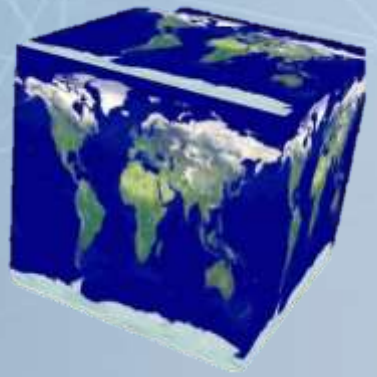
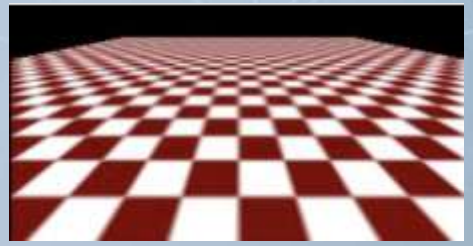
Texture

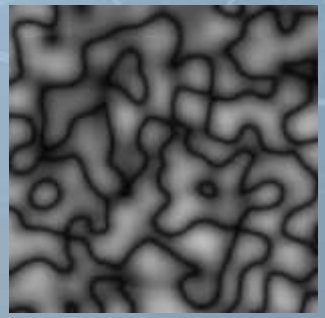
CSU0021: Computer Graphics

Texture Mapping

- A way of adding surface detail
- Two way can achieve the goal
  - Surface detail polygon : create extra polygon to model object details
    - Add scene complexity and slow down the graphics rendering speed
  - Map a texture to the surface (popular method)
    - Complexity of images does not affect the complexity of geometry

