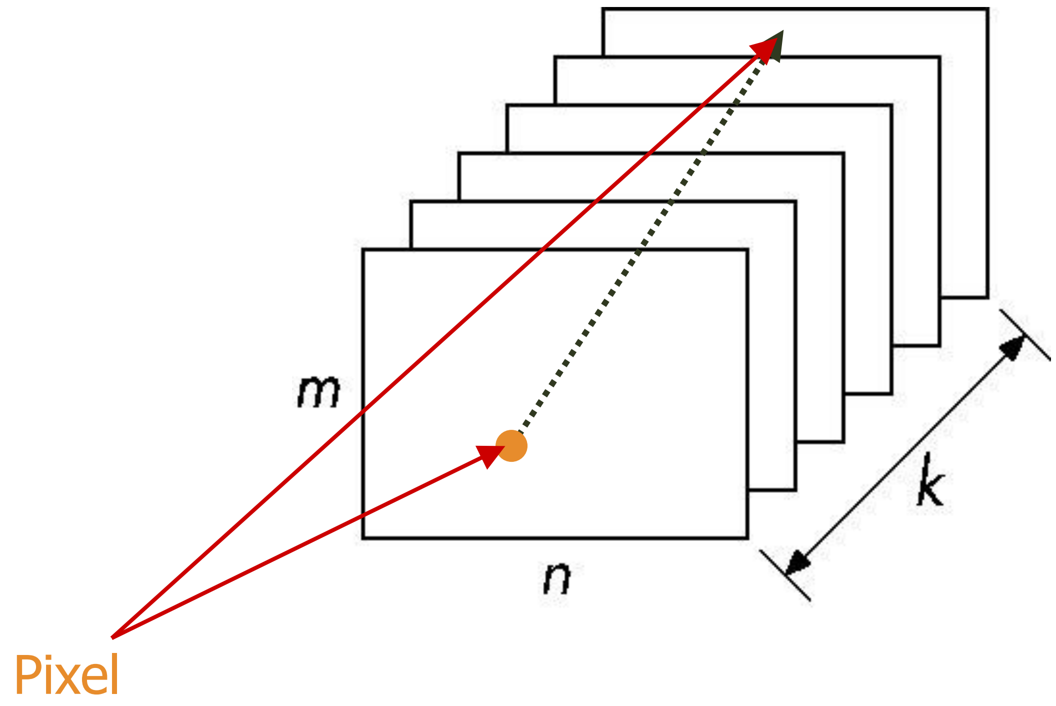
Discrete Techniques

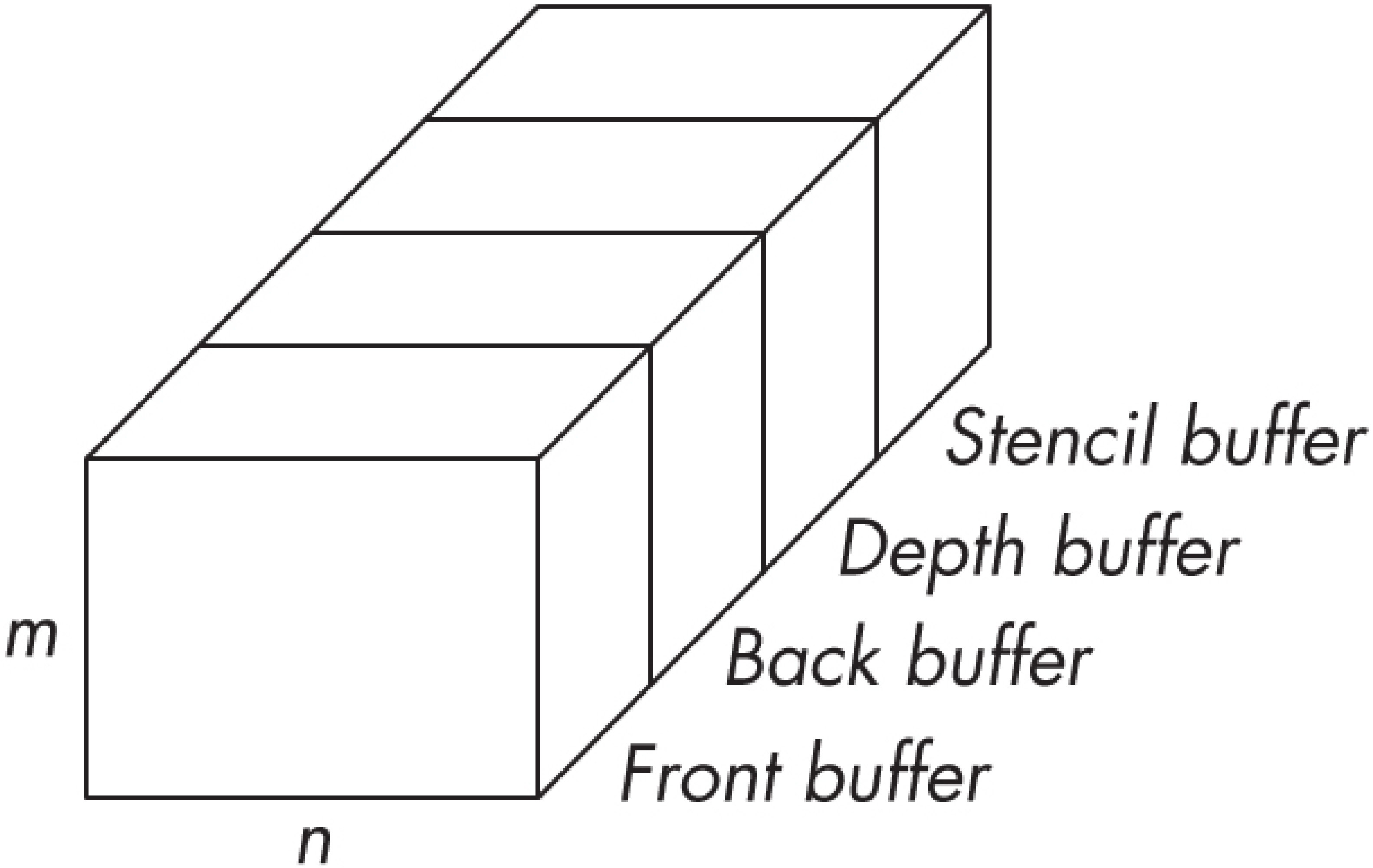
12TH WEEK, 2021

Buffer

- Define a buffer by its spatial resolution ($n \times m$) and its depth (or precision) k, the number of bits/pixel



WebGL Frame Buffer



Where are the Buffers?

- HTML5 Canvas
  - Default front and back color buffers
  - Under control of local window system
  - Physically on graphics card
- Depth buffer also on graphics card
- Stencil buffer
  - Holds masks
- Most RGBA buffers 8 bits per component
- Latest are floating point (IEEE)

Other Buffers

- Desktop OpenGL supported other buffers
  - Auxiliary color buffers
  - Accumulation buffer
  - These were on application side
  - Now deprecated
- GPUs have their own or attached memory
  - Texture buffers
  - Off-screen buffers
    - Not under control of window system
    - May be floating point

Images

- Framebuffer contents are unformatted
  - Usually RGB or RGBA
  - One byte per component
  - No compression
- Standard Web image format
  - Jpeg, gif, png
- WebGL has no conversion functions
  - Understands standard Web formats for texture images

Buffer Reading

- WebGL can read pixels from the framebuffer with gl.readPixels( )
- Returns only 8 bit RGBA values
- In general, the format of pixels in the frame buffer is different from that of processor memory and these two types of memory reside in different places
  - Need packing and unpacking
  - Reading can be slow
- Drawing through texture functions and off-screen memory (frame buffer object)

WebGL Pixel Function

```
gl.readPixels(x,y,width,height,format,type,myimage)
```

start pixel in frame buffer

size

type of image

type of pixels

pointer to processor memory

```
var myimage[512*512*4];

gl.readPixels(0,0, 512, 512, gl.RGBA,
      gl.UNSIGNED_BYTE, myimage);
```

Render to Texture

- GPUs now include a large amount of texture memory that we can write into
- Advantage: fast (not under control of window system)
- Using frame buffer objects (FBOs) we can render into texture memory instead of the frame buffer and then read from this memory
  - Image processing
  - GPGPU

The Limits of Geometric Modeling

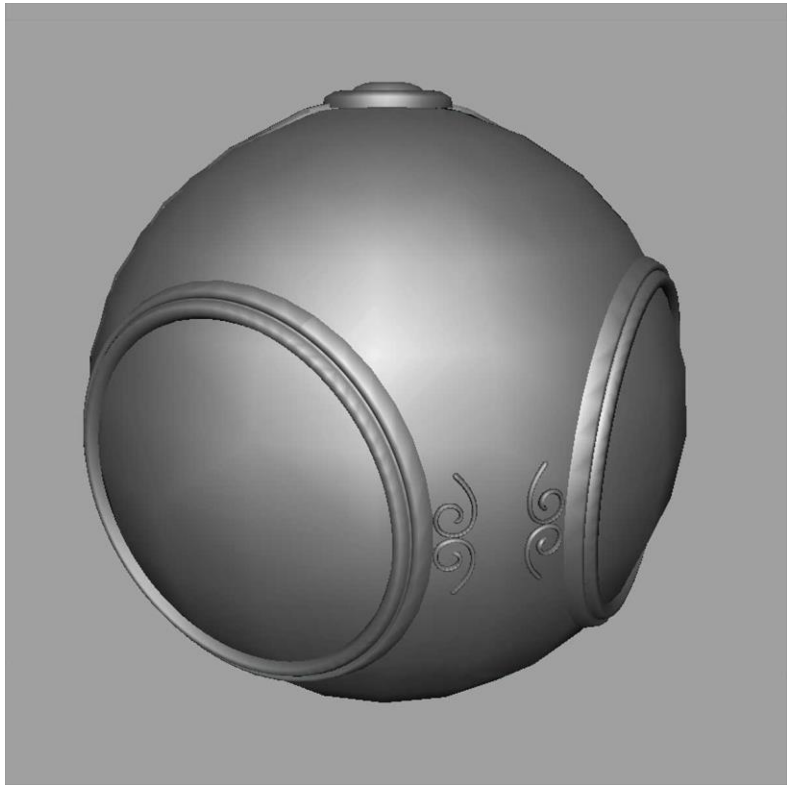
- Although graphics card can render over 10 million polygons per second, that number is insufficient for many phenomena
  - Clouds, grass, terrain, skin, etc.

