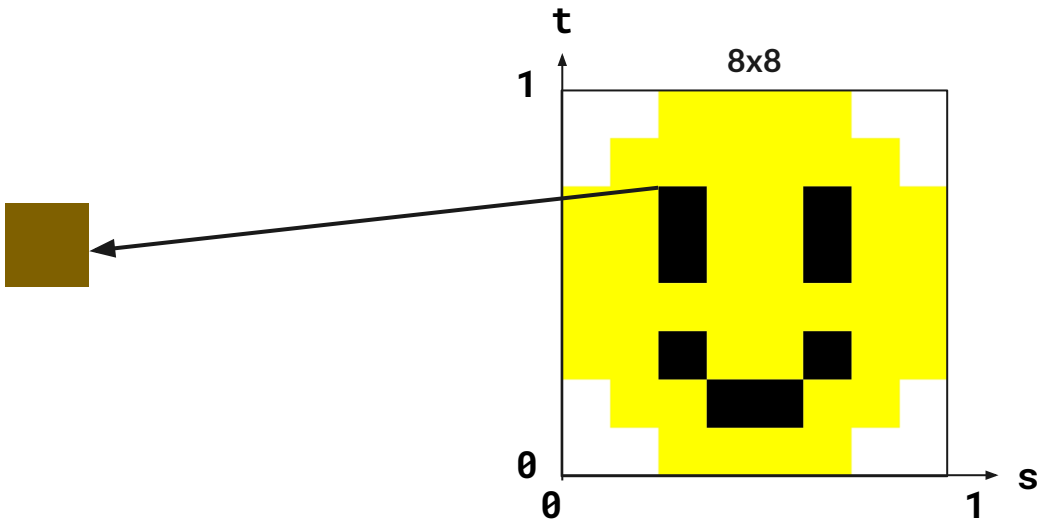
```
vec4 frag_color = texture(sampler, texture_coord);
```

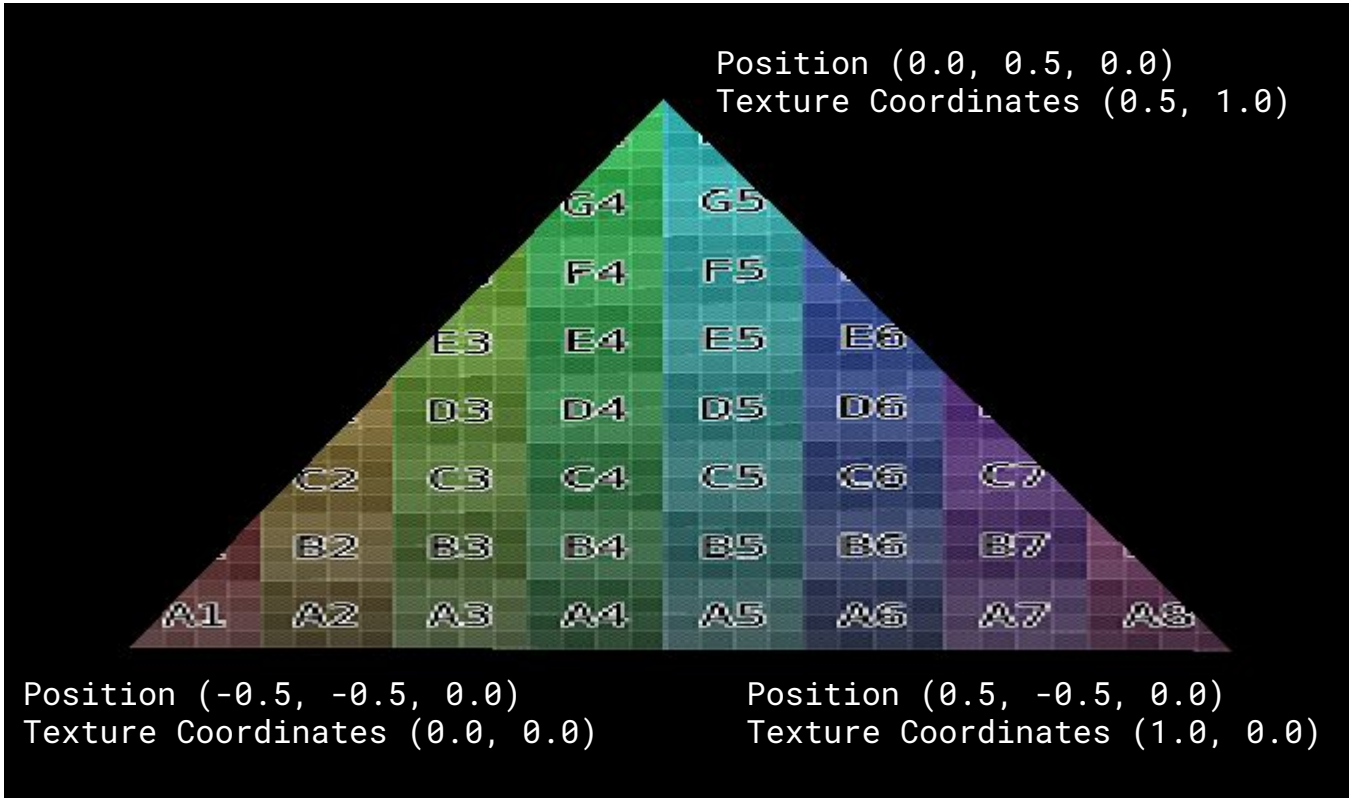
Texture Sampler

Texture Coordinate

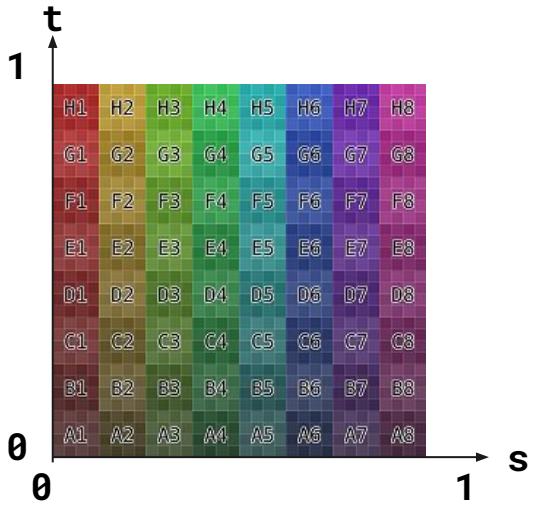
Normalized version of pixel_cord

```
vec4 frag_color = texture(sampler, vec2(0.25,0.75));
```





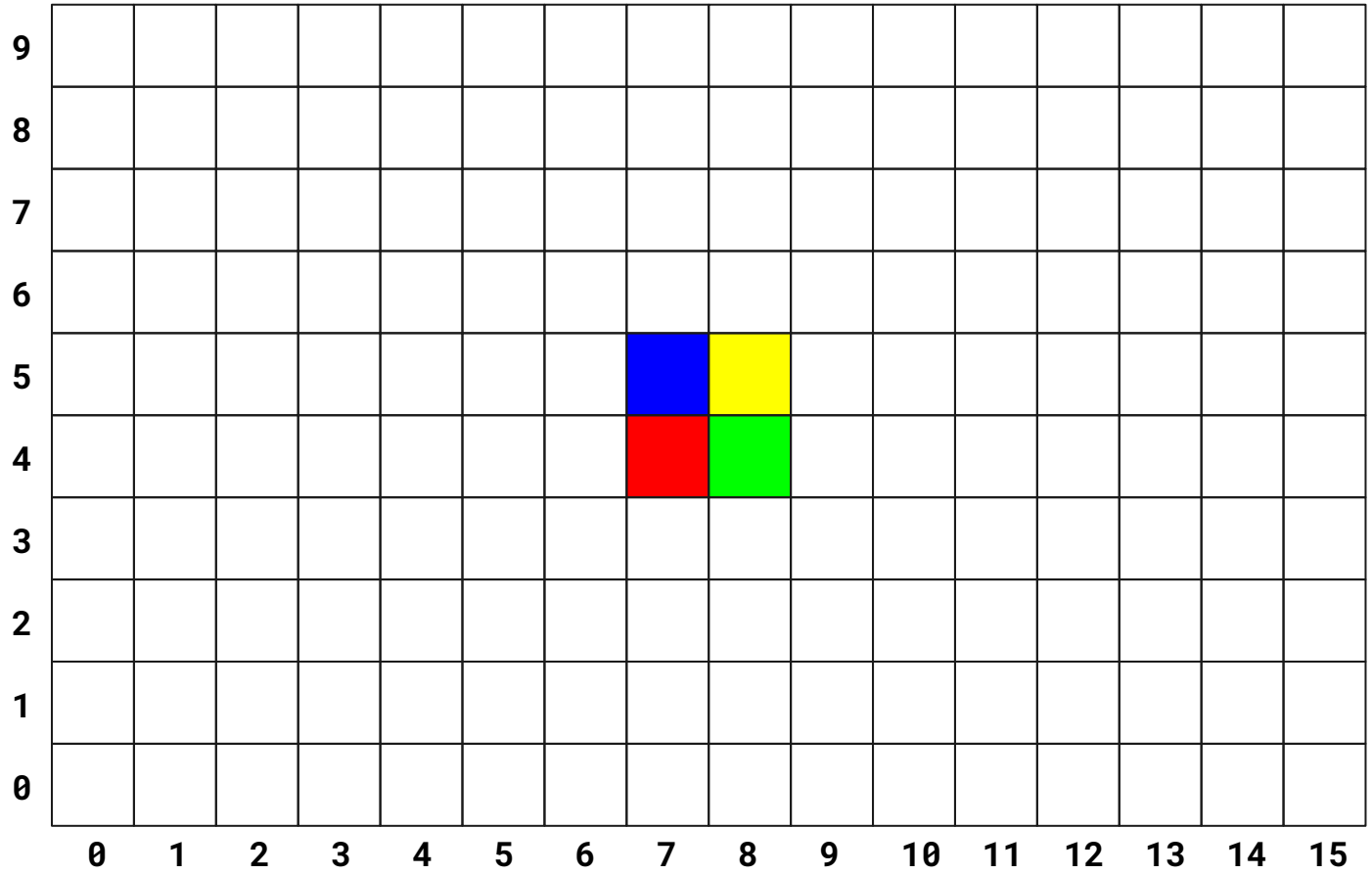
Here he set the points by texture coordinate not color