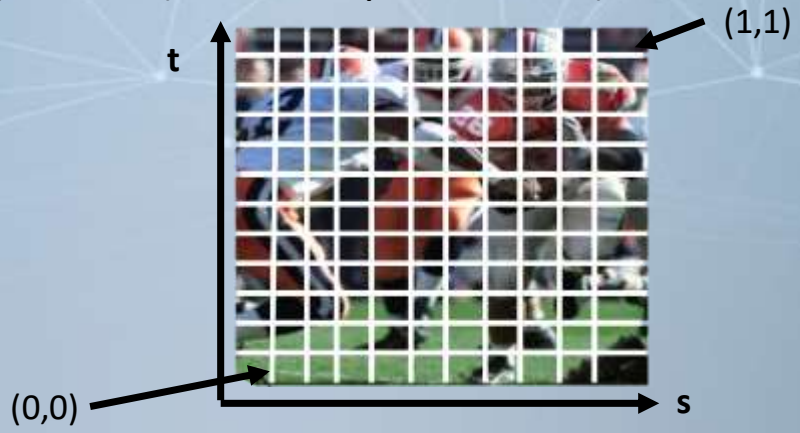






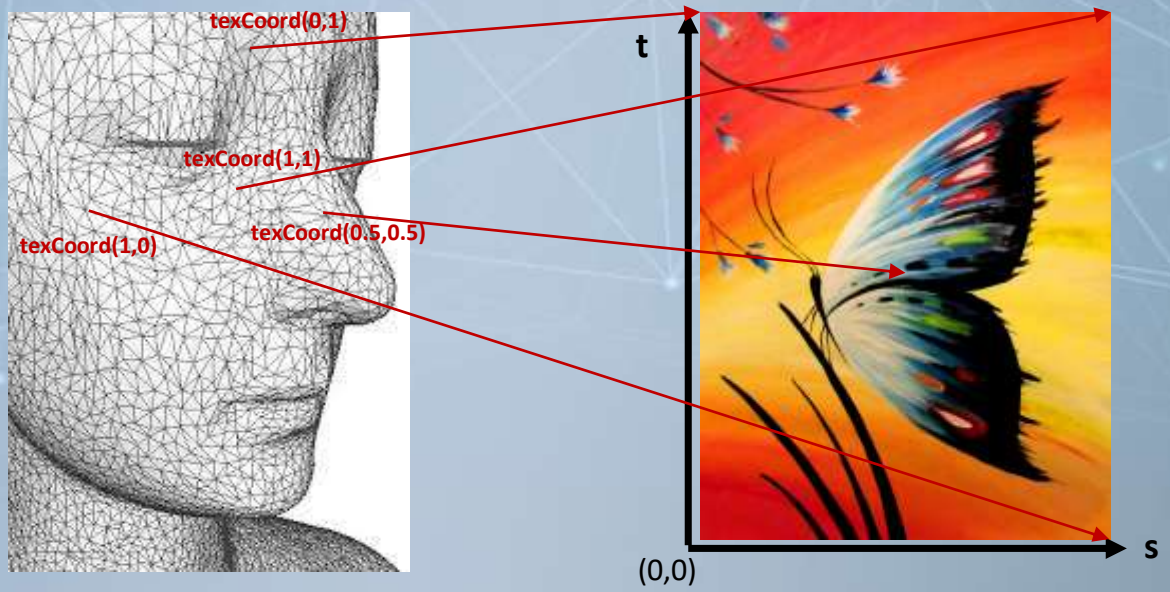
Texture Representation

- Bitmap texture: pixels
  - A 2D image: a 2D array
  - Each pixel (or texel) by a unique pair texture coordinate (s, t)
  - The s and t are usually normalized to a [0, 1] range
  - For any given (s, t) in the normalize range, there is a unique image value (i.e., a unique [R, G, B])



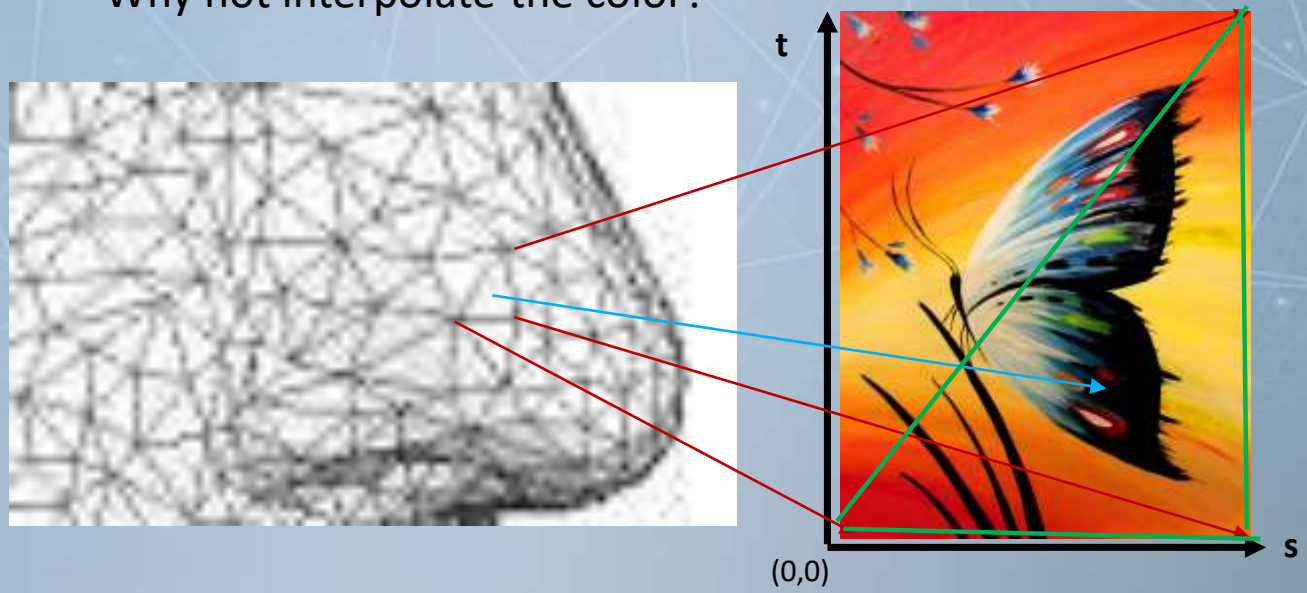
Map Textures to Surfaces

- Vertex: using texture coordinate to establish mapping from texture to surfaces (polygons)