- Consider the problem of modeling an orange
  - An orange-colored sphere → too simple
    ➔ *texture mapping*
  - More complex shape → too many polygons to model all the dimples
    ➔ *bump mapping*

Three Types of Mapping

- *Texture mapping*
  - Uses images to fill inside of polygons
- *Environment* (reflection) *mapping*
  - Uses a picture of the environment for texture maps
  - Allows simulation of highly specular surfaces
- *Bump mapping*
  - Emulates altering normal vectors during the rendering process

Texture Mapping

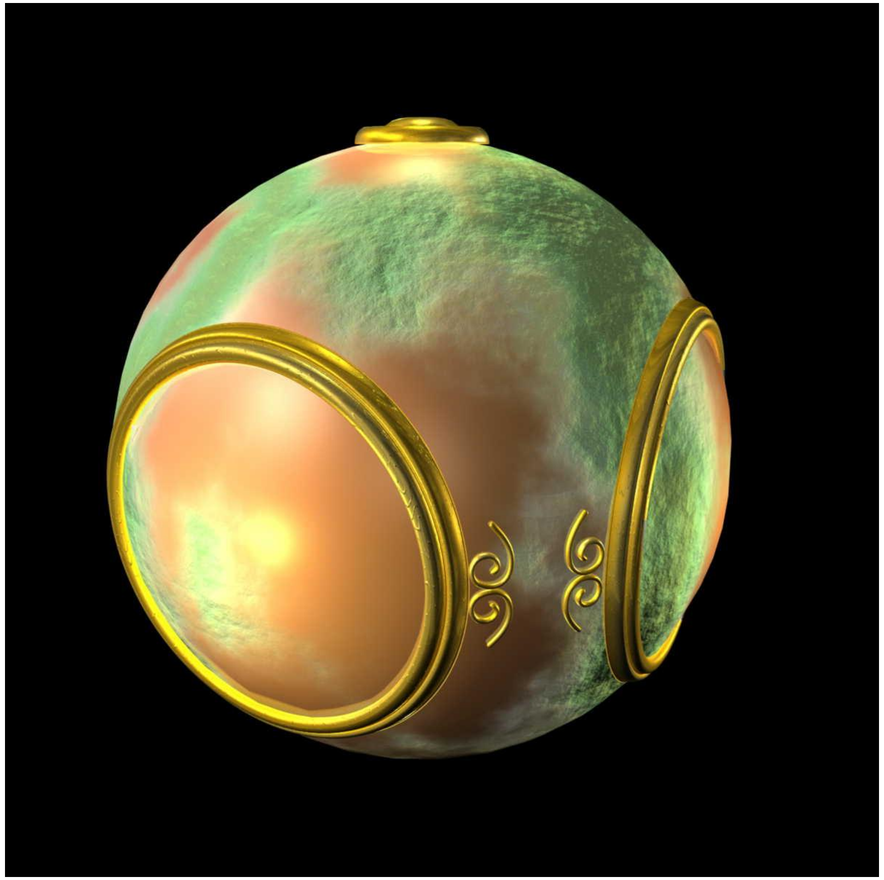


Geometric Model

Texture Mapped

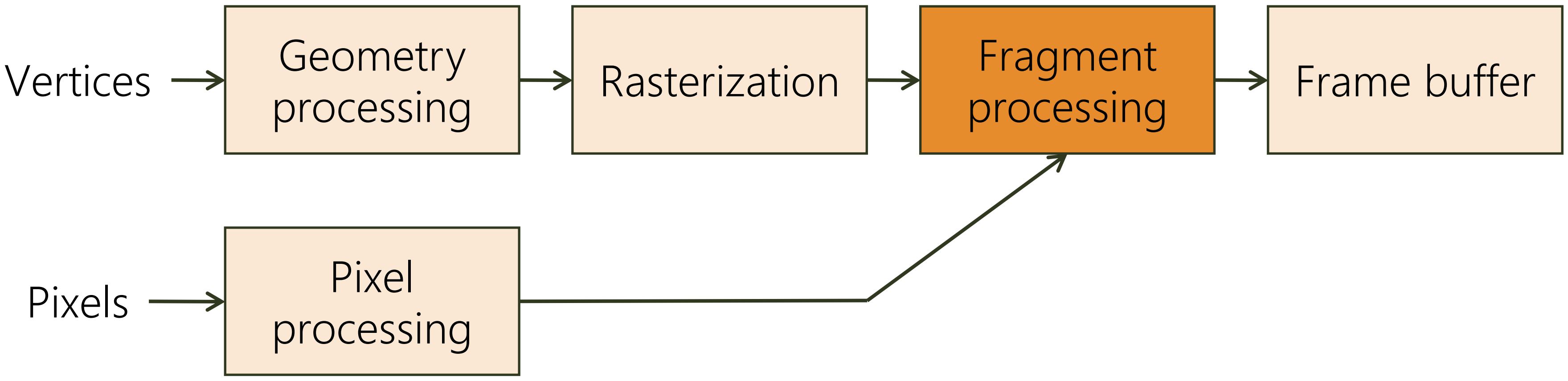
Environment Mapping

Bump Mapping



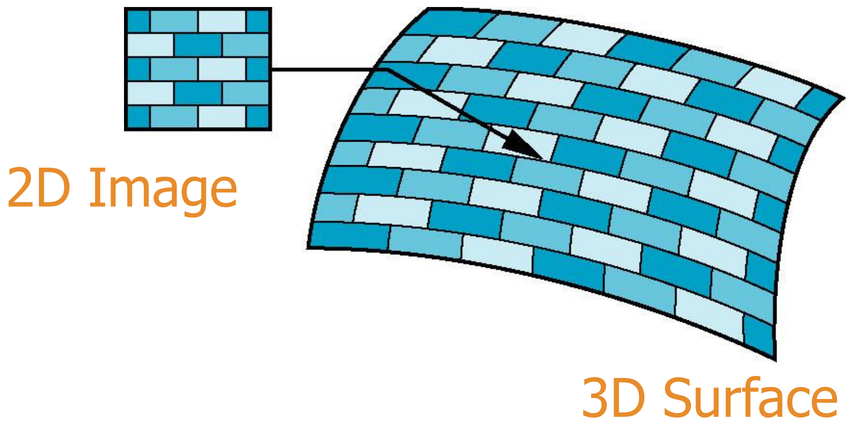
Where Does Mapping Take Place?

- Mapping techniques are implemented at the end of the rendering pipeline
  - Very efficient because a few polygons make it past clipper



Is It Simple?