t

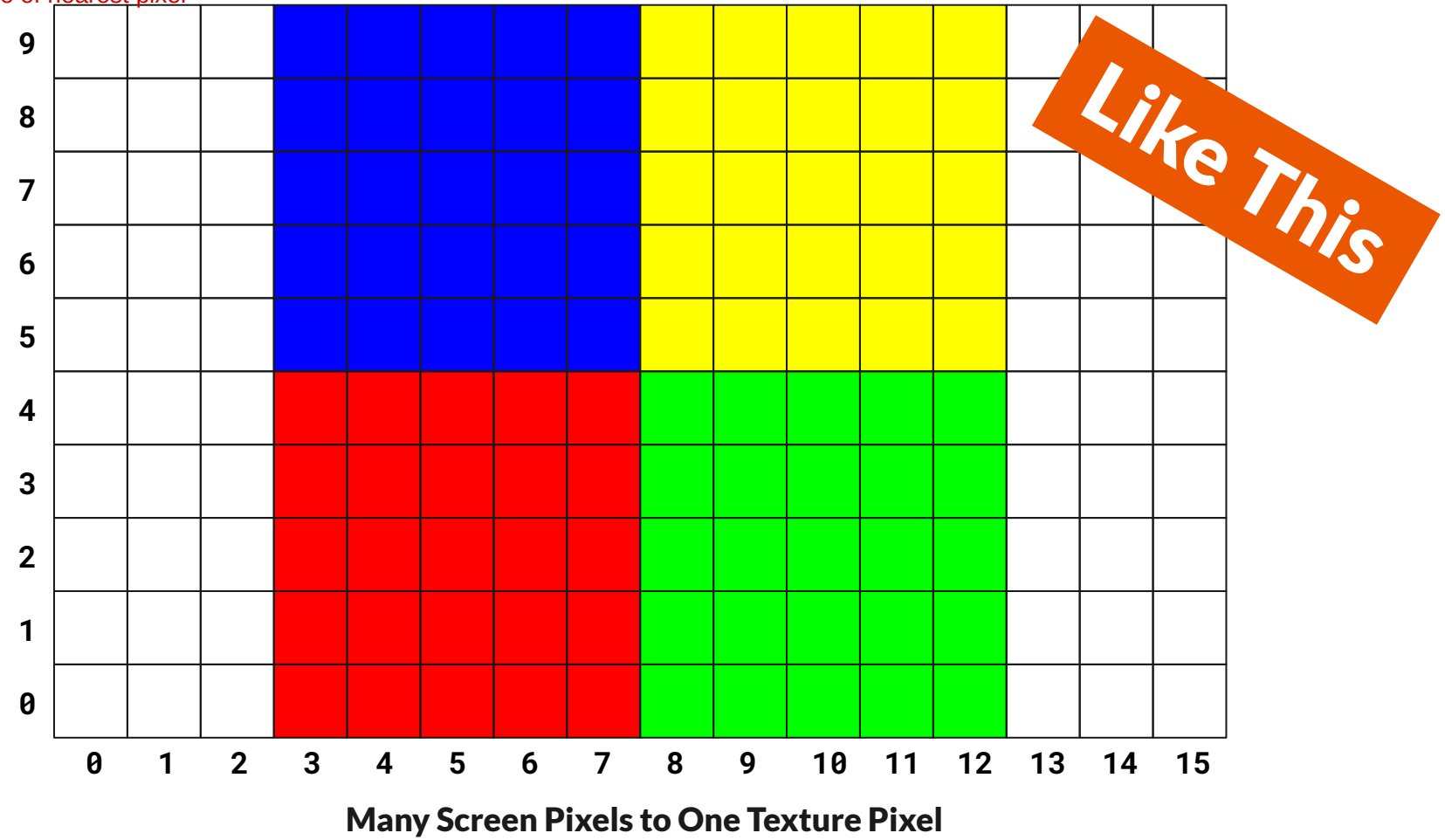
s

Filtering



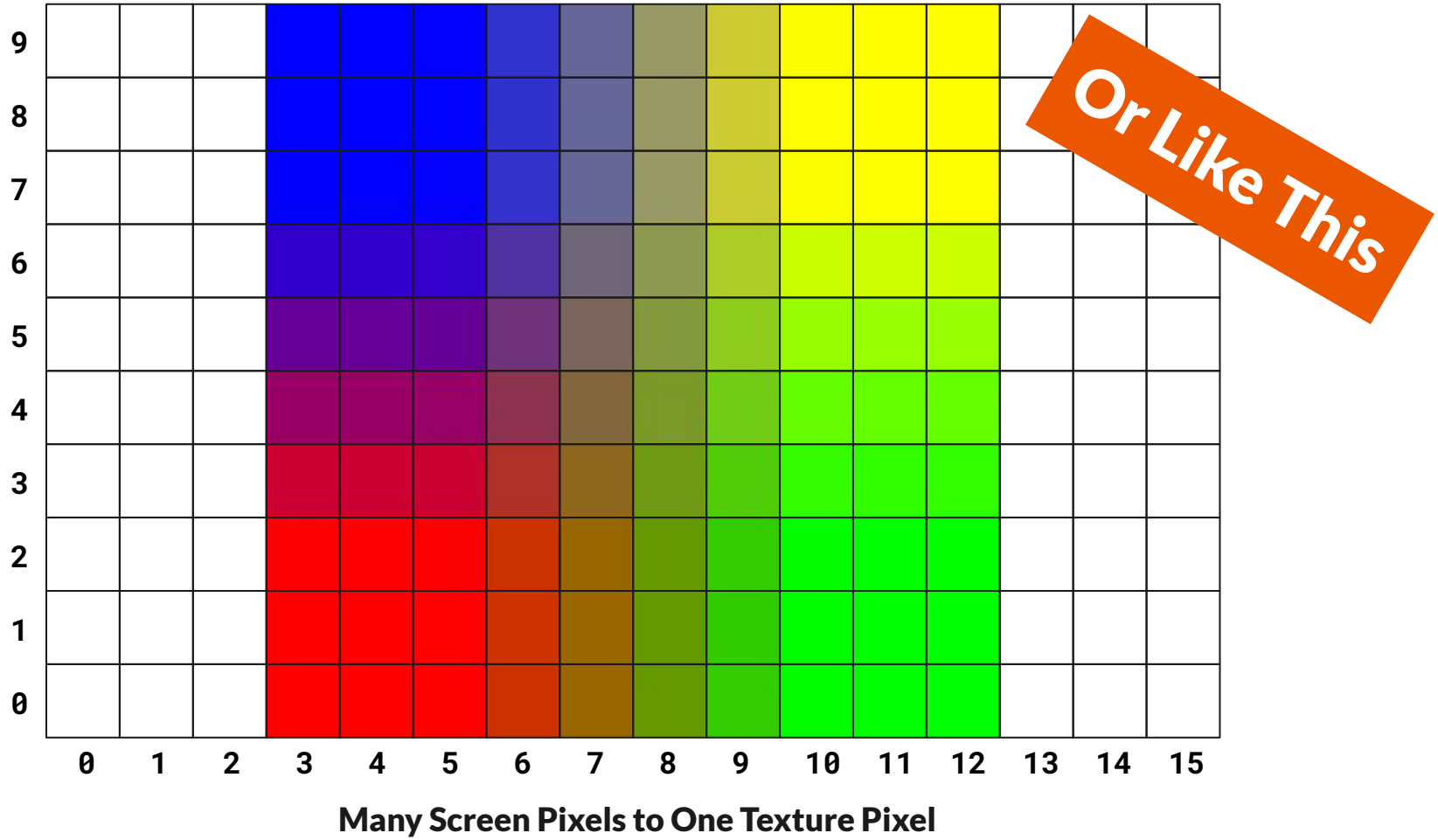
EASY CASE: One Screen Pixel to One Texture Pixel