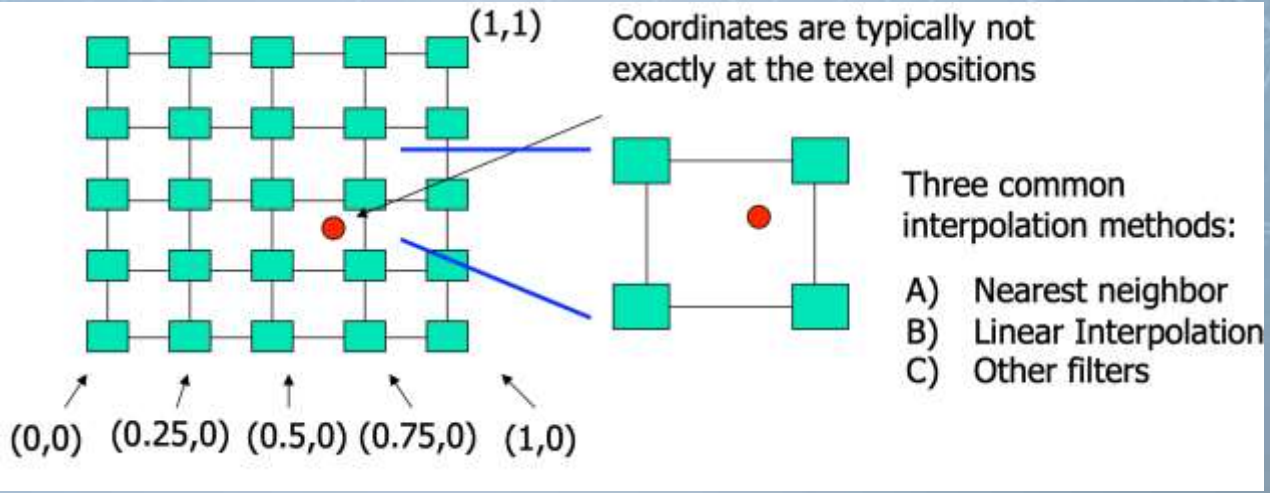
Map Textures to Surfaces

- Inside a triangle: mapping is performed in rasterization
- The texture coordinate is calculated by interpolating the texture coordinates on vertices of the triangle
  - Why not interpolate the color?



Map Textures to Surfaces

- If we would like to have the texture coordinates within a polygon, like other vertex attributes, the texture coordinate is interpolated from vertices of the polygon
- For the given texture coordinate (s, t), we can find a unique image value from the texture map



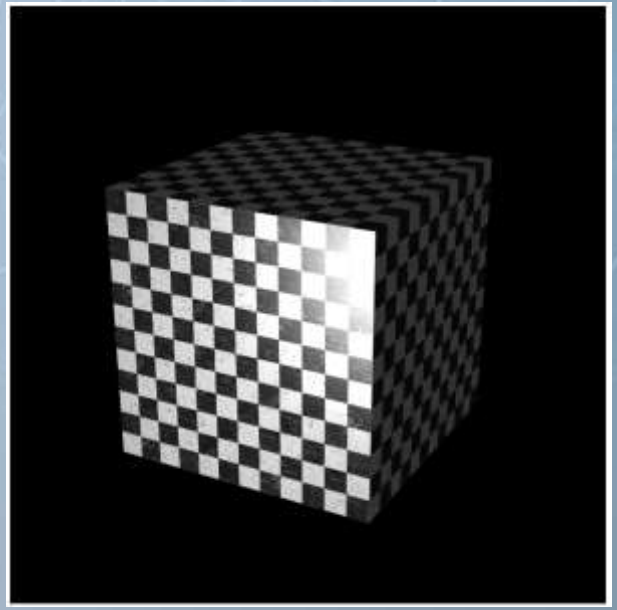
WebGL: Steps to Use Texture

- Load the texture image
- Prepare texture buffer
  - Create texture buffer: gl.createTexture()
  - Bind texture to a target: gl.bindTexture()
  - Indicate how to interpret the image: gl.pixelStorei()
  - Texture parameters: gl.texParameteri()
  - Assign the texture image to the texture target: gl.texImage2D()
- Assign the texture to the shader
  - Active a texture unit: gl.activeTexture()
  - Bind texture to a target if necessary(): gl.bindTexture()
  - Pass the texture unit to a ‘sampler2D’ in shader: gl.uniform1i()
- Call shader to draw
  - Get a color from the texture in shader: texture2D()