- Mapping a pattern (texture) to a surface

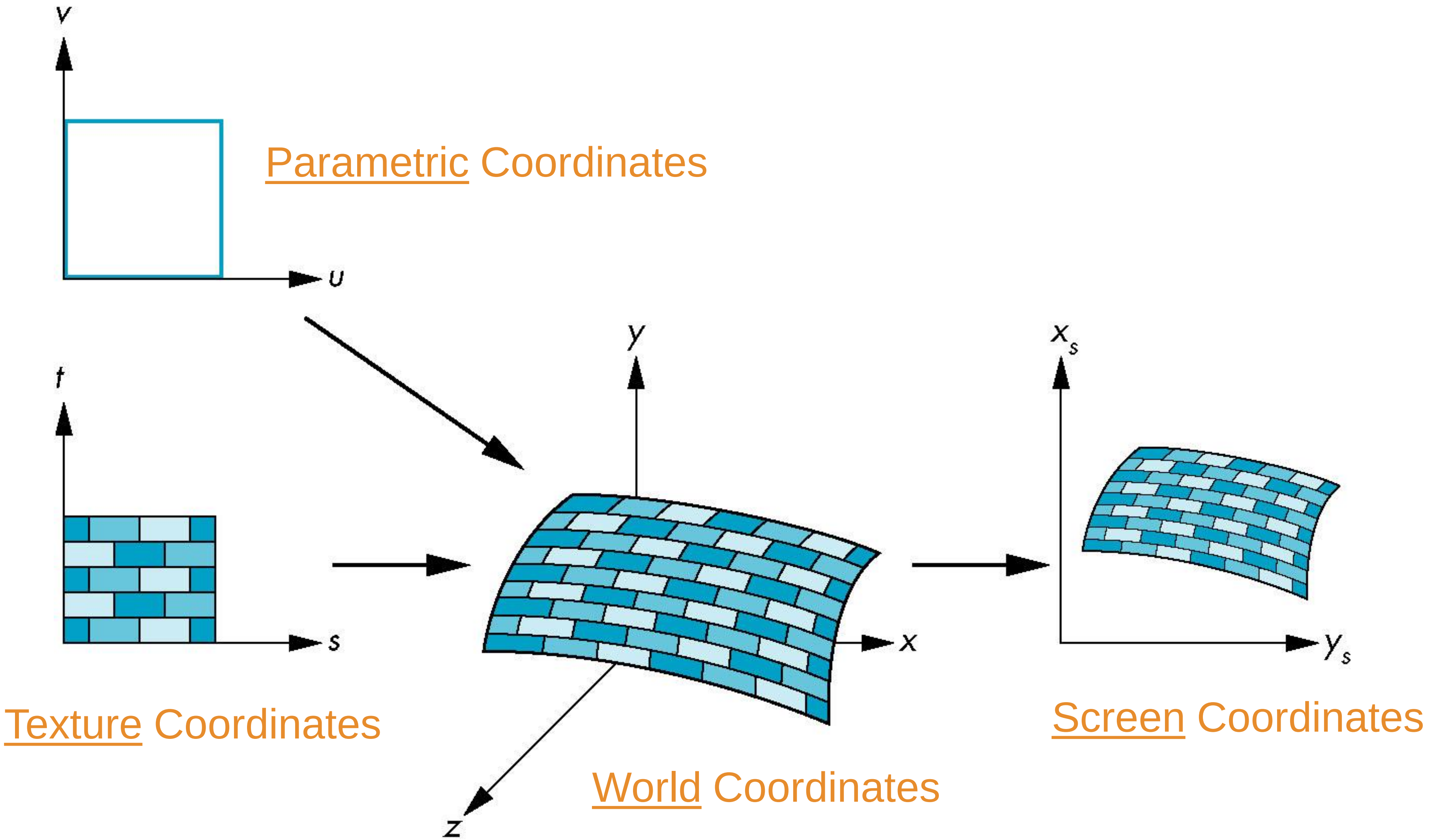


- Although the idea is simple – map an image to a surface – there are 3 or 4 coordinate system involved

Coordinate Systems

- Parametric coordinates
  - May be used to model curves and surfaces
- Texture coordinates
  - Used to identify points in the image to be mapped
- Object or world coordinates
  - Conceptually, where the mapping takes place
- Window or screen coordinates
  - Where the final image is really produced

Texture Mapping



Terminology for Texture Mapping

- *Texel* (texture element)
  - Textures are brought into processor memory as arrays
- *Texture coordinates* $T(s, t)$
  - Continuous rectangular 2D texture pattern
  - Generally varying over the interval (0, 1)
- Texture map
  - World coordinates ↔ texture coordinates

$$x = x(s,t)$$
$$y = y(s,t)$$
$$z = z(s,t)$$

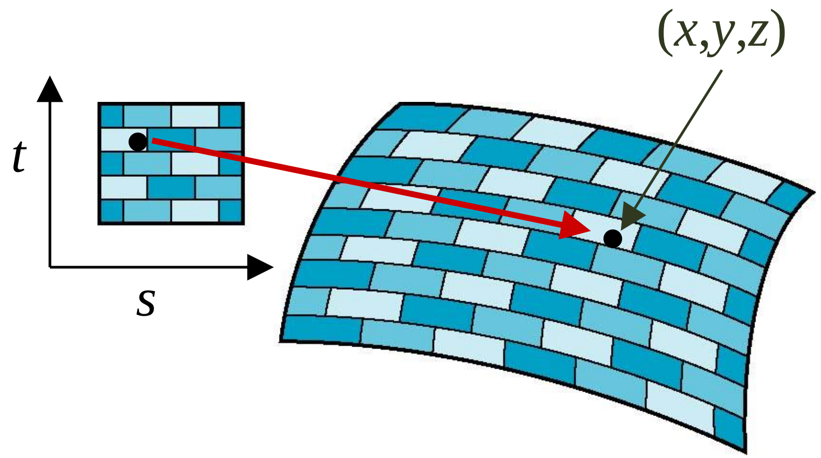
$$\Longleftrightarrow$$

$$s = s(x,y,z)$$
$$t = t(x,y,z)$$

Mapping Functions

- Basic problem is how to find the maps
- Consider mapping from texture coordinates to a point on a surface
- Appear to need three functions

$$x = x(s,t)$$
$$y = y(s,t)$$
$$z = z(s,t)$$



- But we really want to go the other way

Backward Mapping

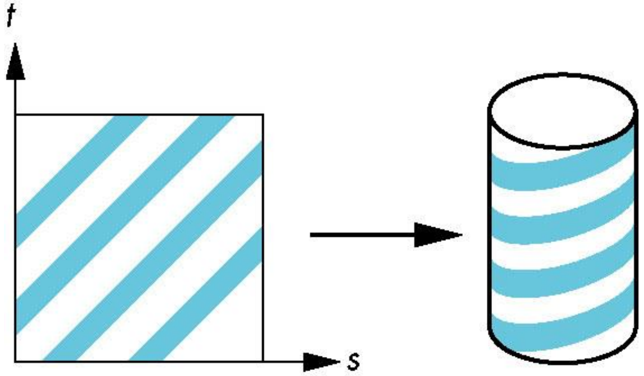
- We really want to go backward
  - Given a texel, we want to know to which point on an object it corresponds → forward
  - Given a point on an object, we want to know to which point in the texture it corresponds → backward
- Need a map of the form

$$s = s(x, y, z)$$
$$t = t(x, y, z)$$

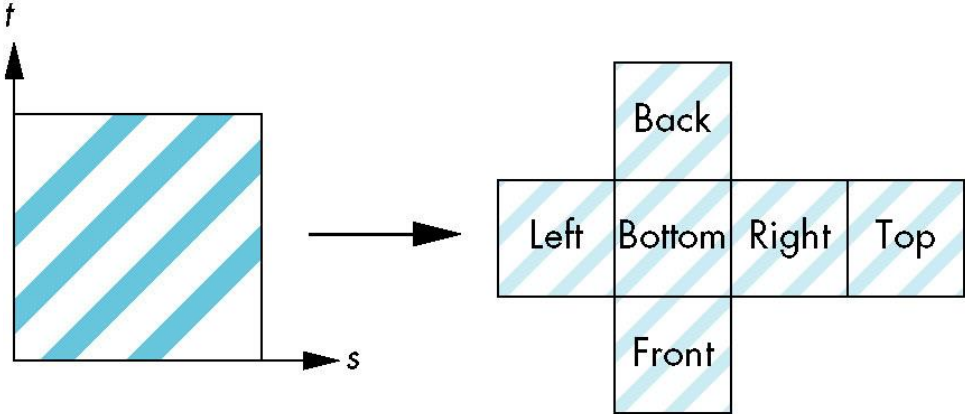
- Such functions are difficult to find in general

Two-Part Mapping

- One solution to the mapping problem is to first map the texture to a simple intermediate surface such as a cylinder, a sphere, a box
- Example:



Texture Mapping with Cylinder



Texture Mapping with a Box

First Mapping

- Cylindrical mapping
  - Parametric cylinder:

$$\boxed{\begin{aligned} x &= r\cos 2\pi u \\ y &= r\sin 2\pi u \\ z &= v/h \end{aligned}}$$

$s=u$
$t=v$

r: radius
h: height

- Spherical mapping
  - Parametric sphere:

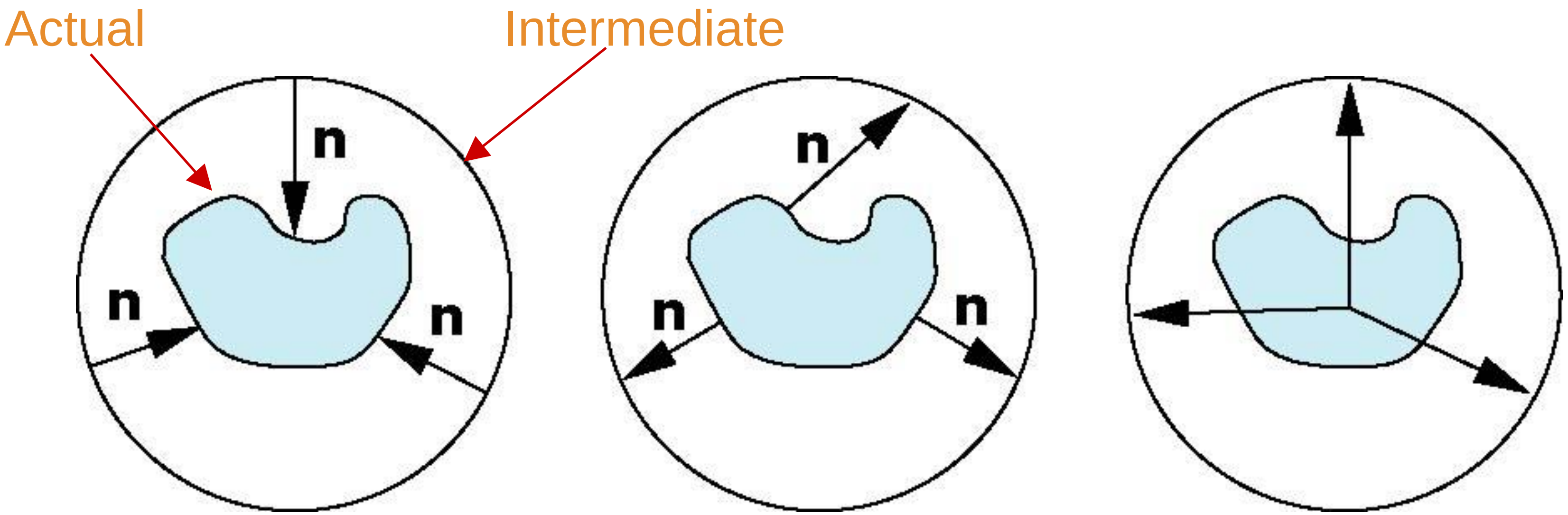
$$\boxed{\begin{aligned} x &= r\cos 2\pi u \\ y &= r\sin 2\pi u\cos 2\pi v \\ z &= r\sin 2\pi u\sin 2\pi v \end{aligned}}$$