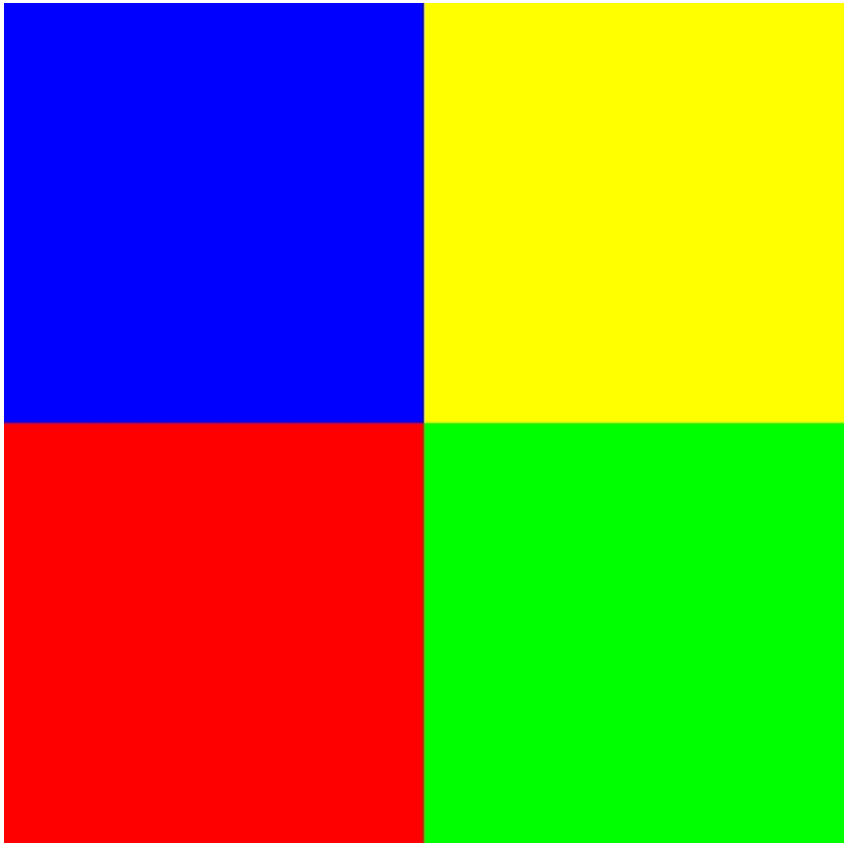
Gets value of nearest pixel



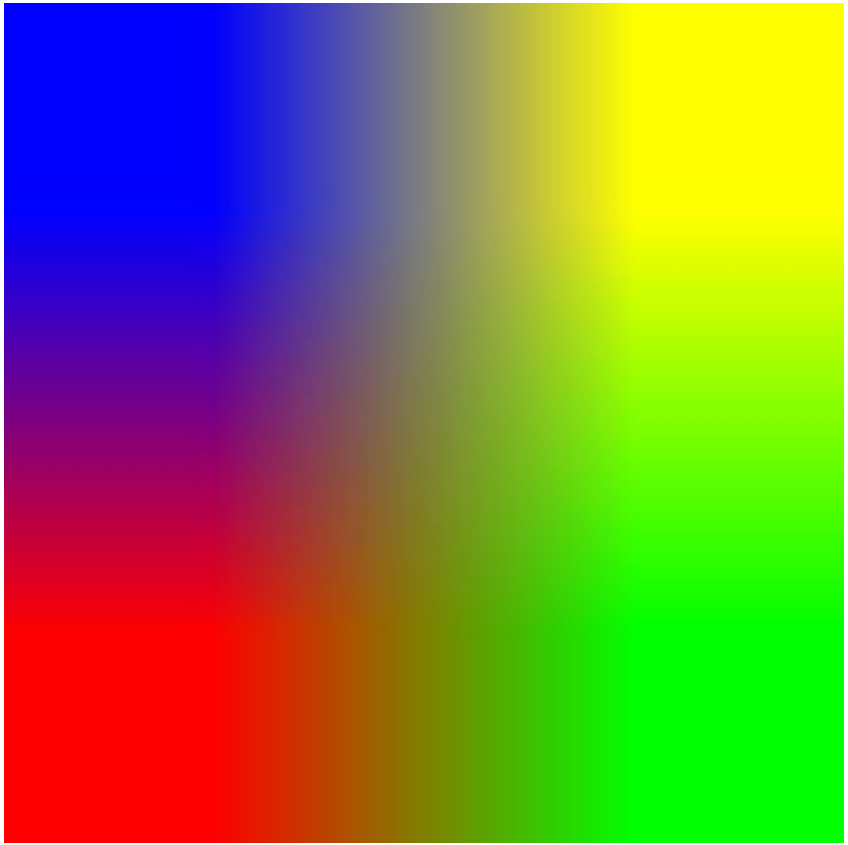
Many Screen Pixels to One Texture Pixel

Linear interpolation

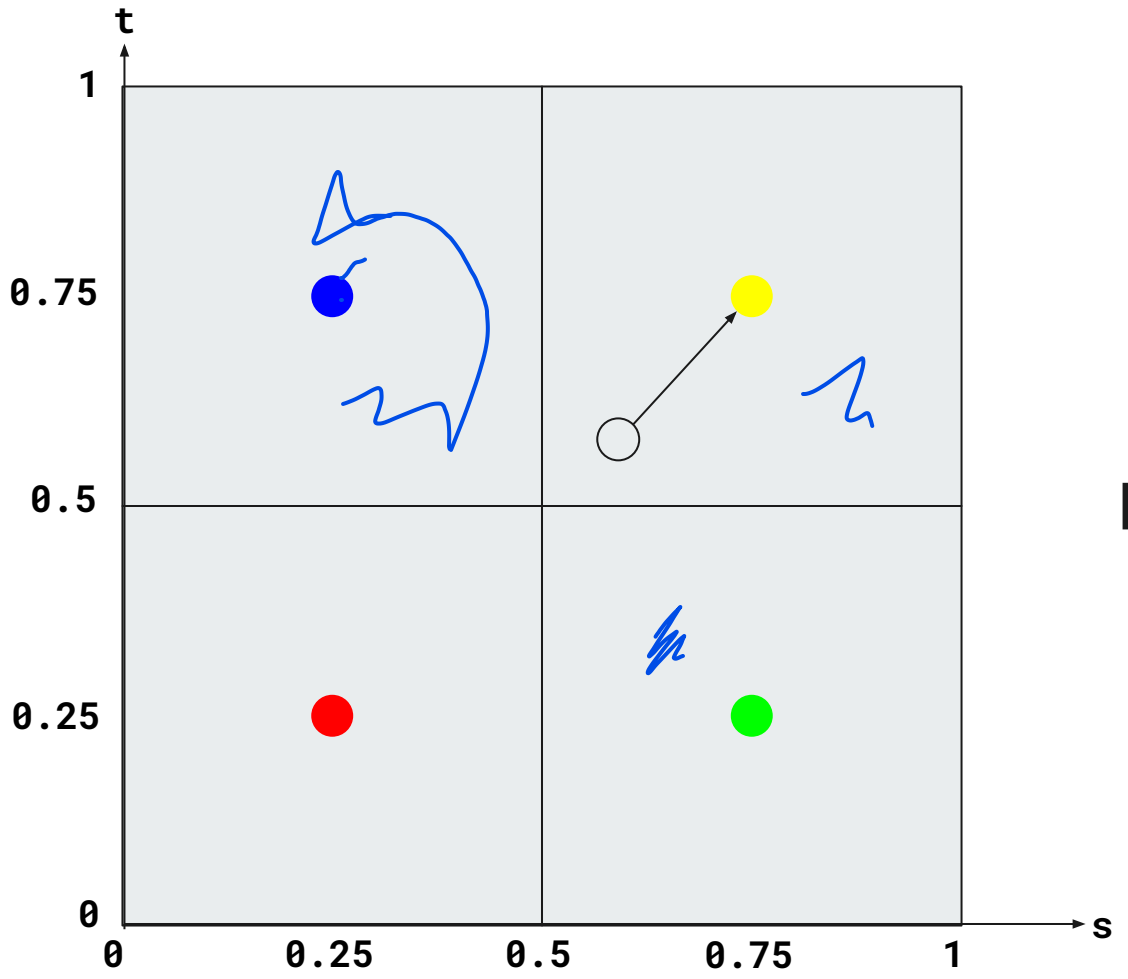




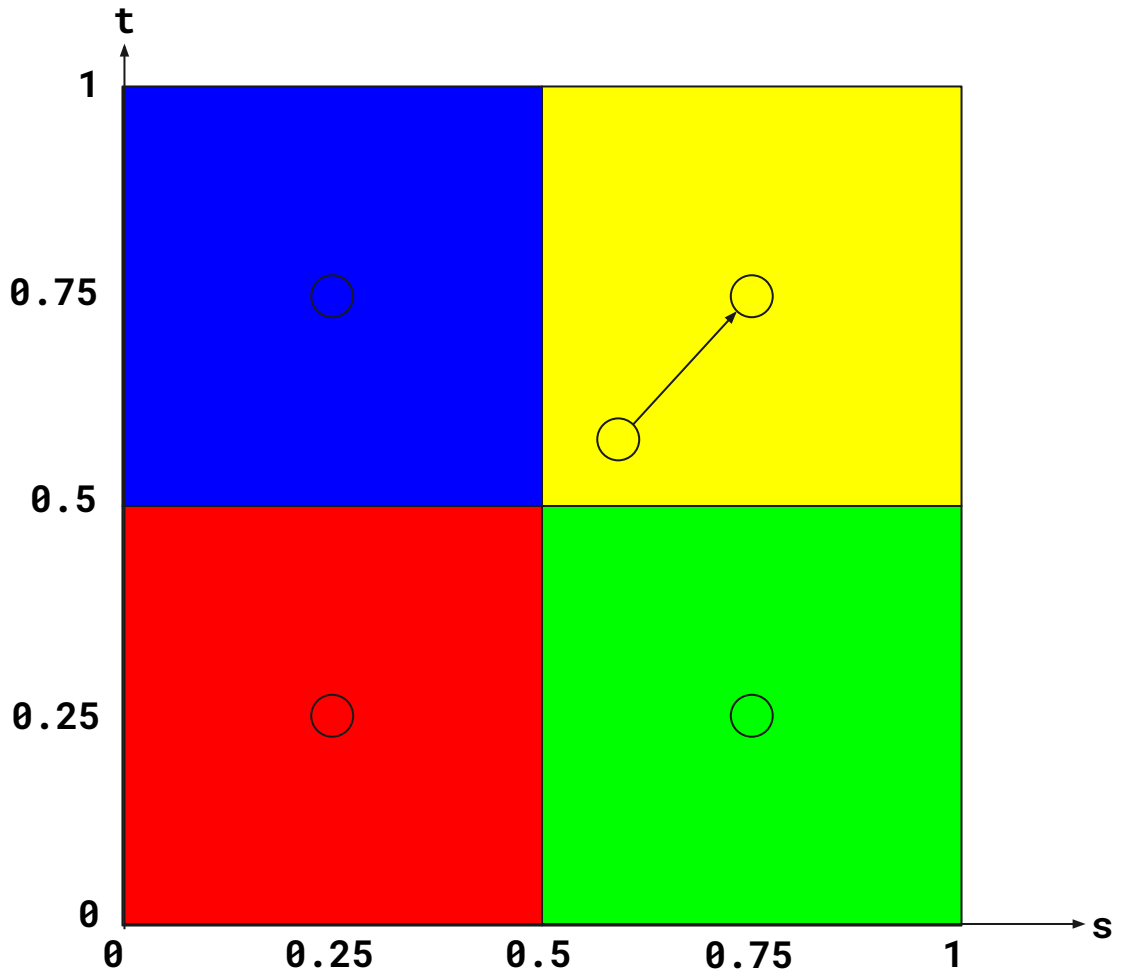
Nearest



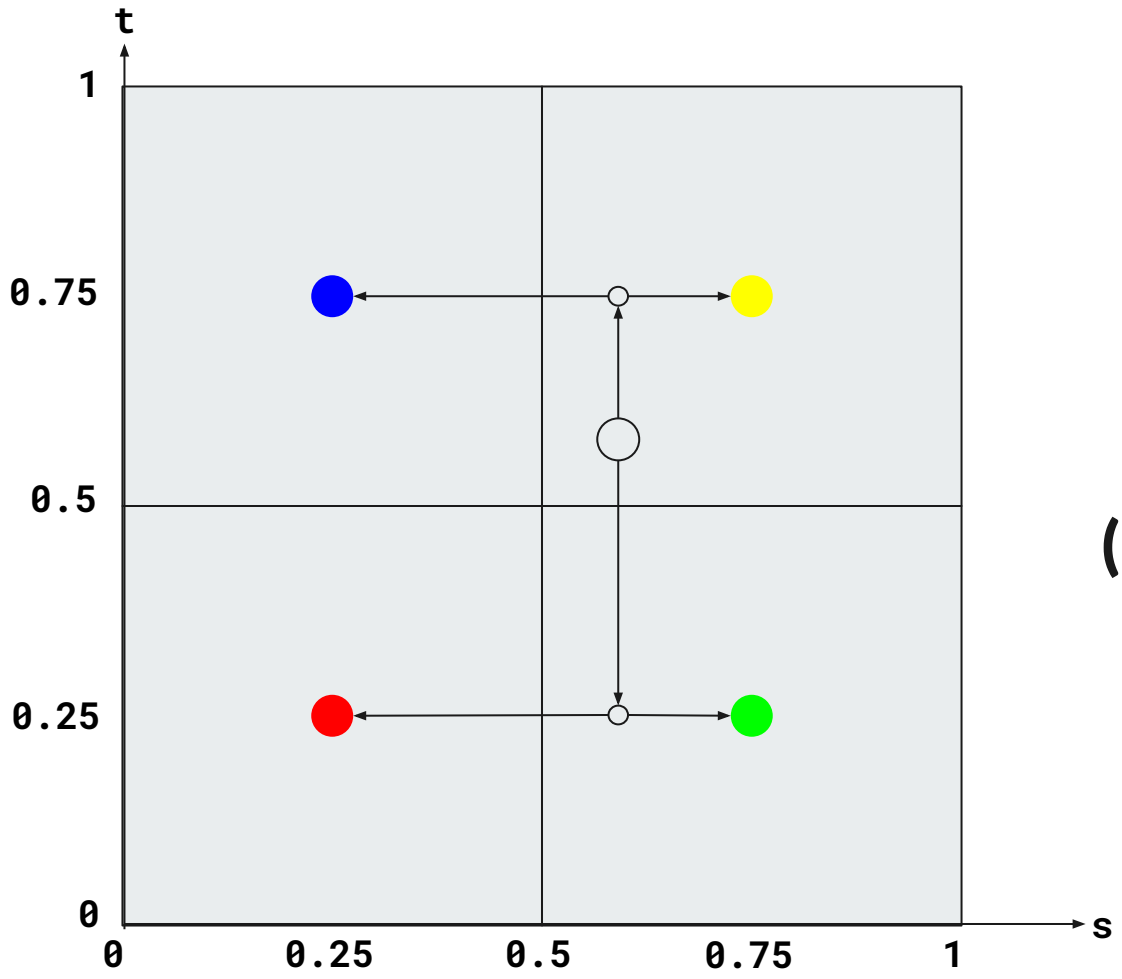
Linear (Bilinear)



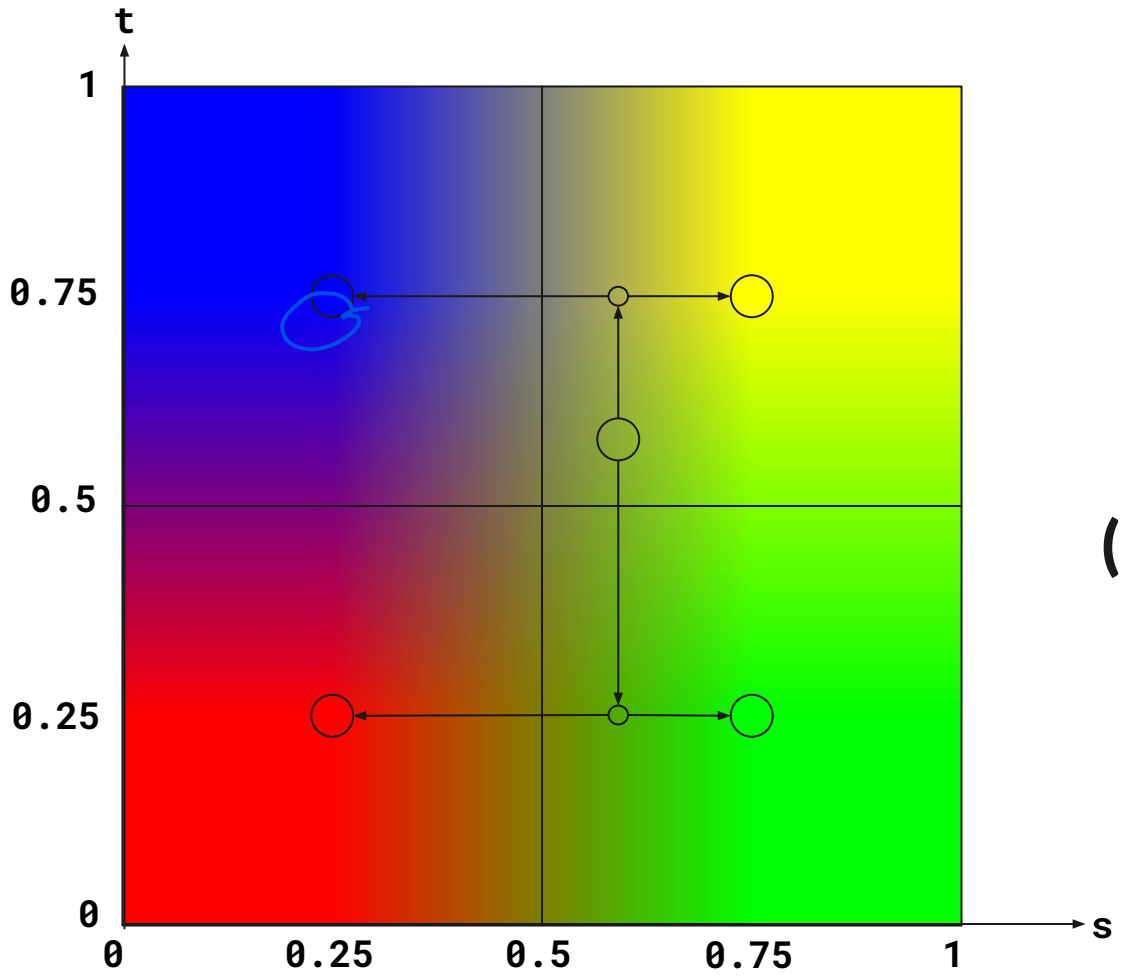
Nearest



Nearest



Linear (Bilinear)



Linear (Bilinear)

Magnification Filter

Many Screen Pixels to One Texture Pixel

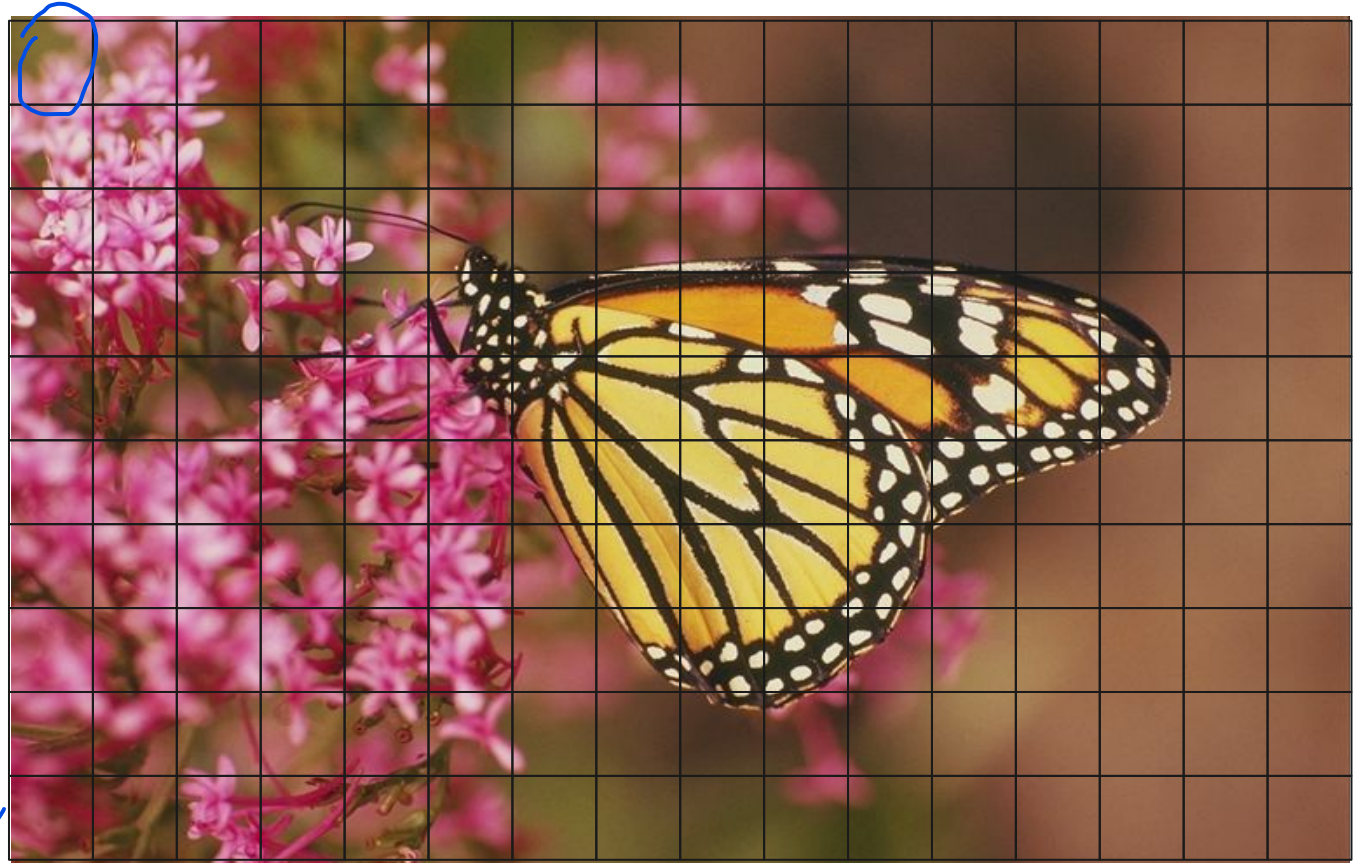
```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_NEAREST);
```

NEAREST

```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
```

LINEAR (BILINEAR)

The opposite We have a big image we need to draw on a small screen



Must compute average of many texture pixels to get color.