Example (Ex08-1)

- Use chessboard texture to color the cube

- Files
  - Index.html
  - WebGL.js
  - cuon-matrix.js
  - cube.obj
  - chess.jpg



Example (Ex08-1)

- main() in WebGL.js

```
var objComponents = [];
var textures = {};
var texCount = 0;
var numTextures = 1; //brick

async function main(){
    canvas = document.getElementById('webgl');
    gl = canvas.getContext('webgl2');
    if(!gl){
        console.log('Failed to get the rendering context for WebGL');
        return ;
    }

    program = compileShader(gl, VSHADER_SOURCE, FSHADER_SOURCE);

    gl.useProgram(program);
```

```
program.a_Position = gl.getAttribLocation(program, 'a_Position');
program.a_TexCoord = gl.getAttribLocation(program, 'a_TexCoord');
program.a_Normal = gl.getAttribLocation(program, 'a_Normal');
program.u_MvpMatrix = gl.getUniformLocation(program, 'u_MvpMatrix');
program.u_modelMatrix = gl.getUniformLocation(program, 'u_modelMatrix');
program.u_normalMatrix = gl.getUniformLocation(program, 'u_normalMatrix');
program.u_LightPosition = gl.getUniformLocation(program, 'u_LightPosition');
program.u_ViewPosition = gl.getUniformLocation(program, 'u_ViewPosition');
program.u_Ka = gl.getUniformLocation(program, 'u_Ka');
program.u_Kd = gl.getUniformLocation(program, 'u_Kd');
program.u_Ks = gl.getUniformLocation(program, 'u_Ks');
program.u_shininess = gl.getUniformLocation(program, 'u_shininess');
program.u_Sampler0 = gl.getUniformLocation(program, "u_Sampler0")

response = await fetch('cube.obj');
text = await response.text();
obj = parseOBJ(text);

for( let i=0; i < obj.geometries.length; i ++ ){
  let o = initVertexBufferForLaterUse(gl,
                                      obj.geometries[i].data.position,
                                      obj.geometries[i].data.normal,
                                      obj.geometries[i].data.texcoord);

  objComponents.push(o);
}
```

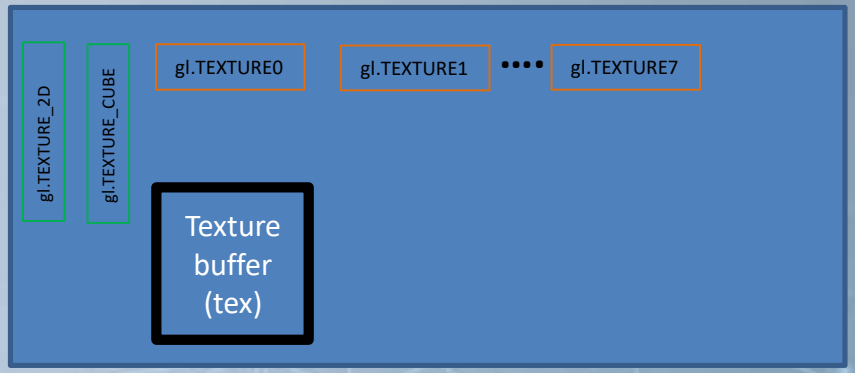
Load “chess.jpg” image

```
var imageChess = new Image();
imageChess.onload = function(){ initTexture(gl, imageChess, "chessTex"); };
imageChess.src = "chess.jpg";

mvpMatrix = new Matrix4();
modelMatrix = new Matrix4();
normalMatrix = new Matrix4();

gl.enable(gl.DEPTH_TEST);

canvas.onmousedown = function(ev){mouseDown(ev)};
canvas.onmousemove = function(ev){mouseMove(ev)};
canvas.onmouseup = function(ev){mouseUp(ev)};
```