$s=u$
$t=v$

  - Spheres are used in environmental maps
- Box mapping
  - Easy to use with simple orthographic projection
  - Also used in environment maps

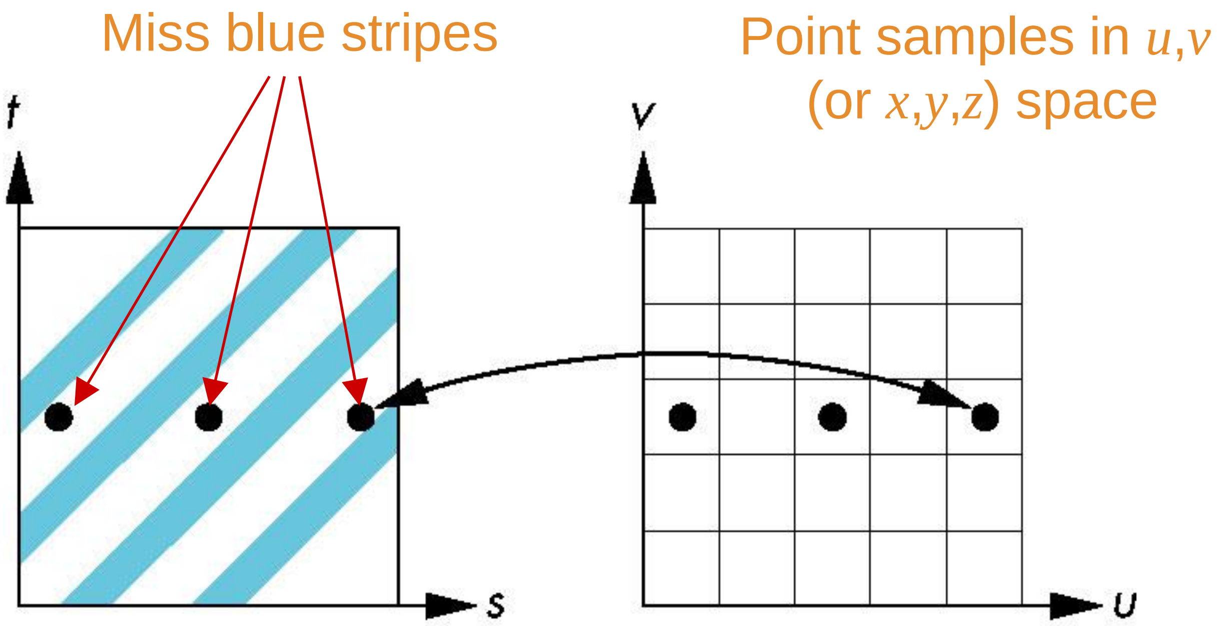
Second Mapping

- Map from intermediate object to actual object
  - Using the normals from intermediate to actual
  - Using the normals from actual to intermediate
  - Using the vectors from center of the object to intermediate



Aliasing

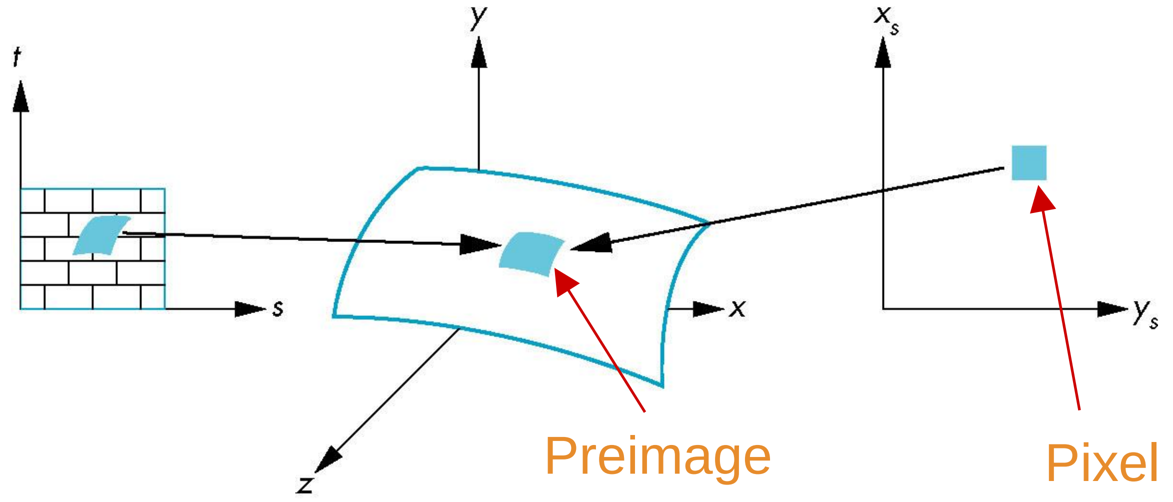
- Point sampling of the texture can lead to aliasing errors



Point samples in texture space

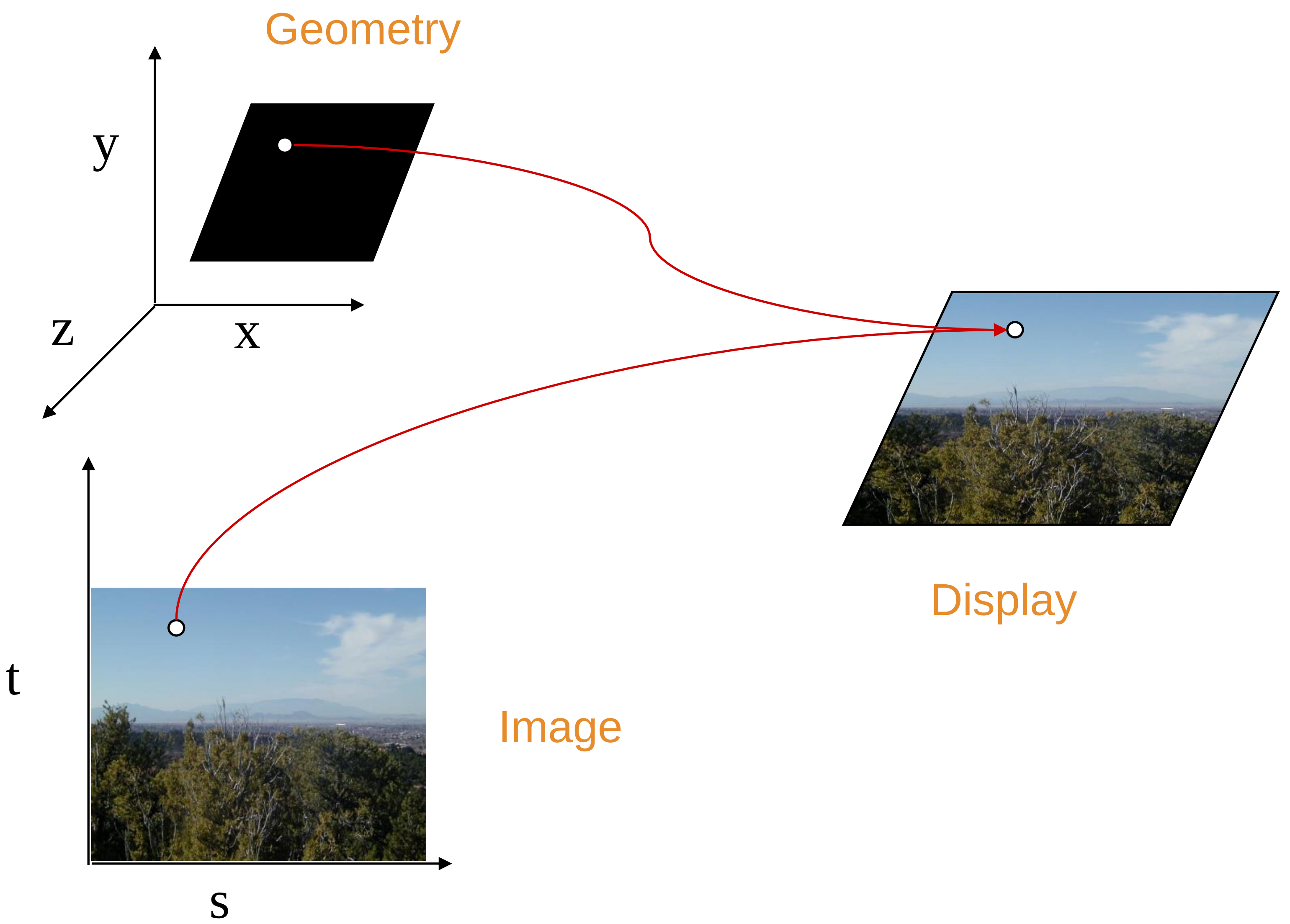
Area Averaging

- A better but slower option is to use area averaging



- *Preimage*
  - The projection of the corners of a pixel backward into object space
  - Preimage of the pixel is curved