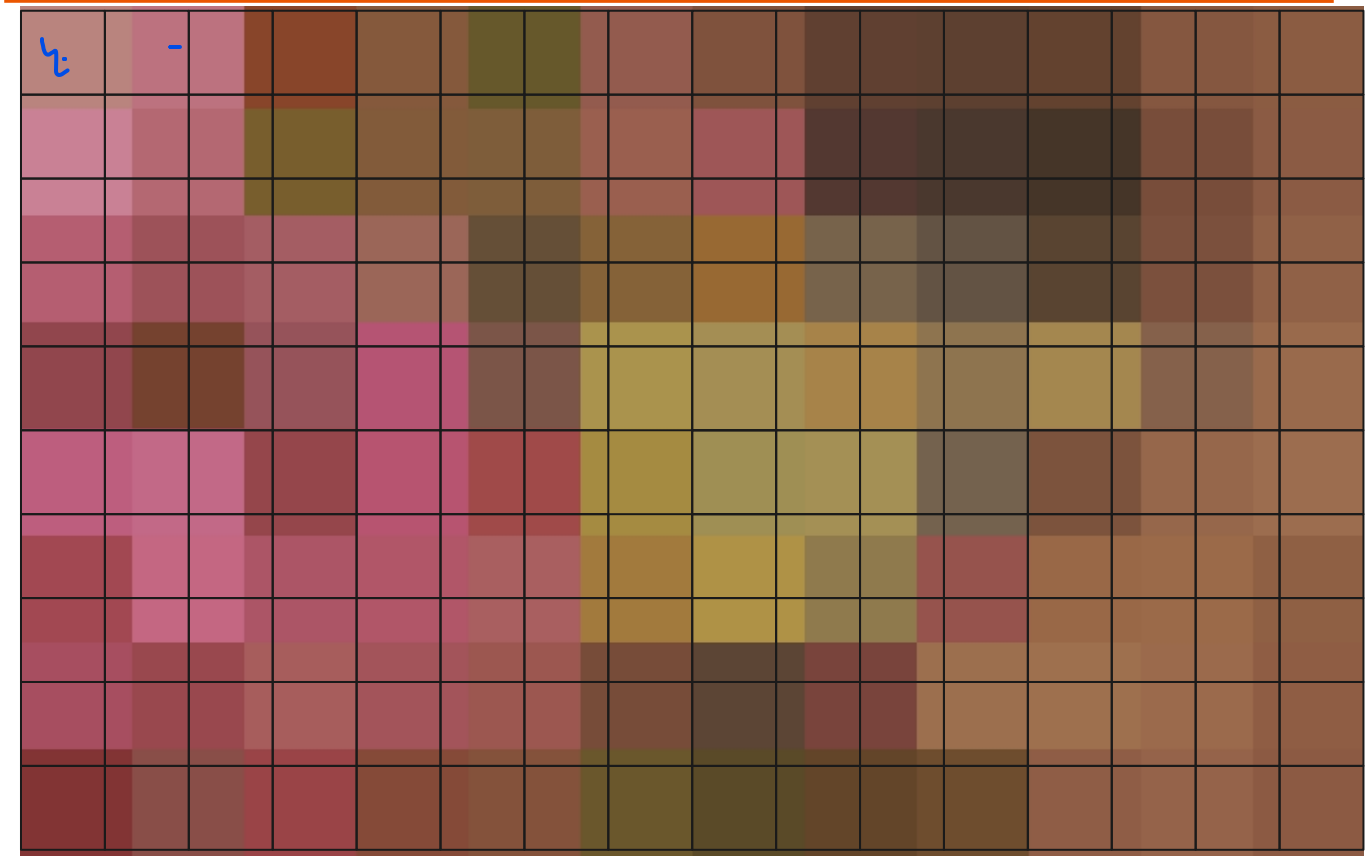
TOO EXPENSIVE.

Texture Size
768x512

Screen Size
16x10

One Screen Pixel to Many Texture Pixels

Should we really pick Level 6?



Use a lower Mip Level.

CHEAP

Level 6 Size
12x8

Screen Size
16x10

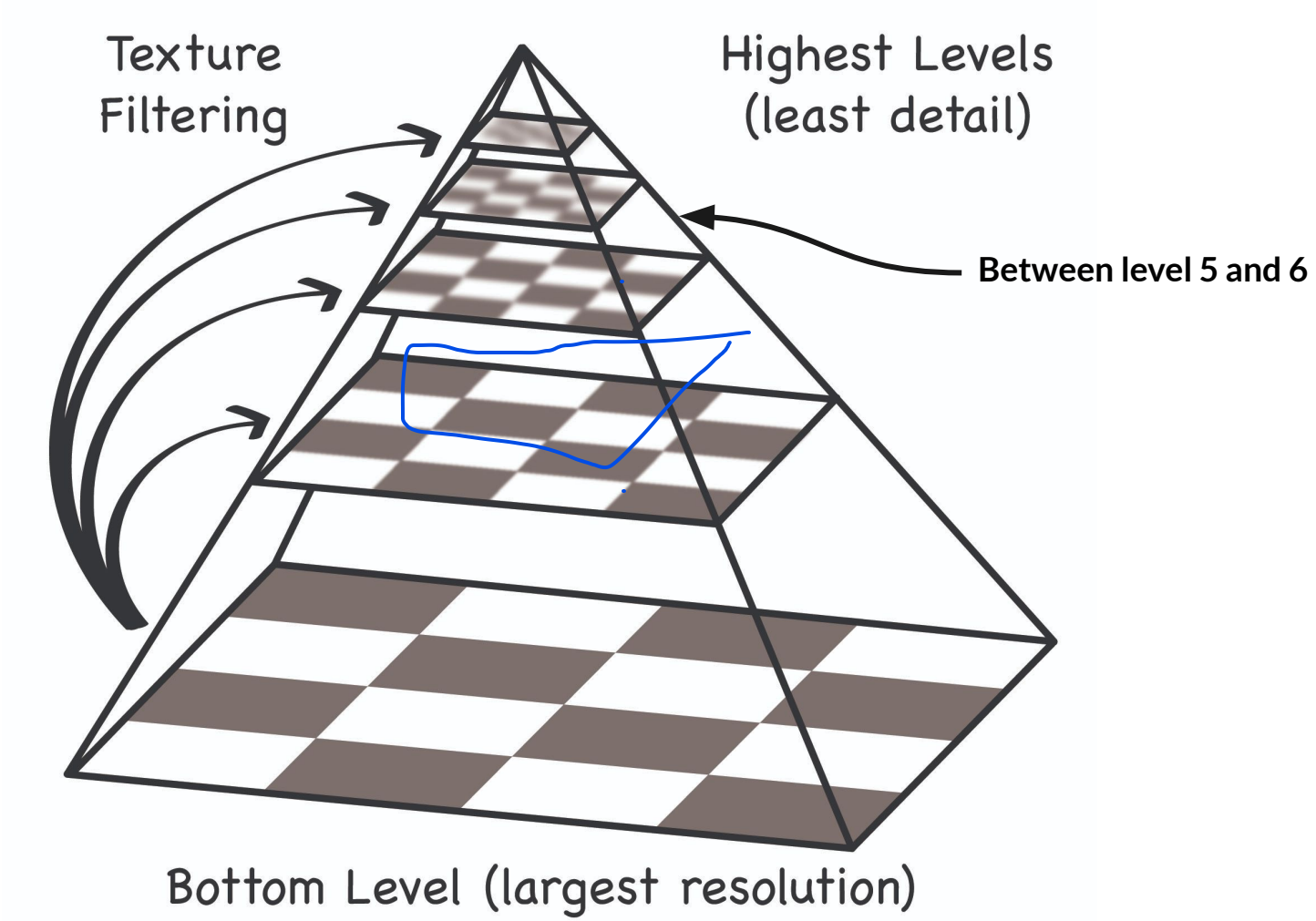
Or should we really pick Level 5?

Use a lower Mip Level.

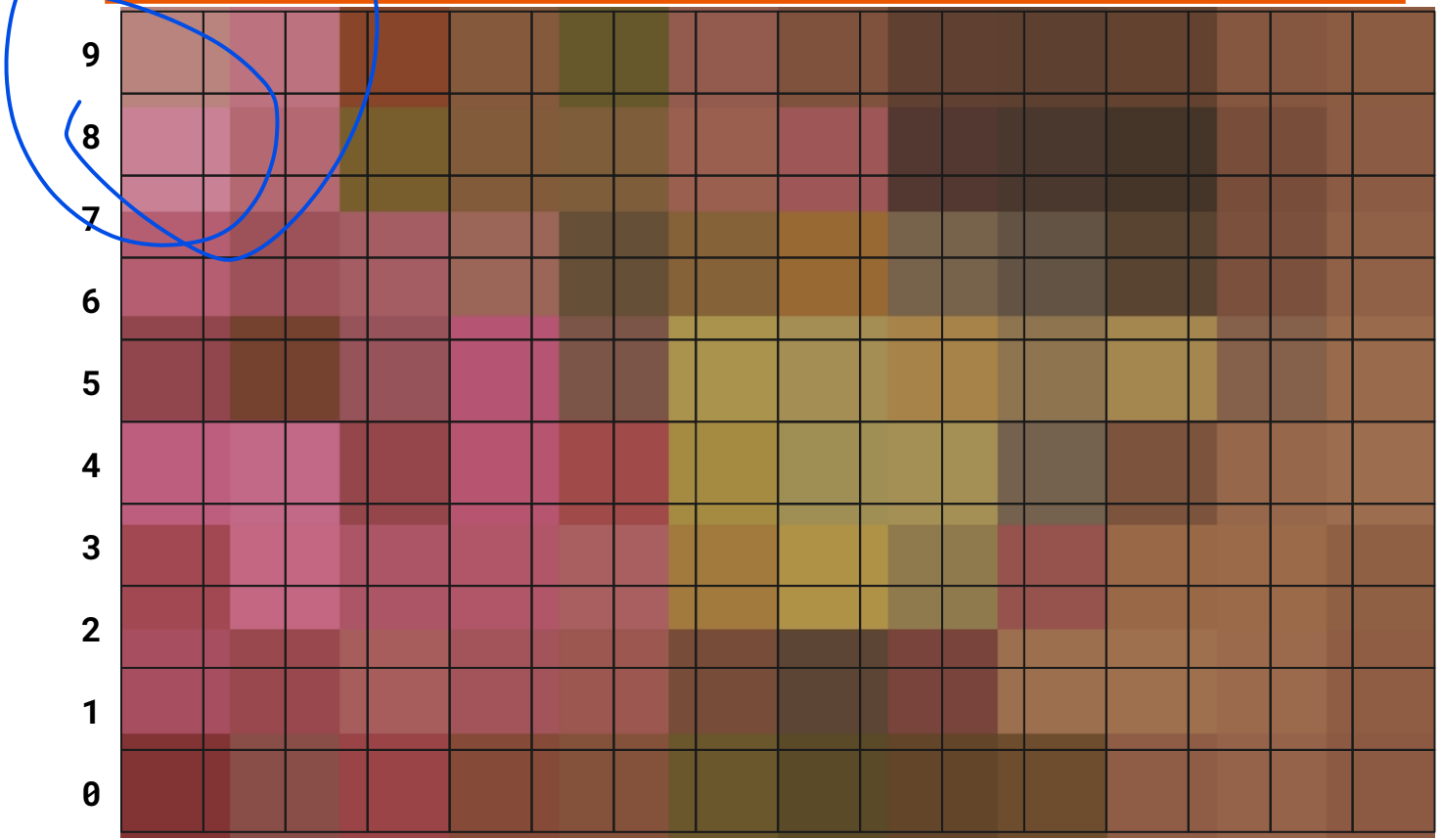
CHEAP

Level 5 Size 24x16

Screen Size 16x10


Texture
Filtering
Highest Levels
(least detail)
Between level 5 and 6
Bottom Level (largest resolution)