When the loading is done,
call initTexture() to create a texture

- Load the texture image
- Prepare texture buffer
  - Create texture buffer: gl.createTexture()
  - Bind texture to a target: gl.bindTexture()
  - Indicate how to interpret the image: gl.pixelStorei()
  - Texture parameters: gl.texParameteri()
  - Assign the texture image to the texture target: gl.texImage2D()
- Assign the texture to the shader
  - Active a texture unit: gl.activeTexture()
  - Bind texture to a target if necessary(): gl.bindTexture()
  - Pass the texture unit to a ‘sampler2D’ in shader: gl.uniform1i()
- Call shader to draw
  - Get a color from the texture in shader: texture2D()

Example (Ex08-1)

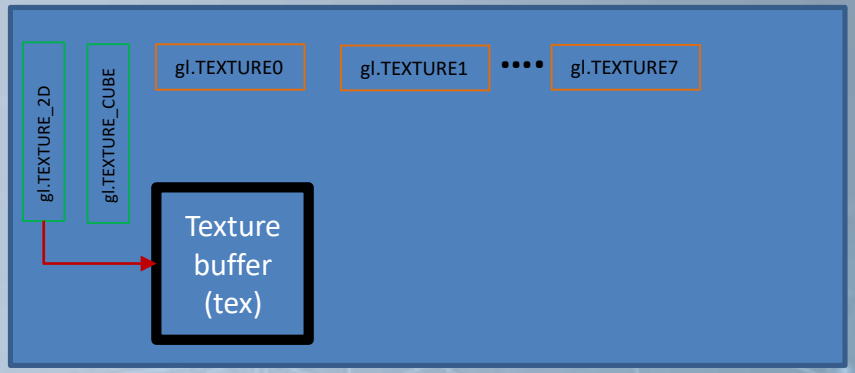


- gl.createTexture()
  - Create a texture object
  - https://developer.mozilla.org/en-US/docs/Web/API/WebGLRenderingContext/createTexture
  - (You will have at least 8 texture units)

- Load the texture image
- Prepare texture buffer
  - Create texture buffer: gl.createTexture()
  - Bind texture to a target: gl.bindTexture()
  - Indicate how to interpret the image: gl.pixelStorei()
  - Texture parameters: gl.texParameteri()
  - Assign the texture image to the texture target: gl.texImage2D()
- Assign the texture to the shader
  - Active a texture unit: gl.activeTexture()
  - Bind texture to a target if necessary(): gl.bindTexture()
  - Pass the texture unit to a 'sampler2D' in shader: gl.uniform1i()
- Call shader to draw
  - Get a color from the texture in shader: texture2D()

```
function initTexture(gl, img, texKey){
  var tex = gl.createTexture();
  gl.bindTexture(gl.TEXTURE_2D, tex);

  gl.pixelStorei(gl.UNPACK_FLIP_Y_WEBGL, 1);
  // Set the parameters so we can render any size image.
  gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_MIN_FILTER, gl.LINEAR);
  // Upload the image into the texture.
  gl.texImage2D(gl.TEXTURE_2D, 0, gl.RGBA, gl.RGBA, gl.UNSIGNED_BYTE, img);

  textures[texKey] = tex;

  texCount++;
  if( texCount == numTextures)draw();
}
```

Example (Ex08-1)



- gl.bindTexture(target, texture)
  - target: gl.TEXTURE_2D or gl.TEXTURE_CUBE
  - texture: texture object
  - https://developer.mozilla.org/en-US/docs/Web/API/WebGLRenderingContext/bindTexture