Texture Mapping

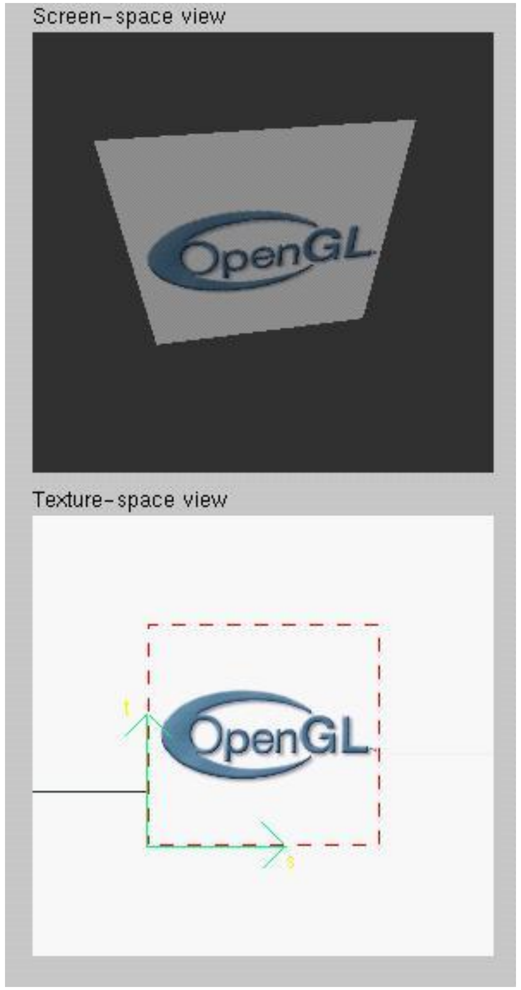


Basic Strategy

- Three steps to apply a texture
  1. Specify the texture
     - Read or generate image
     - Assign to texture
     - Enable texturing
  2. Assign texture coordinates to vertices
     - Proper mapping function is left to application
  3. Specify texture parameters
     - Wrapping, filtering

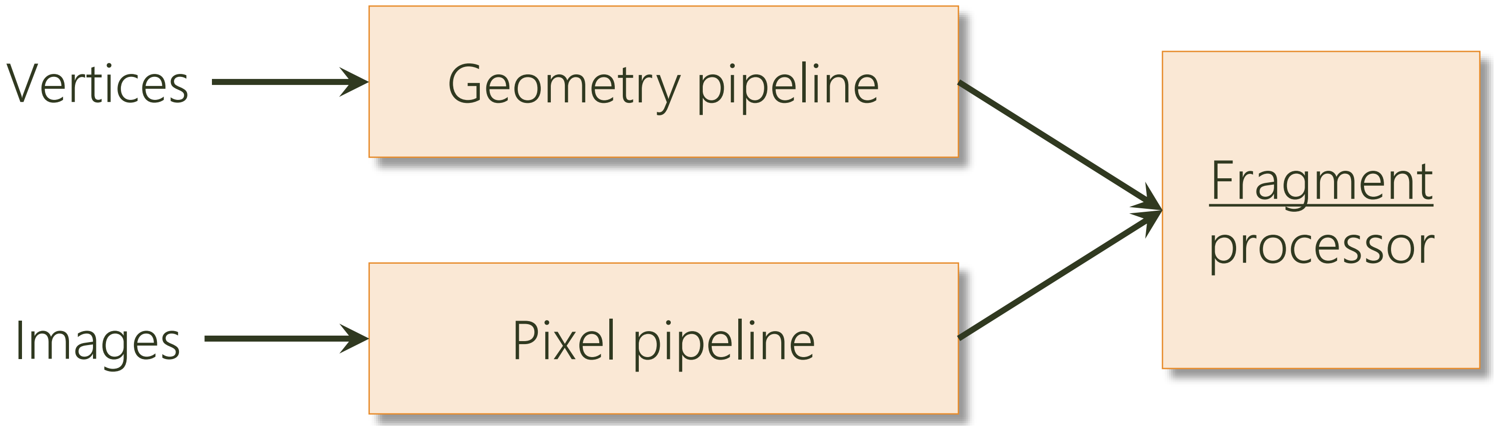
Texture Example

- The texture (below) is a 256×256 image that has been mapped to a rectangular polygon which is viewed in perspective



Texture Mapping and the WebGL Pipeline

- Images and geometry flow through separate pipelines that join during fragment processing
  - "Complex" textures do not affect geometric complexity



Specifying a Texture Image

- Define a texture image from an array of ***texels*** (texture element) in CPU memory
- Use an image in a standard format such as BMP
  - Scanned image
  - Generated by application code
- WebGL supports only 2 dimensional texture maps
  - No need to enable as in desktop OpenGL
  - Desktop OpenGL supports 1~4 dimensional texture maps

Define Image as a Texture

```
void gl.texImage2D(target, level, components,
                   width, height, border,
                   format, type, texels);
```

- **`target:`** type of texture (e.g. **`gl.TEXTURE_2D`**)
- **`level:`** used for mipmapping (discussed later)
- **`components:`** elements per texel
- **`w, h:`** width and height of **`texels`** in pixels
- **`border:`** used for smoothing (discussed later)
- **`format and type:`** describe texels
- **`texels:`** pointer to texel array

ex) `gl.texImage2D(gl.TEXTURE_2D, 0, 3, 512, 512, 0, gl.RGB, gl.UNSIGNED_BYTE, my_texels);`

A Checkboard Image

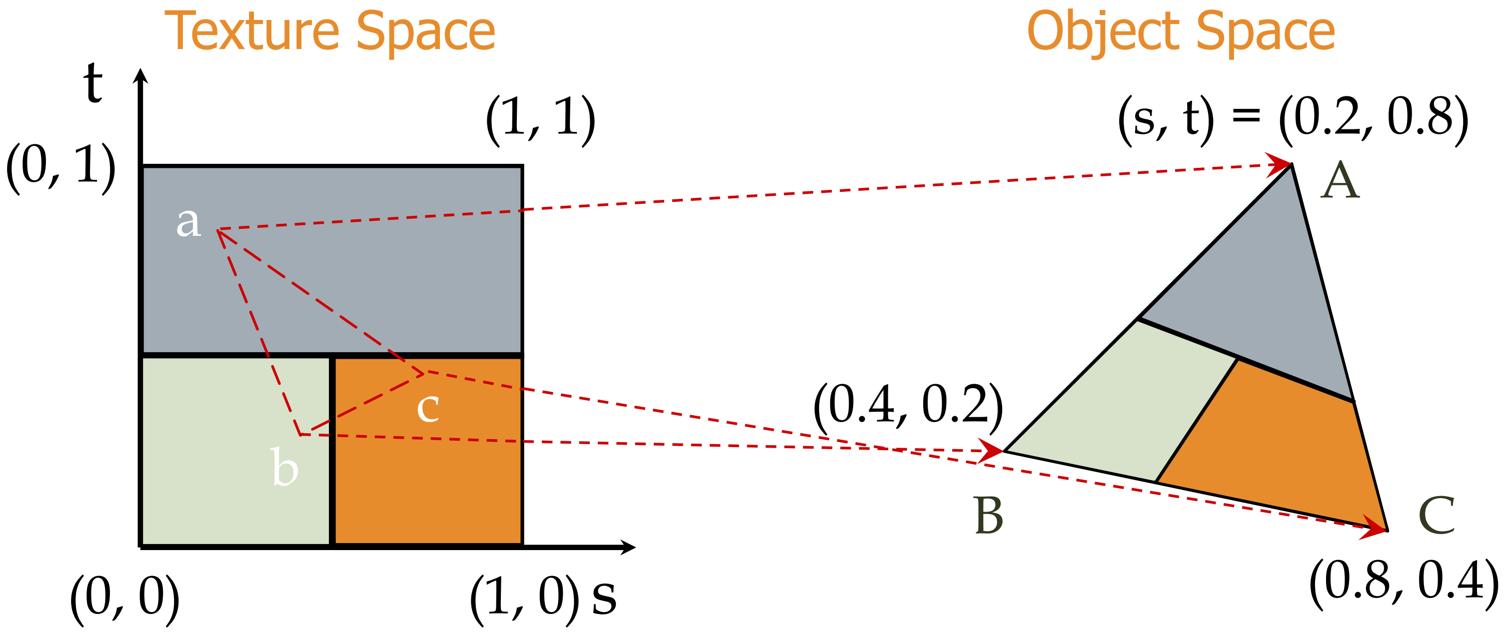
```
var image1 = new Uint8Array(4*texSize*texSize);
    for ( var i = 0; i < texSize; i++ ) {
        for ( var j = 0; j <texSize; j++ ) {
            var patchx = Math.floor(i/(texSize/numChecks));
            var patchy = Math.floor(j/(texSize/numChecks));
            if(patchx%2 ^ patchy%2) c = 255;
            else c = 0;
            //c = 255*(((i & 0x8) == 0) ^ ((j & 0x8)  == 0))
            image1[4*i*texSize+4*j] = c;
            image1[4*i*texSize+4*j+1] = c;
            image1[4*i*texSize+4*j+2] = c;
            image1[4*i*texSize+4*j+3] = 255;
        }
    }
```