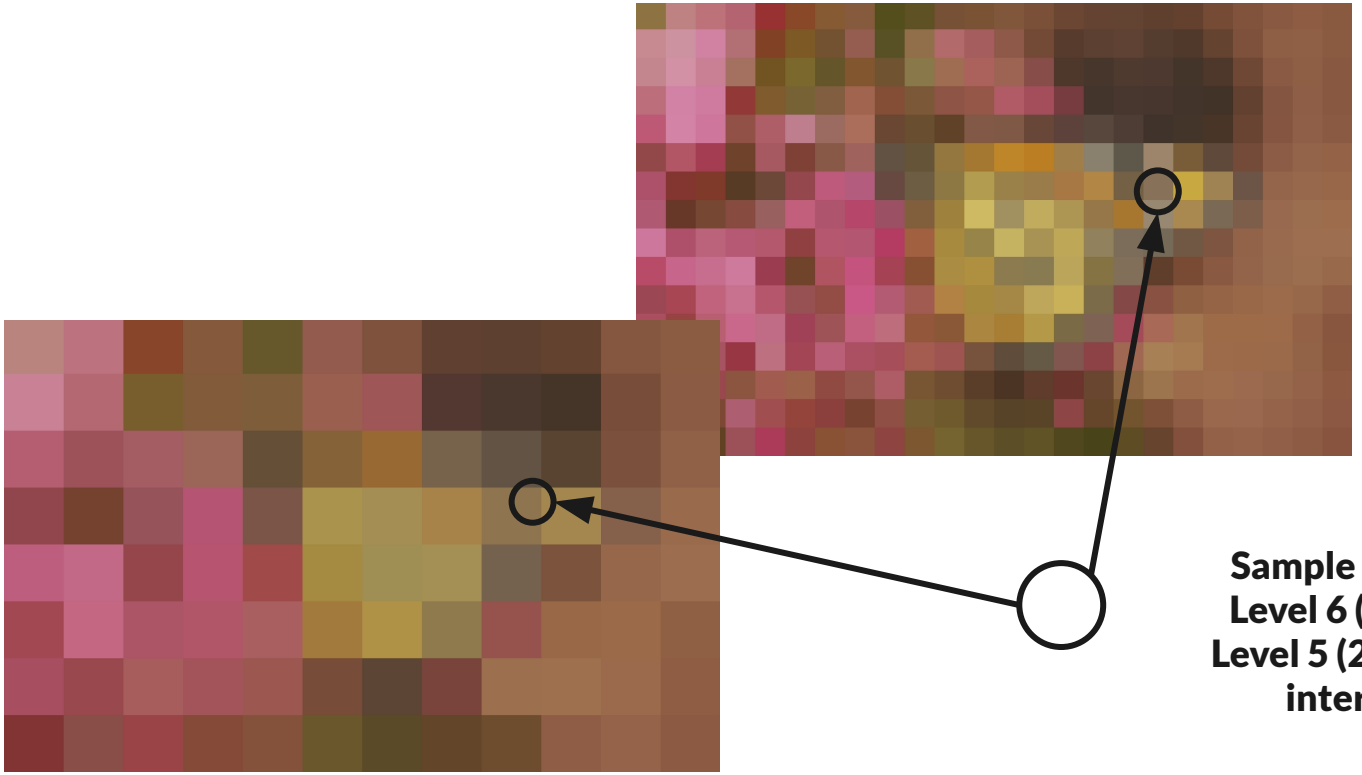
Option 1: “NEAREST” Mip Level



One Screen Pixel to Many Texture Pixels

Level 6 (12x8) is nearer to Screen Size (16x10) than Level 5 (24x16)

Option 2: “LINEAR” Mip Filtering



Sample from both Level 6 (12x8) and Level 5 (24x16) then interpolate

Minification Filter

One Screen Pixels to Many Texture Pixel

DOESN'T USE THE MIPMAP

```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_NEAREST);
```

NEAREST (FROM MIP LEVEL 0)

```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);
```

LINEAR (FROM MIP LEVEL 0)

THIS WILL JITTER A LOT WHILE MOVING

Minification Filter

One Screen Pixels to Many Texture Pixel

WITH MIPMAPS

```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_NEAREST_MIPMAP_NEAREST);
```

PICK NEAREST MIP LEVEL THEN PICK NEAREST PIXEL

```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR_MIPMAP_NEAREST);
```

PICK NEAREST MIP LEVEL THEN FILTER PIXELS LINEARLY

THE DETAILS WILL CHANGE SUDDENLY AS OBJECT DISTANCE CHANGES

Minification Filter

One Screen Pixels to Many Texture Pixel

WITH MIPMAPS

```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_NEAREST_MIPMAP_LINEAR);
```

PICK THE NEAREST PIXEL IN EACH MIP LEVEL THEN INTERPOLATE LINEARLY BETWEEN LEVELS

Take avg in each level then take avg between these 2 average :D

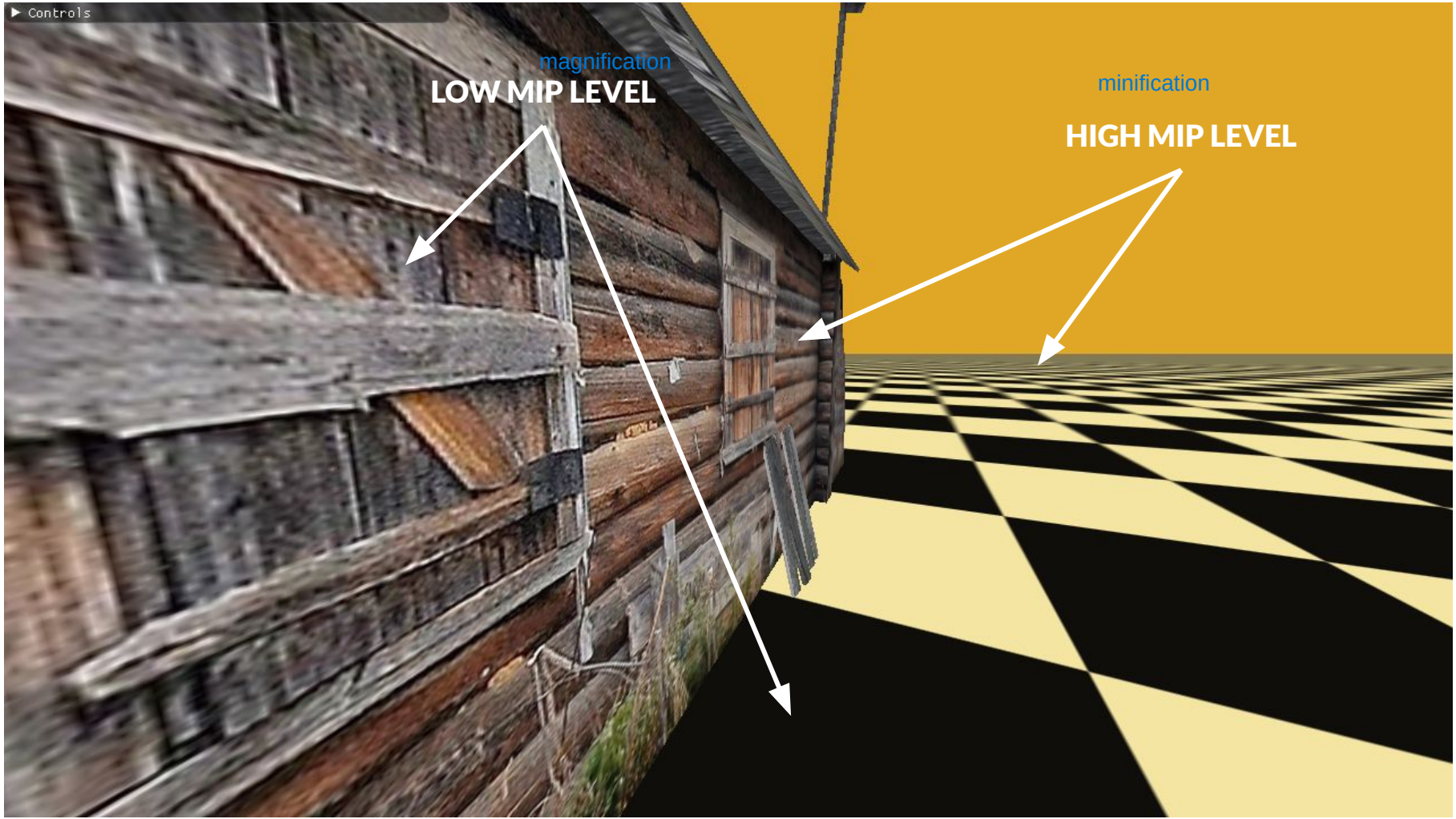
```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR_MIPMAP_LINEAR);
```

FILTER PIXELS LINEARLY IN EACH MIP LEVEL THEN INTERPOLATE LINEARLY BETWEEN LEVELS

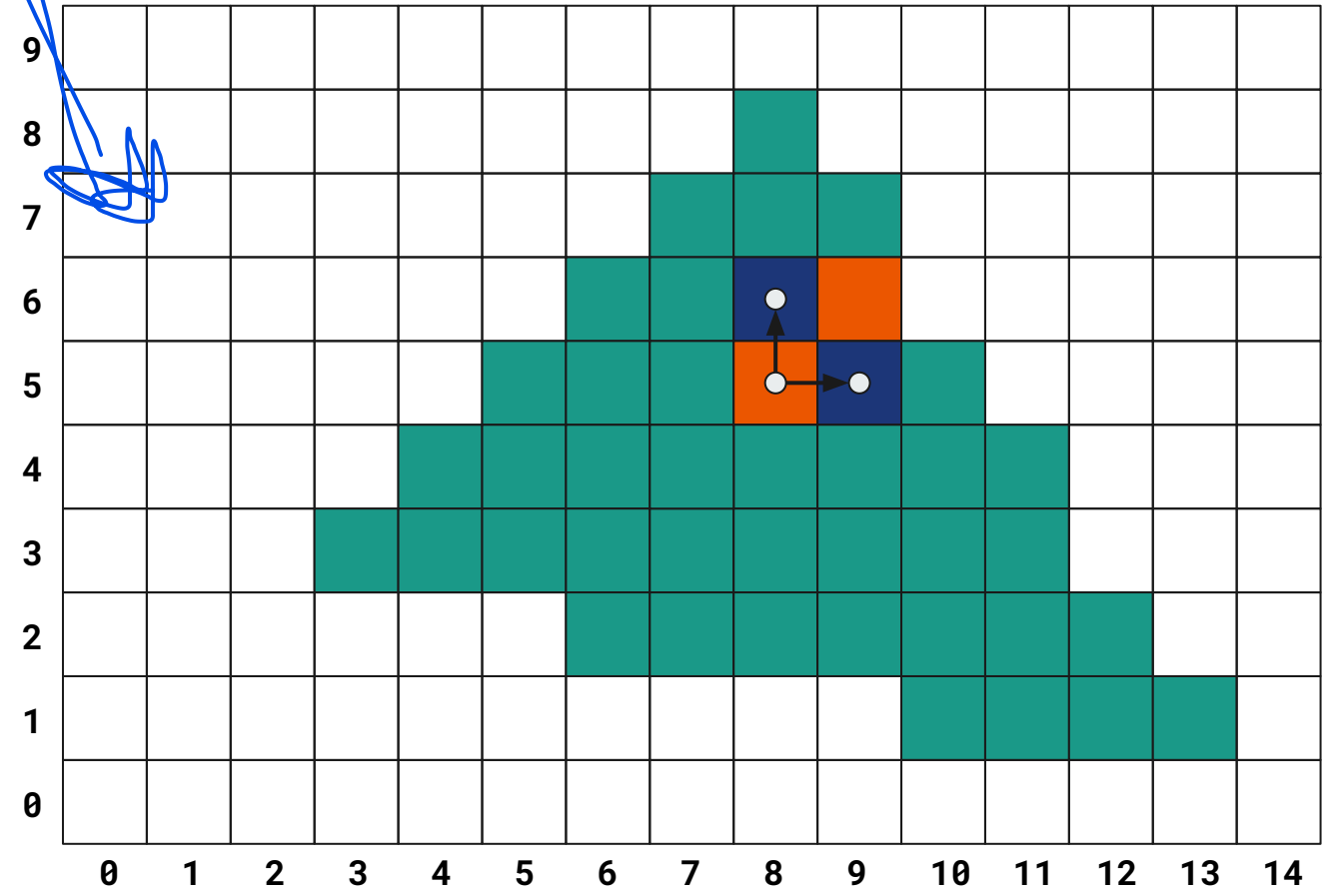
Called trilinear filtering bec we make 3 averages 2 across each level and one between 2 levels

GL_LINEAR_MIP_LINEAR IS THE BEST (AND MOST EXPENSIVE) OPTION FOR REALISM. COMMONLY CALLED "TRILINEAR FILTERING"