- Load the texture image
- Prepare texture buffer
  - Create texture buffer: gl.createTexture()
  - Bind texture to a target: gl.bindTexture()
  - Indicate how to interpret the image: gl.pixelStorei()
  - Texture parameters: gl.texParameteri()
  - Assign the texture image to the texture target: gl.texImage2D()
- Assign the texture to the shader
  - Active a texture unit: gl.activeTexture()
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- Call shader to draw
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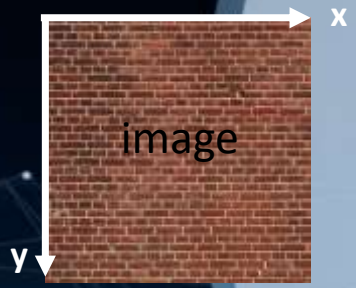
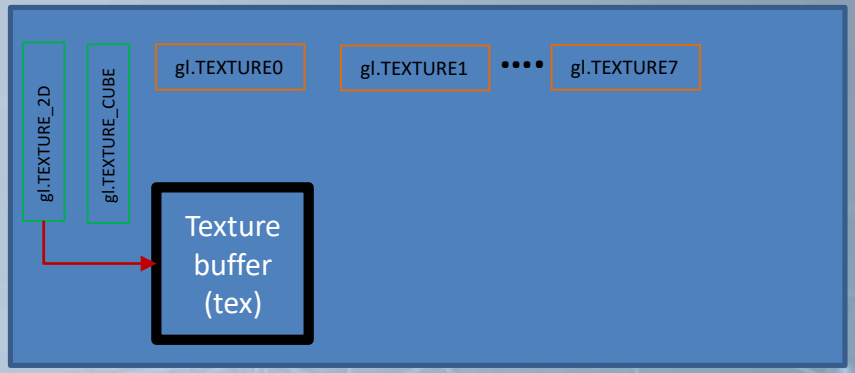
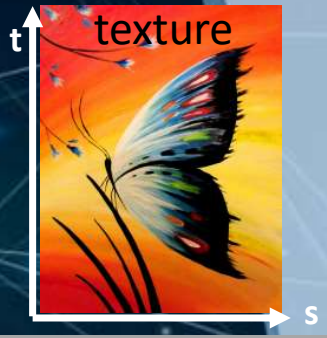
```
function initTexture(gl, img, texKey){
  var tex = gl.createTexture();
  gl.bindTexture(gl.TEXTURE_2D, tex);

  gl.pixelStorei(gl.UNPACK_FLIP_Y_WEBGL, 1);
  // Set the parameters so we can render any size image.
  gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_MIN_FILTER, gl.LINEAR);
  // Upload the image into the texture.
  gl.texImage2D(gl.TEXTURE_2D, 0, gl.RGBA, gl.RGBA, gl.UNSIGNED_BYTE, img);

  textures[texKey] = tex;

  texCount++;
  if( texCount == numTextures)draw();
}
```



Example (Ex08-1)





- gl.pixelStorei(pname, param)
  - https://developer.mozilla.org/en-US/docs/Web/API/WebGLRenderingContext/pixelStorei
- if pname: gl.UNPACK_FLIP_Y_WEBGL and param = 1, the image is flipped along the y-axis

- Load the texture image
- Prepare texture buffer
  - Create texture buffer: gl.createTexture()
  - Bind texture to a target: gl.bindTexture()
  - Indicate how to interpret the image: gl.pixelStorei()
  - Texture parameters: gl.texParameteri()
  - Assign the texture image to the texture target: gl.texImage2D()
- Assign the texture to the shader
  - Active a texture unit: gl.activeTexture()
  - Bind texture to a target if necessary(): gl.bindTexture()
  - Pass the texture unit to a 'sampler2D' in shader: gl.uniform1i()
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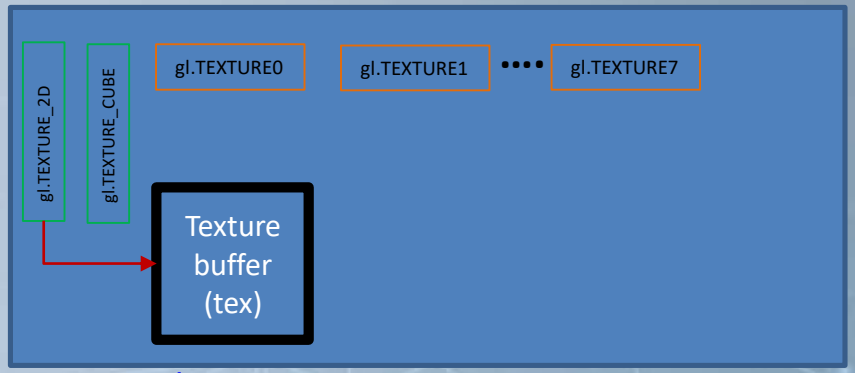
```
function initTexture(gl, img, texKey){
  var tex = gl.createTexture();
  gl.bindTexture(gl.TEXTURE_2D, tex);

  gl.pixelStorei(gl.UNPACK_FLIP_Y_WEBGL, 1);
  // Set the parameters so we can render any size image.
  gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_MIN_FILTER, gl.LINEAR);
  // Upload the image into the texture.
  gl.texImage2D(gl.TEXTURE_2D, 0, gl.RGBA, gl.RGBA, gl.UNSIGNED_BYTE, img);

  textures[texKey] = tex;

  texCount++;
  if( texCount == numTextures)draw();
}
```