Using a GIF Image

```
// specify image in JS file

var image = new Image();
    image.onload = function() {
         configureTexture( image );
    }
    image.src = "SA2011_black.gif”

// or specify image in HTML file with <img> tag

// <img id = "texImage" src = "SA2011_black.gif"></img>

var image = document.getElementById("texImage”)
window.onload = configureTexture( image );
```

Mapping a Texture

- Based on parametric texture coordinates
  - Specify texture coordinates as a 2D vertex attribute

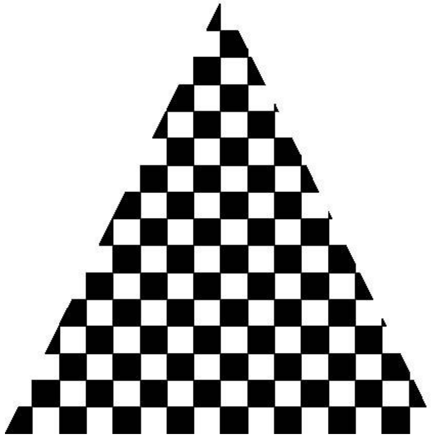


Cube Example

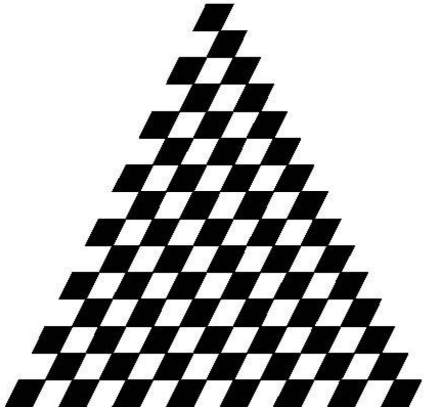
```
var texCoord = [
    vec2(0, 0),
    vec2(0, 1),
    vec2(1, 1),
    vec2(1, 0)
];

function quad(a, b, c, d) {
     pointsArray.push(vertices[a]);
     colorsArray.push(vertexColors[a]);
     texCoordsArray.push(texCoord[0]);

     pointsArray.push(vertices[b]);
     colorsArray.push(vertexColors[a]);
     texCoordsArray.push(texCoord[1]);
// etc
```

Interpolation

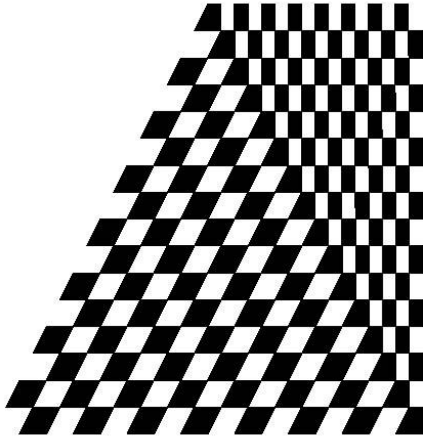
- WebGL uses <u>interpolation</u> to find proper texels from specified texture coordinates
  - Can be distortion



Good selection of tex coordinates



Poor selection of tex coordinates



Texture stretched over trapezoid showing effects of bilinear interpolation

Using Texture Objects

1. Specify textures in texture objects
2. Set texture filter
3. Set texture function
4. Set texture wrap mode
5. Set optional perspective correction hint
6. Bind texture object
7. Enable texturing
8. Supply texture coordinates for vertex
   - Coordinates can also be generated

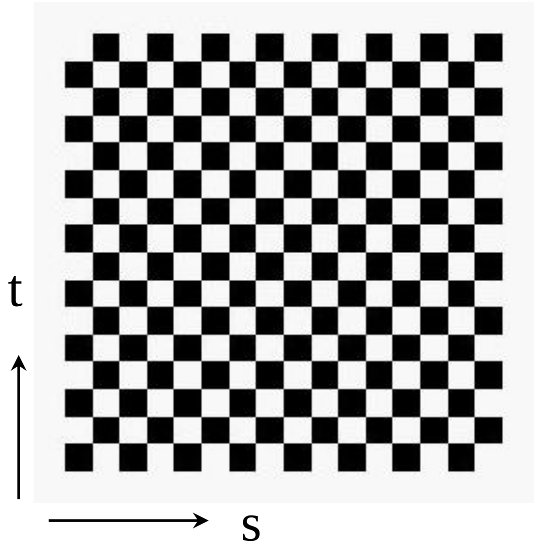
Texture Parameters

- WebGL has a variety of parameters that determine how texture is applied
  - Wrapping parameters determine what happens if s and t are outside the (0, 1) range
  - Filter modes allow us to use area averaging instead of point samples
  - Mipmapping allows us to use textures at multiple resolutions
  - Environment parameters determine how texture mapping interacts with shading

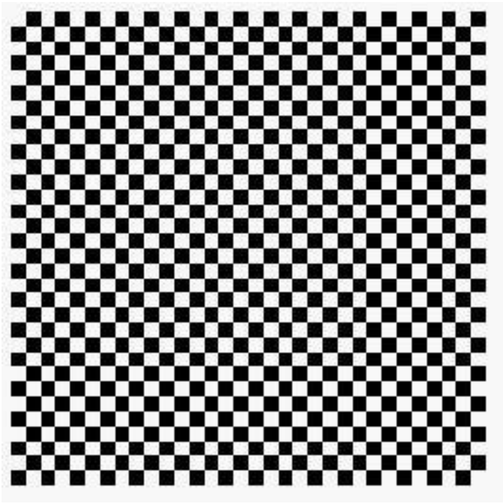
Wrapping Modes

- Clamping: if $s, t > 1$ use 1, if $s, t < 0$ use 0
- Wrapping: use s, t modulo 1

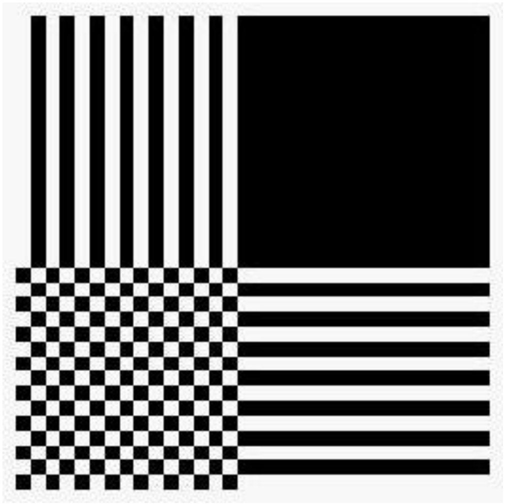
```
gl.texParameteri( gl.TEXTURE_2D, gl.TEXTURE_WRAP_S, gl.CLAMP );
gl.texParameteri( gl.TEXTURE_2D, gl.TEXTURE_WRAP_T, gl.REPEAT );
```