But most expensive


▶ Controls
magnification
LOW MIP LEVEL
minification
HIGH MIP LEVEL

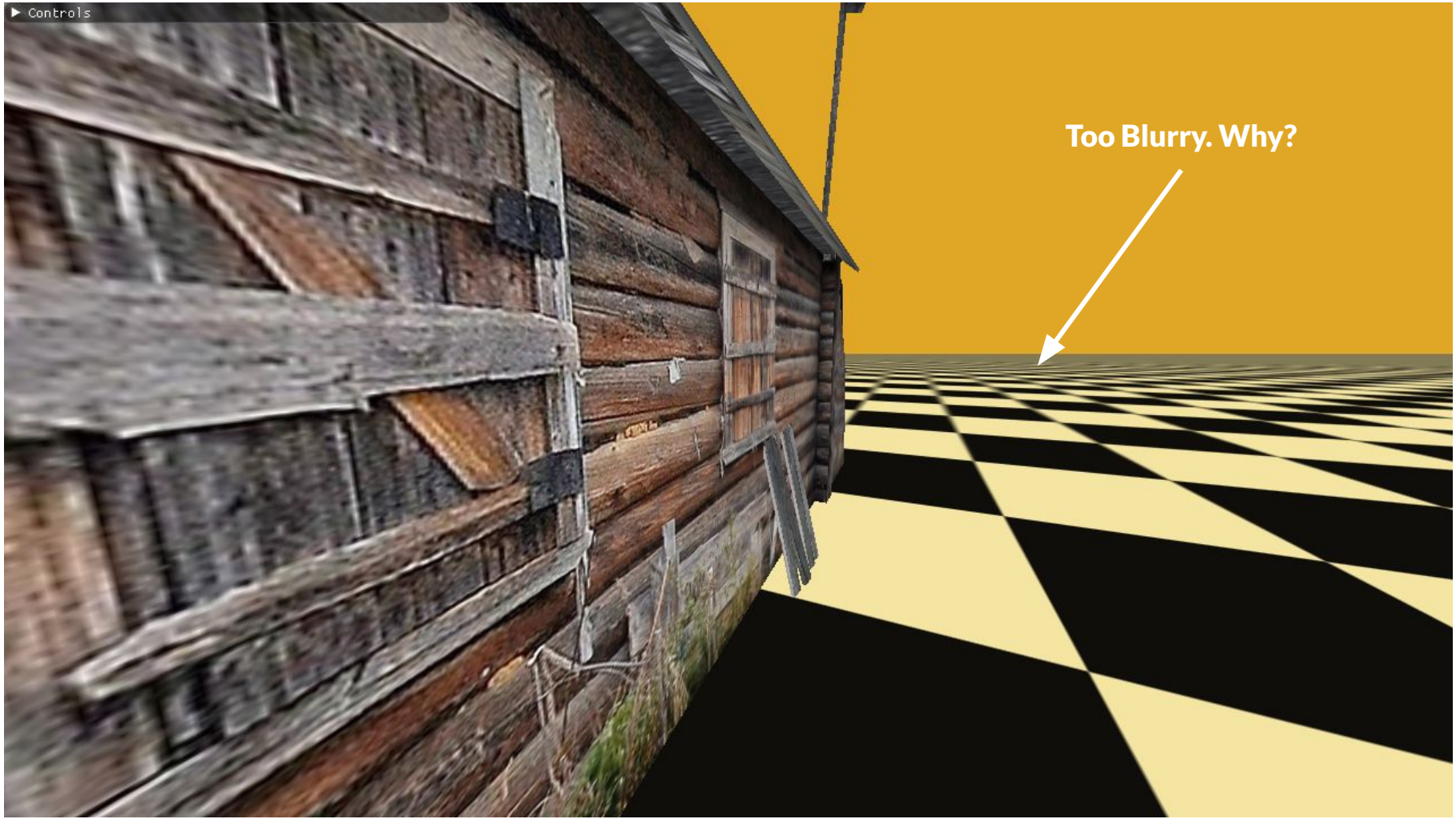
How to calculate the required mip level

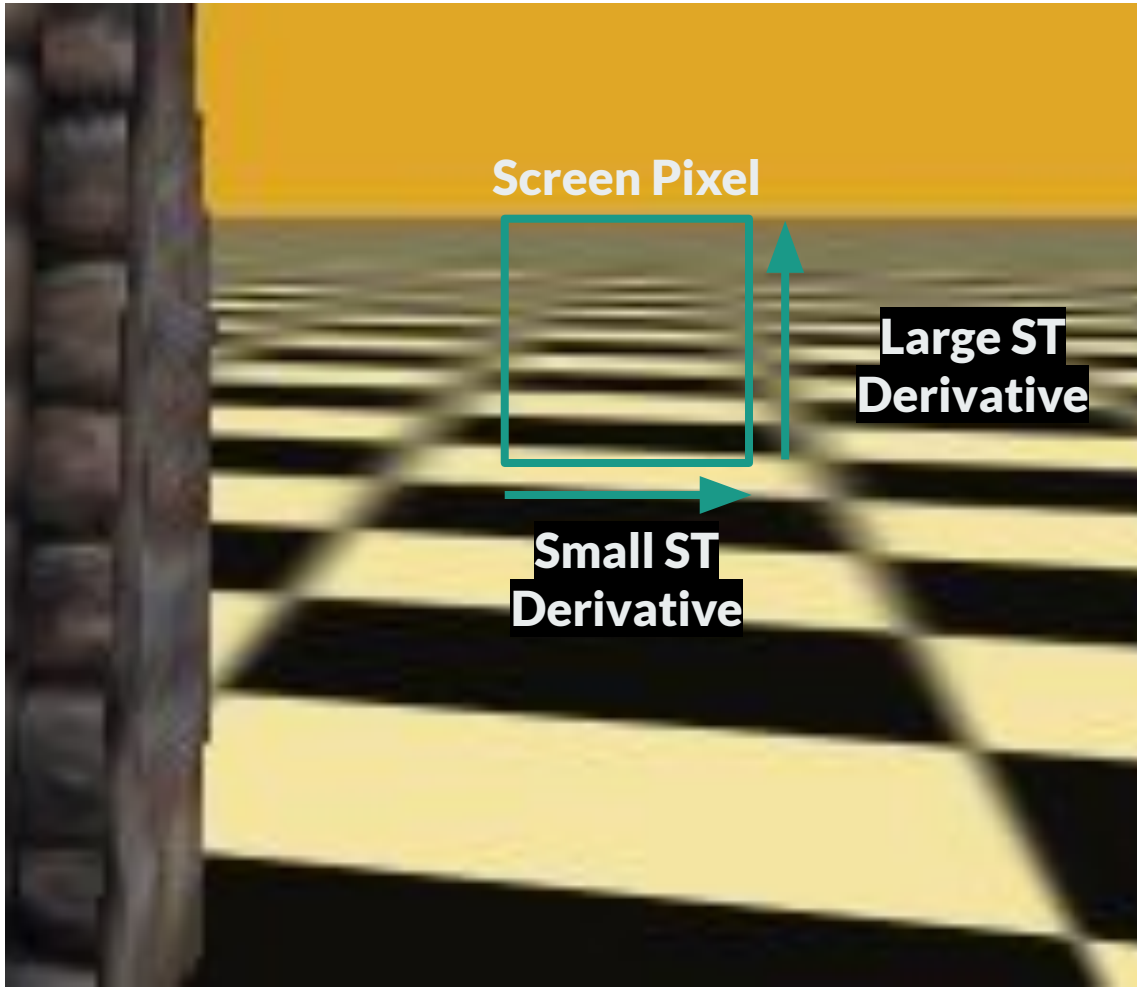


Use the numerical derivative of the texture coordinates.
GPUs compute fragments in a 2x2 block.

```
vec2 pixel = tex_coord *
textureSize(sampler, 0);

vec2 dx = dFdx(pixel);
vec2 dy = dFdy(pixel);

float d = max(
     dot(dx, dx),
     dot(dy, dy)
     );

float lod = 0.5 * log2(d);
```

This is automatically computed in “texture” function. No need to write it ourselves.


▶ Controls
Too Blurry. Why?



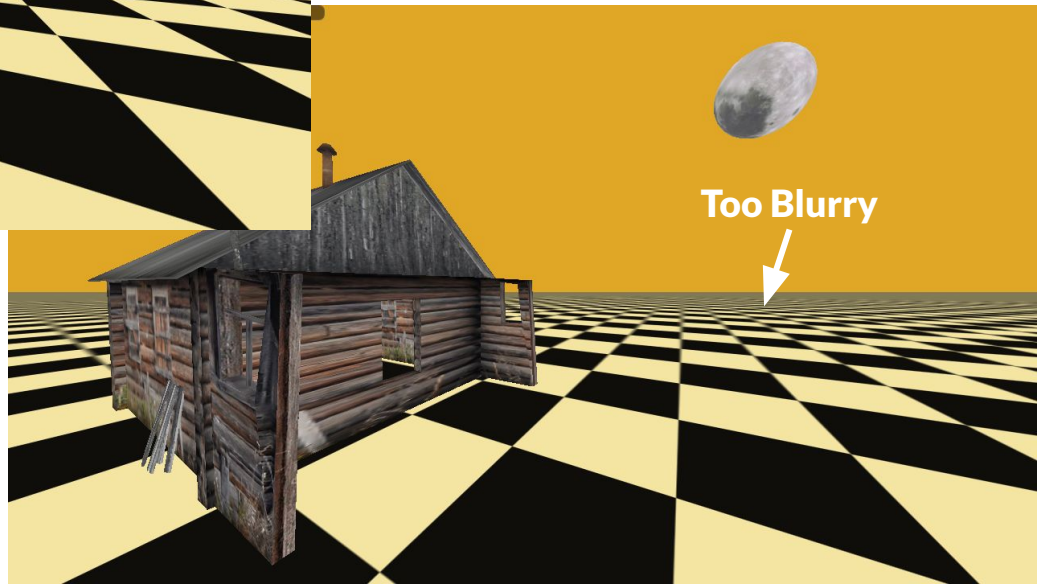
Since the mip level formula picks the maximum derivative, the mip level will be high even if the derivative is small on one dimension

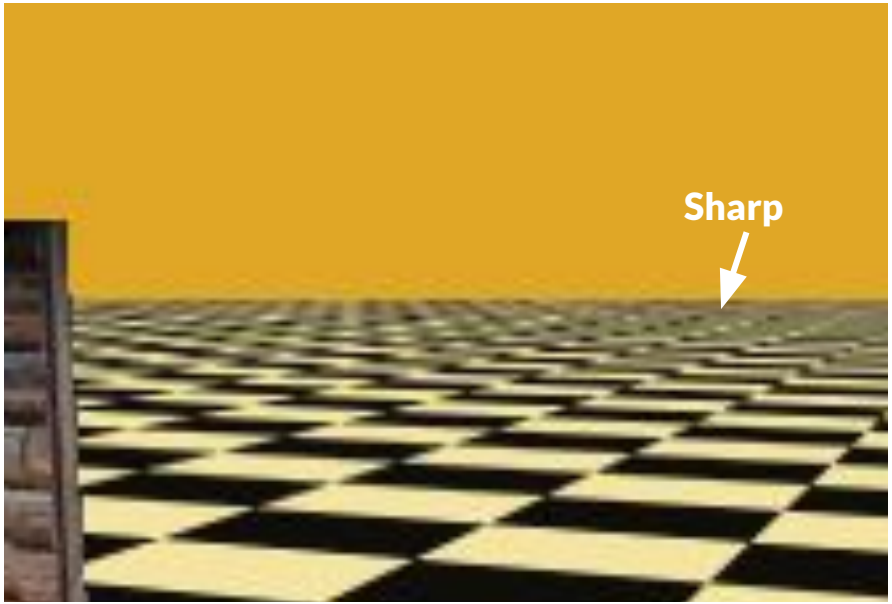
```
vec2 pixel = tex_coord *
textureSize(sampler, 0);

vec2 dx = dFdx(pixel);
vec2 dy = dFdy(pixel);

float d = max(
     dot(dx, dx),
     dot(dy, dy)
     );

float lod = 0.5 * log2(d);
```

Anisotropy works when direction of distortion is different from one direction to another