texture



gl.REPEAT wrapping



gl.CLAMP wrapping

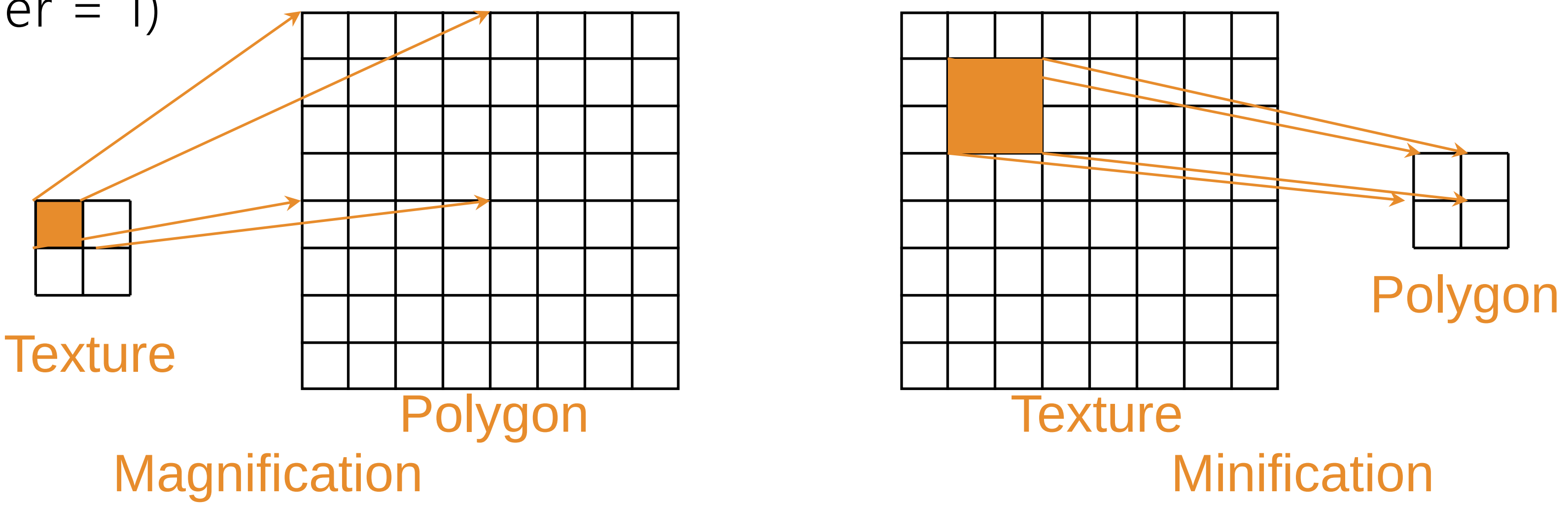
Filter Modes

- Mode determined by

```
gl.texParameteri( target, type, mode )
```

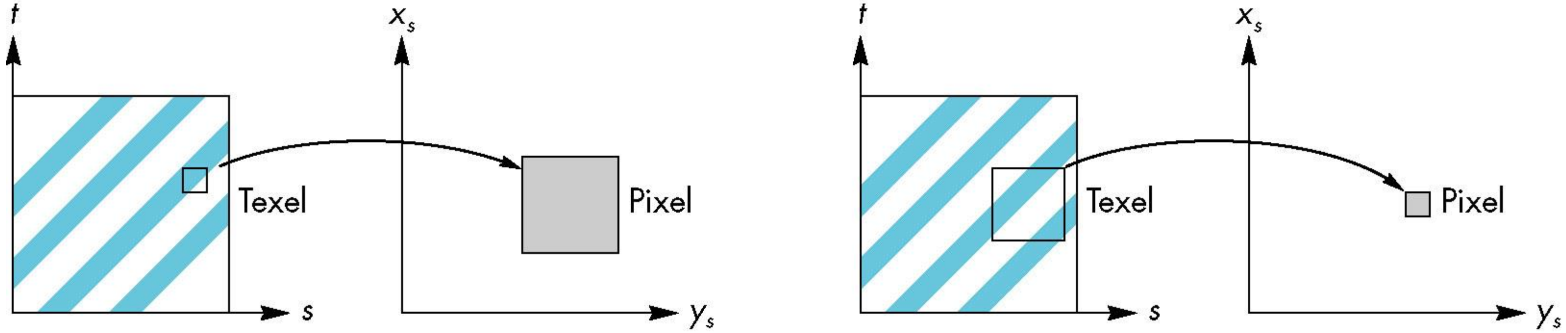
```
gl.texParameteri(gl.TEXTURE_2D, gl.TEXURE_MAG_FILTER, gl.NEAREST);
gl.texParameteri(gl.TEXTURE_2D, gl.TEXURE_MIN_FILTER, gl.LINEAR);
```

- Note that linear filtering requires a border of an extra texel for filtering at edges (border = 1)

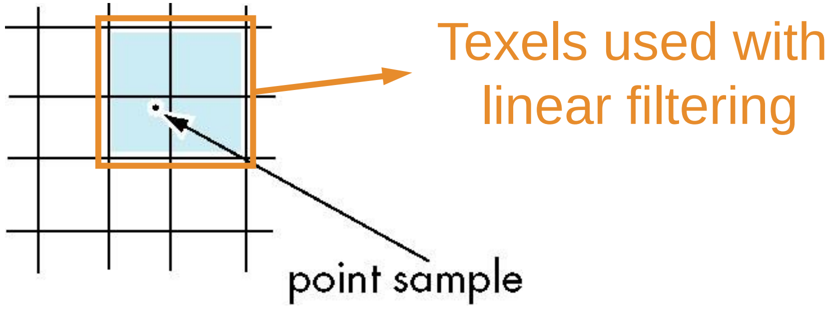


Magnification and Minification

- More than one texel can cover a pixel (*minification*) or more than one pixel can cover a texel (*magnification*)



- Can use *point sampling* (nearest texel) or *linear filtering* (2x2 filter) to obtain texture values



Mipmapped Textures

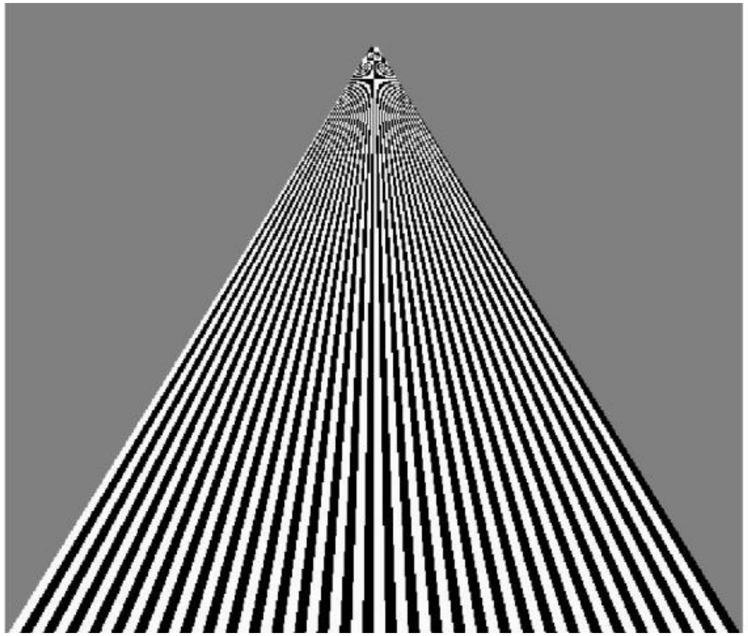
- *Mipmapping* allows for prefiltered texture maps of decreasing resolutions
- Lessens interpolation errors for smaller textured objects
- Declare mipmap level during texture definition

```
gl.texImage2D(gl.TEXTURE_*D, level, … )
```

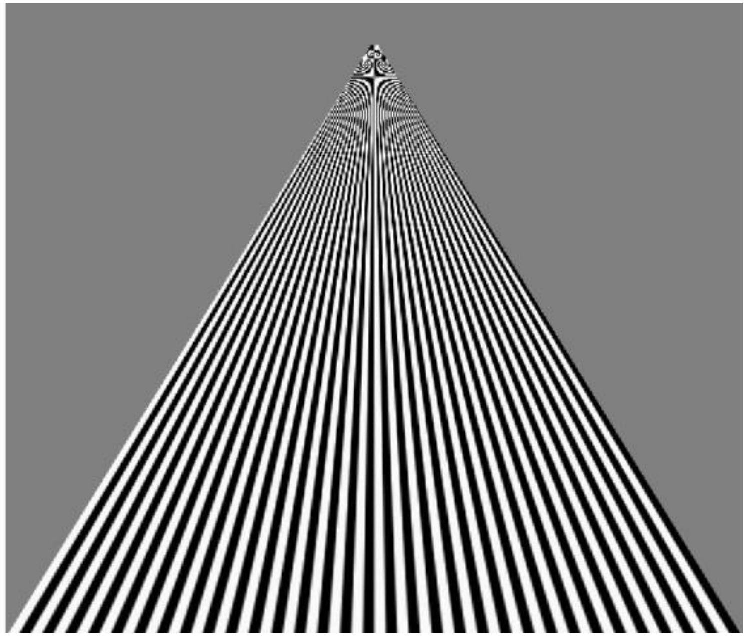
Mipmapped Textures

- Fast and easy for hardware

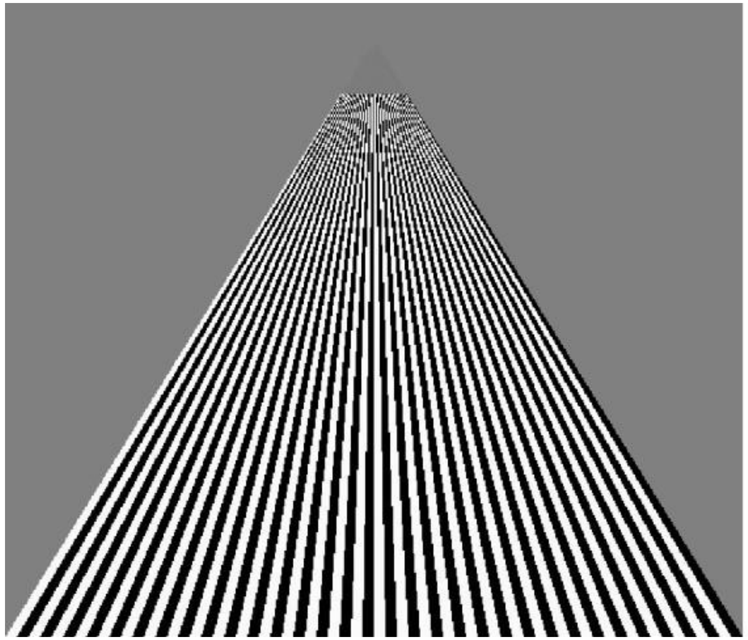
Example



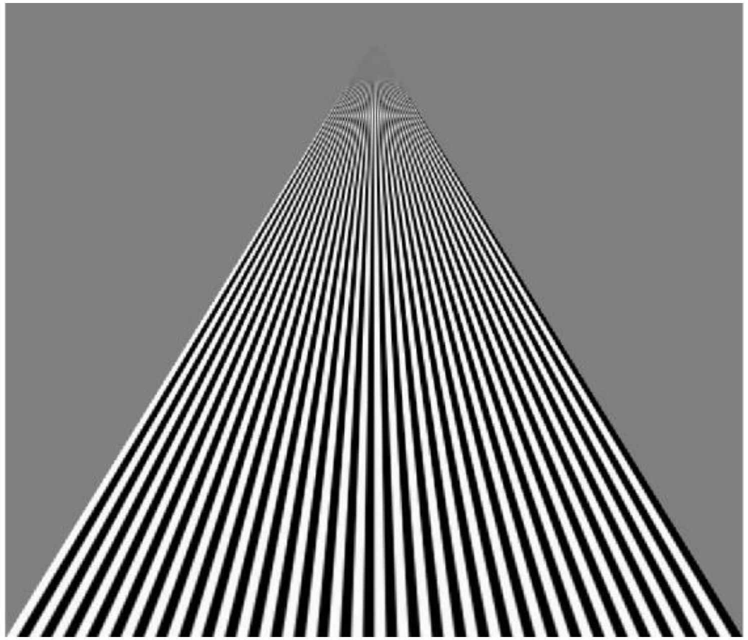
Point sampling



Linear filtering



Mipmapped point sampling



Mipmapped linear filtering

Environment Modes

- Texture can be applied many ways
  - Texture fully determines color
  - Modulated with a computed color
  - Blended with and environmental color
- Fixed function pipeline has a function glTexEnv to set mode
  - Deprecated
  - Can get all desired functionality via fragment shader
- Can also use multiple texture units