Maximum Anisotropy = 16

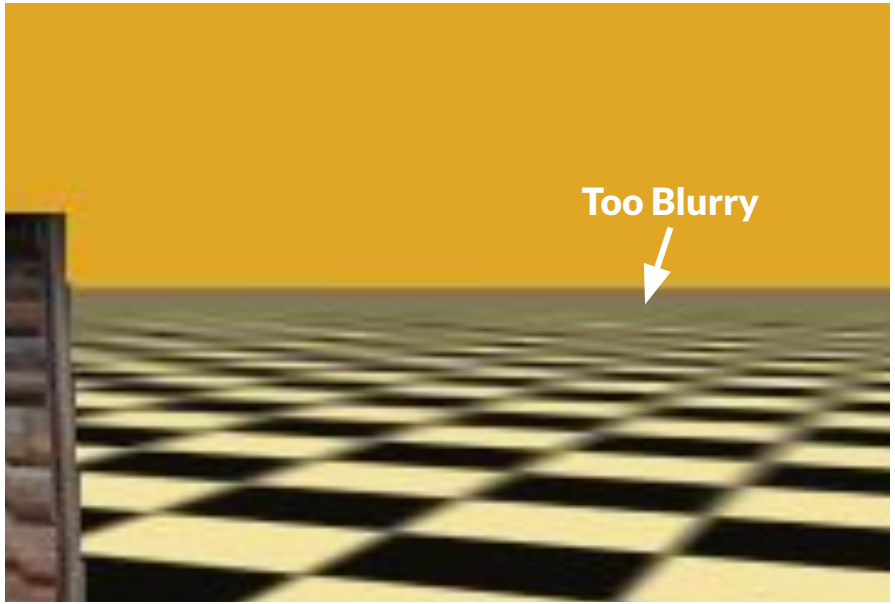
Maximum Anisotropy = 1

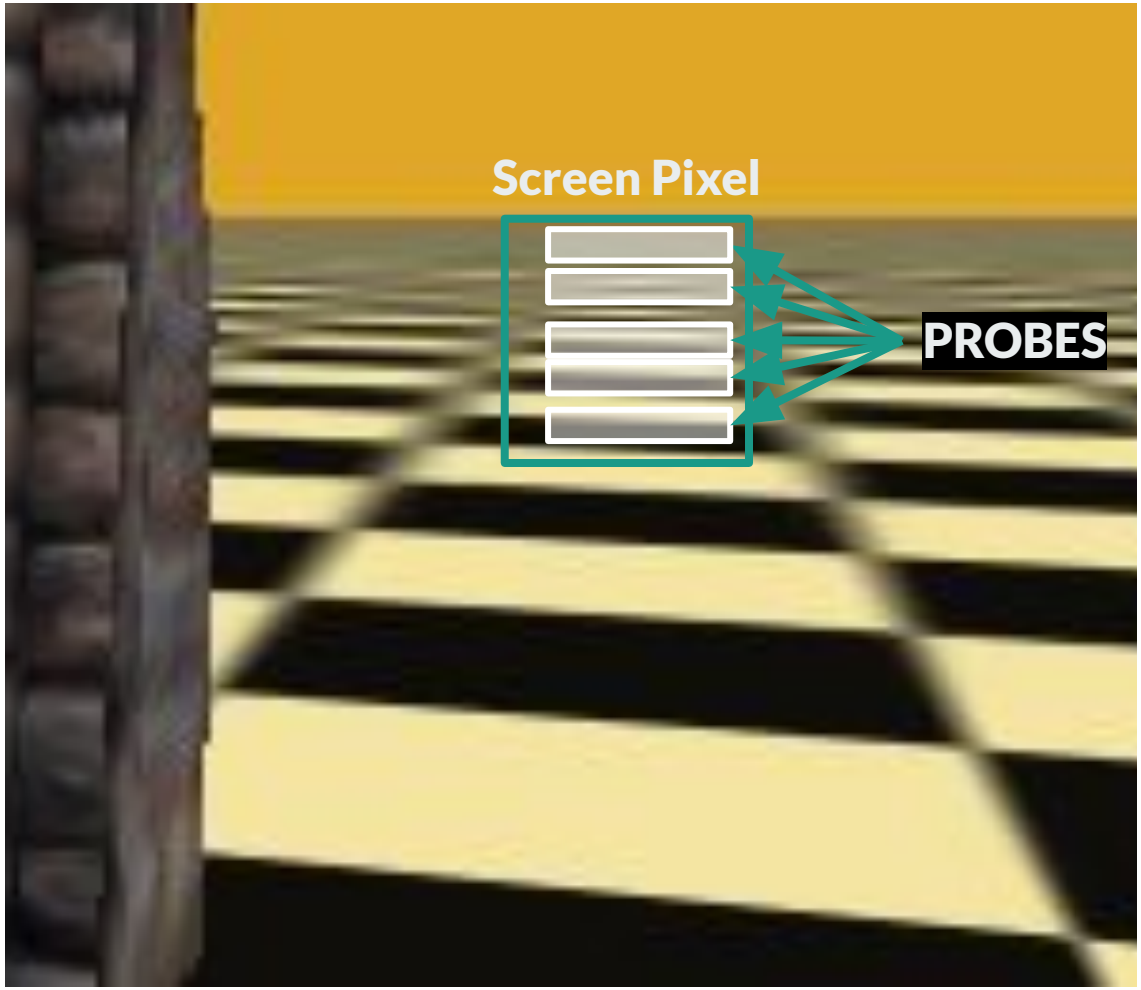




Maximum Anisotropy = 16

Maximum Anisotropy = 1





Anisotropic Filtering uses multiple probes to sample the color and the samples are then merged together.

Each probe is sampled with filtering (with mipmaps).

The details of the anisotropic filtering mechanism is not specified by OpenGL so it is vendor specific.

Anisotropic filtering is not a replacement for mipmap filtering; they are used commonly together.

Anisotropic Filtering

16 is like the image in slide 54

```
glTexParameterf(GL_TEXTURE_2D, GL_TEXTURE_MAX_ANISOTROPY_EXT, 16.0f);
```

Pick maximum anisotropy for filtering the texture (Minimum possible value = 1.0f)

```
GLfloat max_anisotropy_upper_bound;
glGetFloatv(GL_MAX_TEXTURE_MAX_ANISOTROPY_EXT, &max_anisotropy_upper_bound);
```

Ask OpenGL for the maximum possible value for “Maximum Anisotropy”.

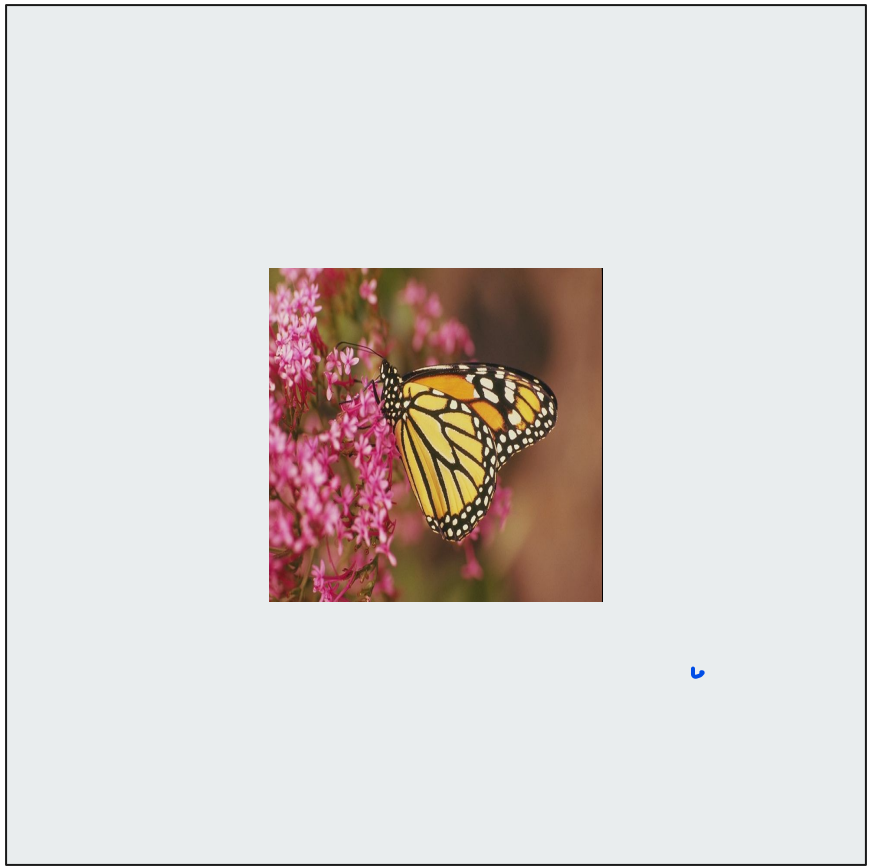
The highest possible maximum anisotropy depends on the GPU capabilities.

0.0, 1.0 1.0, 1.0

0.0, 0.0 1.0, 0.0

-1.0, 2.0

2.0, 2.0



???

-1.0, -1.0

2.0, -1.0

-1.0, 2.0

2.0, 2.0

GL_REPEAT

-1.0, -1.0

2.0, -1.0

-1.0, 2.0

2.0, 2.0

GL_MIRRORED_REPEAT

-1.0, -1.0

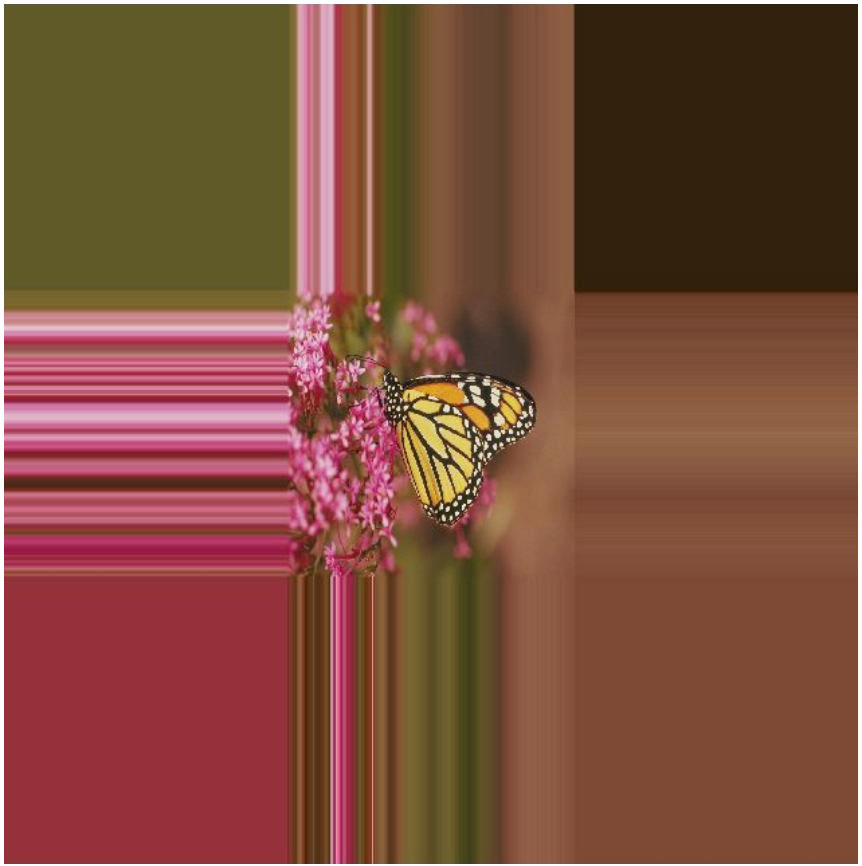
2.0, -1.0

-1.0, 2.0

2.0, 2.0

Repeat pixels @ borders

GL_CLAMP_TO_EDGE



-1.0, -1.0

2.0, -1.0

-1.0, 2.0

2.0, 2.0

GL_CLAMP_TO_BORDER

-1.0, -1.0

2.0, -1.0

Wrapping Mode

Wrapping mode over the S coordinate

```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_REPEAT);
```

```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_MIRRORED_REPEAT);
```

```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_CLAMP_TO_EDGE);
```

```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_CLAMP_TO_BORDER);
```

Wrapping mode over the T coordinate

```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_REPEAT);
```

```
...
```

Wrapping Mode

```
float color[] = {1.0f, 0.0f, 0.0f, 1.0f};
glTexParameterfv(GL_TEXTURE_2D, GL_TEXTURE_BORDER_COLOR, color);
```

Choose border color

Sampler State

```
glBindTexture(GL_TEXTURE_2D, texture);

glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, magnification_filter);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, minification_filter);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, wrap_s);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, wrap_t);
glTexParameterfv(GL_TEXTURE_2D, GL_TEXTURE_BORDER_COLOR, border_color);
glTexParameterf(GL_TEXTURE_2D, GL_TEXTURE_MAX_ANISOTROPY_EXT, max_anisotropy);
```

There are more states that are not defined here

Using “glTexParameter”, the sampler state must be defined for each texture individually.

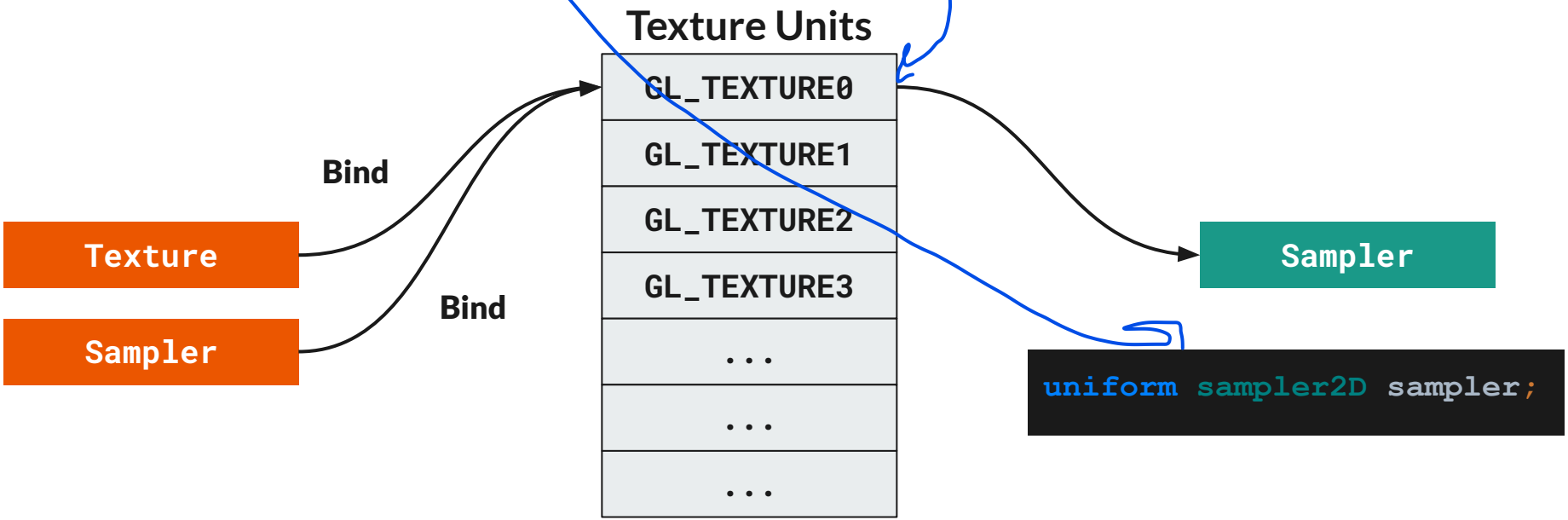
Sampler Objects

```
GLuint sampler;
glGenSamplers(1, &sampler);

glSamplerParameteri(sampler, GL_TEXTURE_MAG_FILTER, magnification_filter);
glSamplerParameteri(sampler, GL_TEXTURE_MIN_FILTER, minification_filter);
glSamplerParameteri(sampler, GL_TEXTURE_WRAP_S, wrap_s);
glSamplerParameteri(sampler, GL_TEXTURE_WRAP_T, wrap_t);
glSamplerParameterfv(sampler, GL_TEXTURE_BORDER_COLOR, border_color);
glSamplerParameterf(sampler, GL_TEXTURE_MAX_ANISOTROPY_EXT, max_anisotropy);
```