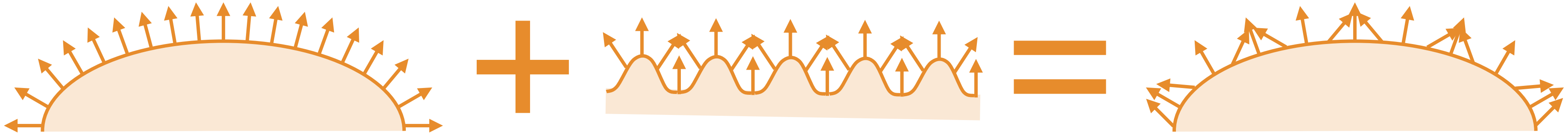
Other Texture Features

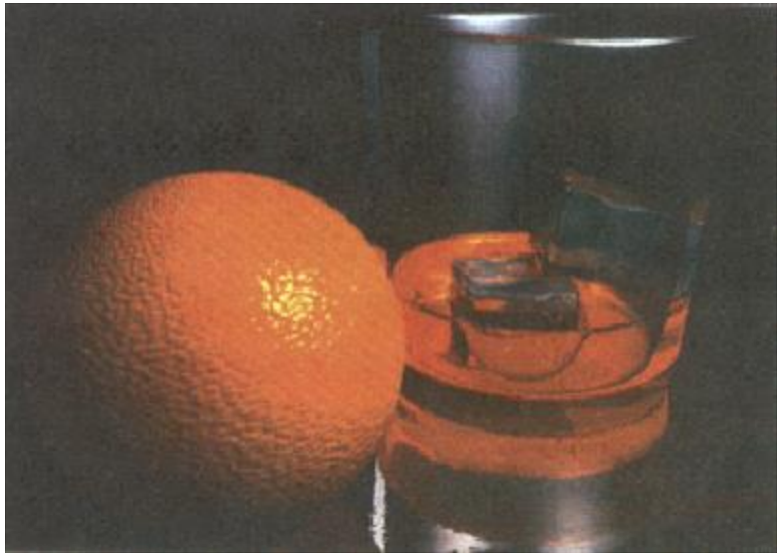
- *Environment maps*
  - Start with image of environment through wide angle lens
    - Can be either a real scanned image or an image created in OpenGL
  - Use this texture to generate a spherical map
  - Use automatic texture coordinate generation

- *Multitexturing*
  - Apply a sequence of textures through cascaded texture units

Bump Mapping

- Render objects so that they appear to have fine details (bumps) that give the surface a rough appearance affected by the light position





Applying Textures

- Textures are applied during fragments shading by a sampler
- Samplers return a texture color from a texture object

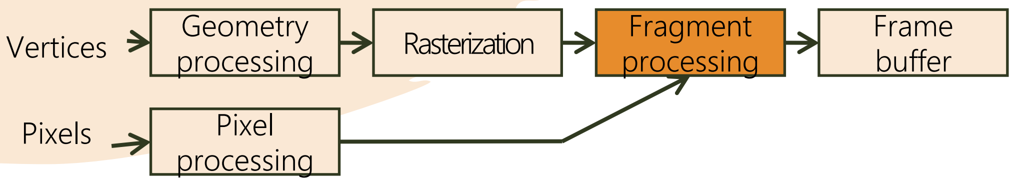
```
varying vec4 color;  //color from rasterizer
varying vec2 texCoord; //texure coordinate from rasterizer
uniform sampler2D texture; //texture object from application

void main()  {
    gl_FragColor = color * texture2D( texture, texCoord );
}
```

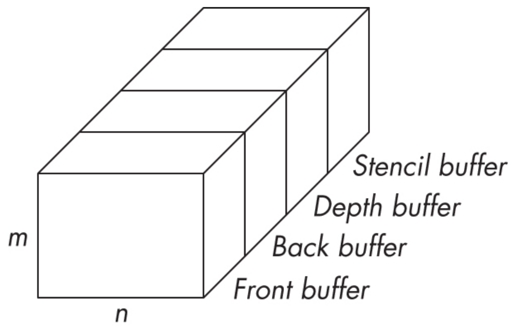
Vertex Shader

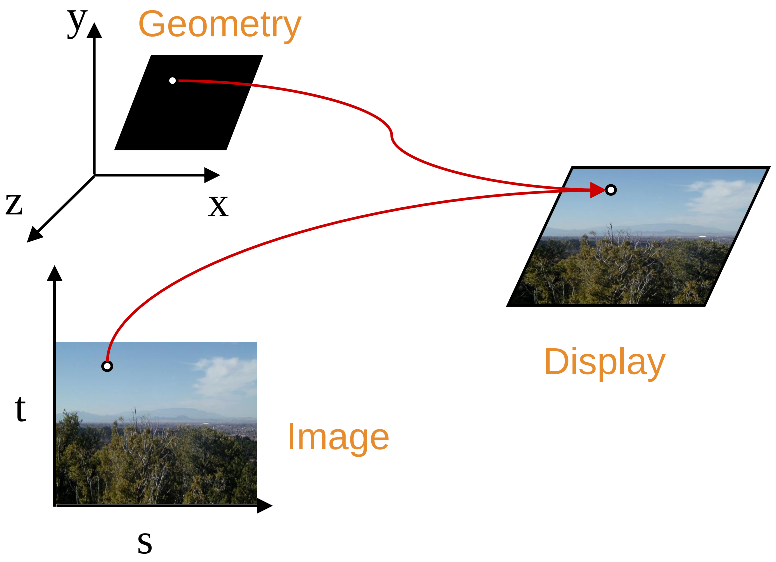
- Usually vertex shader will output texture coordinates to be rasterized
- Must do all other standard tasks too
  - Compute vertex position
  - Compute vertex color if needed

```
attribute vec4 vPosition; //vertex position in object coordinates
attribute vec4 vColor;    //vertex color from application
attribute vec2 vTexCoord; //texture coordinate from application

varying vec4 color; //output color to be interpolated
varying vec2 texCoord; //output tex coordinate to be interpolated
```

- WebGL frame buffer







- **Texture mapping**
  1. Specify the texture
     - Read or generate image
     - Assign to texture
     - Enable texturing
  2. Assign texture coordinates to vertices
     - Proper mapping function is left to application
  3. Specify texture parameters
     - Wrapping, filtering

```
void gl.texImage2D(target, level, components,
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                   format, type, texels);
```
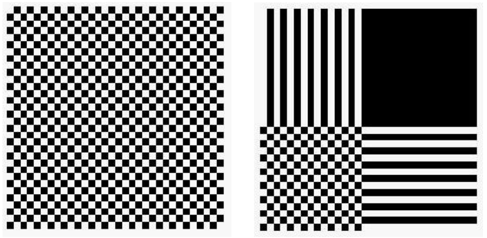
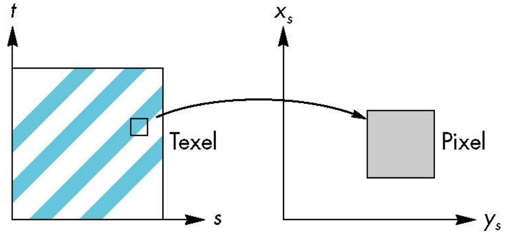
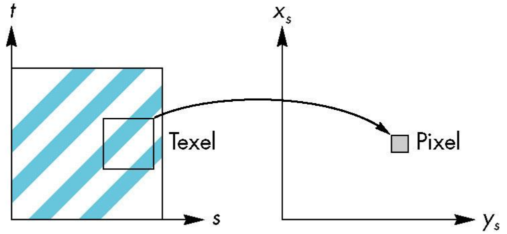
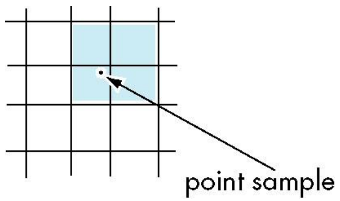

```
gl.texParameteri( gl.TEXTURE_2D, gl.TEXTURE_WRAP_S, gl.CLAMP );
gl.texParameteri( gl.TEXTURE_2D, gl.TEXTURE_WRAP_T, gl.REPEAT );
```

```
gl.texParameteri(gl.TEXTURE_2D, gl.TEXURE_MAG_FILTER, gl.NEAREST);
gl.texParameteri(gl.TEXTURE_2D, gl.TEXURE_MIN_FILTER, gl.LINEAR);
```









수고하셨습니다