So use same sampler for different textures :D. just properties for the texture we got saved it

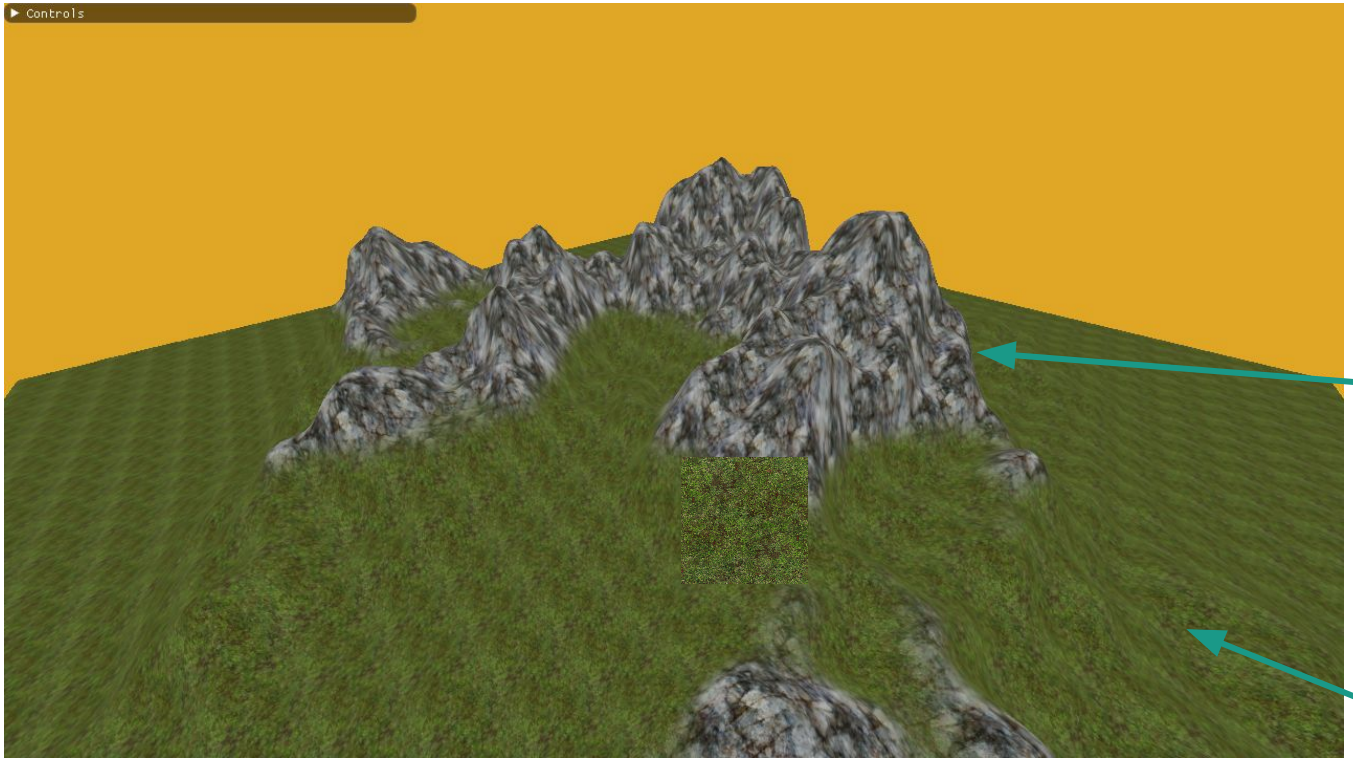
A sampler object can be used with multiple textures (no need to redefine sampler state for each texture).

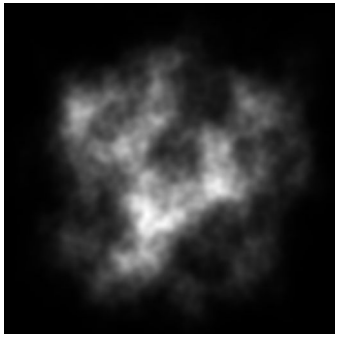
```
glActiveTexture(GL_TEXTURE0);
glBindTexture(GL_TEXTURE_2D, texture);
glBindSampler(0, sampler);
GLuint sampler_loc = glGetUniformLocation(program, "sampler");
glUniform1i(sampler_loc , 0);
```

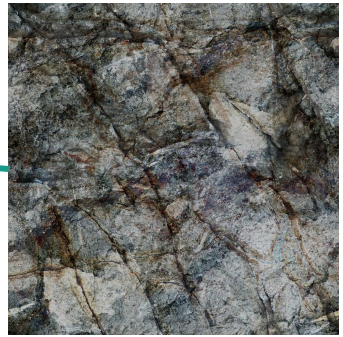


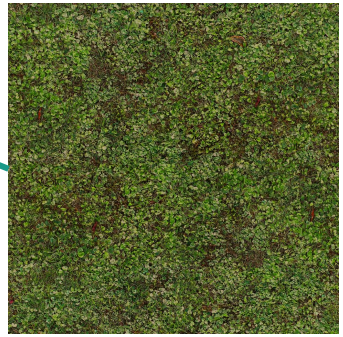
Textures were mainly created to store color data

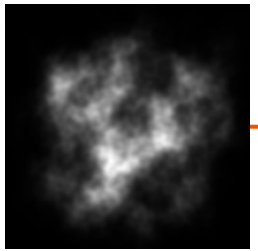
But you can store any kind of data in it as long as they are vectors.


Controls

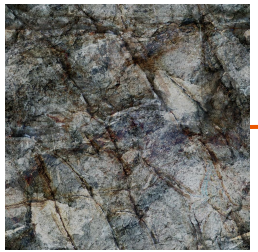


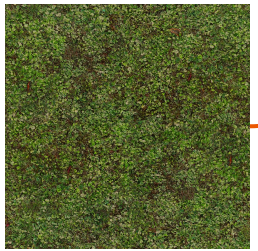






Height Sampler





Color Sampler

Texture Units

GL_TEXTURE0
GL_TEXTURE1
GL_TEXTURE2
GL_TEXTURE3
...
...
...

```
uniform sampler2D height_sampler;
uniform sampler2D top_sampler;
uniform sampler2D bottom_sampler;
```

```
glGenSamplers(1, &height_sampler);

glSamplerParameteri(height_sampler, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
glSamplerParameteri(height_sampler, GL_TEXTURE_MIN_FILTER, GL_LINEAR);
glSamplerParameteri(height_sampler, GL_TEXTURE_WRAP_S, GL_CLAMP_TO_EDGE);
glSamplerParameteri(height_sampler, GL_TEXTURE_WRAP_T, GL_CLAMP_TO_EDGE);
```

```
glGenSamplers(1, &color_sampler);

glSamplerParameteri(color_sampler, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
glSamplerParameteri(color_sampler, GL_TEXTURE_MIN_FILTER, GL_LINEAR_MIPMAP_LINEAR);
glSamplerParameteri(color_sampler, GL_TEXTURE_WRAP_S, GL_REPEAT);
glSamplerParameteri(color_sampler, GL_TEXTURE_WRAP_T, GL_REPEAT);
```

```
glActiveTexture(GL_TEXTURE0);
glBindTexture(GL_TEXTURE_2D, height_texture);
glBindSampler(0, height_sampler);
glUniform1i(glGetUniformLocation(program, "height_sampler") , 0);

glActiveTexture(GL_TEXTURE1);
glBindTexture(GL_TEXTURE_2D, top_texture);
glBindSampler(1, color_sampler);
glUniform1i(glGetUniformLocation(program, "top_sampler") , 1);

glActiveTexture(GL_TEXTURE2);
glBindTexture(GL_TEXTURE_2D, bottom_texture);
glBindSampler(2, color_sampler);
glUniform1i(glGetUniformLocation(program, "bottom_sampler") , 2);
```

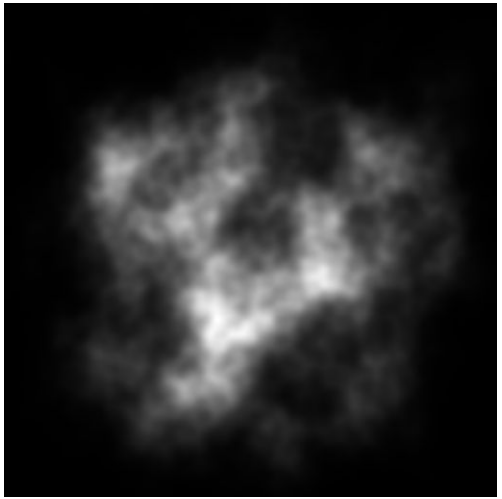
glad/gl.h

```
#define GL_TEXTURE0 0x84C0
#define GL_TEXTURE1 0x84C1
#define GL_TEXTURE2 0x84C2
#define GL_TEXTURE3 0x84C3
#define GL_TEXTURE4 0x84C4
#define GL_TEXTURE5 0x84C5
#define GL_TEXTURE6 0x84C6
#define GL_TEXTURE7 0x84C7
...
```

GL_TEXTURE*N* = GL_TEXTURE0 + *N*

```
glPixelStorei(GL_UNPACK_ALIGNMENT, 1);
glTexImage2D(GL_TEXTURE_2D, 0, GL_R8, size.x, size.y, 0, GL_RED, GL_UNSIGNED_BYTE, data);
```

Internal Format (only red channel)



Part of Vertex Shader

```
float height = texture(height_sampler, tex_coord).r;

gl_Position = transform * vec4(position + vec3(0, height, 0), 1.0);

vsout.terrain_height = height;
```

Part of Fragment Shader

```
vec4 top_color = texture(terrain_top_sampler, fsin.tex_coord);
vec4 bottom_color = texture(terrain_bottom_sampler, fsin.tex_coord);

float mix_factor = smoothstep(bottom, top, fsin.terrain_height);

frag_color = mix(bottom_color, top_color, mix_factor);
```

Frame Buffers

- 2D Array of Pixels
- Color Data
- We can draw on it

- 2D Array of Pixels
- Color Data
- Can we draw on it???

Create and Bind Frame Buffer

```
GLuint frame_buffer;
glGenFramebuffers(1, &frame_buffer);
glBindFramebuffer(GL_DRAW_FRAMEBUFFER, frame_buffer);
```

Bind Target can be:

- GL_DRAW_FRAMEBUFFER to which we can draw.
- GL_READ_FRAMEBUFFER from which we can read pixels.
- GL_FRAMEBUFFER which can be used for both reading and drawing.

Create and Attach a Color Target Texture

```
glGenTextures(1, &texture);
glBindTexture(GL_TEXTURE_2D, texture);

GLuint mip_levels = glm::floor(glm::log2(glm::max<float>(width, height))) + 1;
glTexStorage2D(GL_TEXTURE_2D, mip_levels, GL_RGBA8, width, height);

glFramebufferTexture2D(GL_DRAW_FRAMEBUFFER, GL_COLOR_ATTACHMENT0, GL_TEXTURE_2D,
texture, 0);
```

Create an Empty Texture

How many mips to allocate

Level (must be 0)

You can attach multiple color target to a single framebuffer (useful for some techniques).

Create and Attach a Depth Target Texture

```
glGenTextures(1, &texture);
glBindTexture(GL_TEXTURE_2D, texture);


glTexStorage2D(GL_TEXTURE_2D, 1, GL_DEPTH_COMPONENT32, width, height);

glFramebufferTexture2D(GL_DRAW_FRAMEBUFFER, GL_DEPTH_ATTACHMENT, GL_TEXTURE_2D,
texture, 0);
```

Depth only needs 1 mip level

Level (must be 0)

Depth should be attached a depth attachment

Check if Framebuffer is complete

```
if (glCheckFramebufferStatus(GL_DRAW_FRAMEBUFFER) != GL_FRAMEBUFFER_COMPLETE){
    std::cerr << "Frame buffer is incomplete" << std::endl;
}
```

There are some rules for FrameBuffer completeness. All of them are mentioned here:
https://www.khronos.org/opengl/wiki/Framebuffer_Object#Framebuffer_Completeness

Draw

STEP 1:

```
glBindFramebuffer(GL_DRAW_FRAMEBUFFER, frame_buffer);
glViewport(0, 0, framebuffer_width, framebuffer_height);
```

STEP 2: **Draw stuff to framebuffer**

STEP 3:

```
glBindFramebuffer(GL_DRAW_FRAMEBUFFER, 0);
glViewport(0, 0, window_width, window_height);
```

STEP 4: **Draw stuff to window (You can use the render target texture here).**

Without Post Processing

Why do we need to draw in frame buffer then map to the screen not to directly draw on the screen

With Post Processing

Planar Reflection

Render frame without this reflection then make post processing to make reflection

Thank you