Example (Ex08-1)



- gl.texParameteri(target, pname, param)
  - https://developer.mozilla.org/en-US/docs/Web/API/WebGLRenderingContext/texParameter

(1) Nearest neighbor (low quality, fast)

gl.textParameter(..., gl.TEXTURE_MIN_FILTER, gl.NEAREST)

(2) Linear interpolation (high quality, slow)

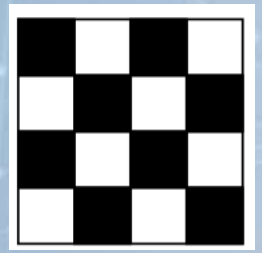
gl.textParameter(..., gl.TEXTURE_MIN_FILTER, gl..LINEAR)

- Load the texture image
- Prepare texture buffer
  - Create texture buffer: gl.createTexture()
  - Bind texture to a target: gl.bindTexture()
  - Indicate how to interpret the image: gl.pixelStorei()
  - Texture parameters: gl.texParameteri()
  - Assign the texture image to the texture target: gl.texImage2D()
- Assign the texture to the shader
  - Active a texture unit: gl.activeTexture()
  - Bind texture to a target if necessary(): gl.bindTexture()
  - Pass the texture unit to a 'sampler2D' in shader: gl.uniform1i()
- Call shader to draw
  - Get a color from the texture in shader: texture2D()

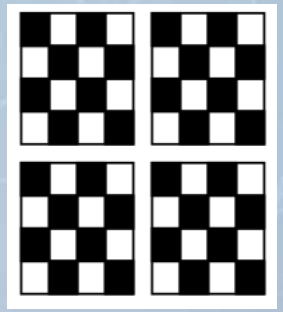
```
function initTexture(gl, img, texKey){
  var tex = gl.createTexture();
  gl.bindTexture(gl.TEXTURE_2D, tex);

  gl.pixelStorei(gl.UNPACK_FLIP_Y_WEBGL, 1);
  // Set the parameters so we can render any size image.
  gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_MIN_FILTER, gl.LINEAR);
  // Upload the image into the texture.
  gl.texImage2D(gl.TEXTURE_2D, 0, gl.RGBA, gl.RGBA, gl.UNSIGNED_BYTE, img);

  textures[texKey] = tex;

  texCount++;
  if( texCount == numTextures)draw();
}
```

Example (Ex08-1)

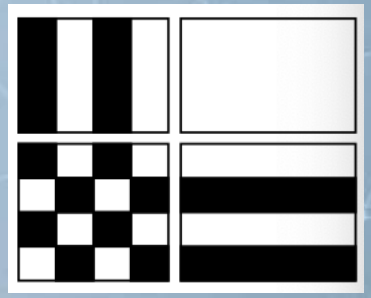
- What if the given texture coordinates (s, t) are outside [0,1] range?
  - Ex:
    - gl.texParameteri(…, gl.TEXTURE_WRAP_S, gl.CLAMP)
    - gl.texParameteri(…, gl.TEXTURE_WRAP_T, gl.CLAMP)



Original texture

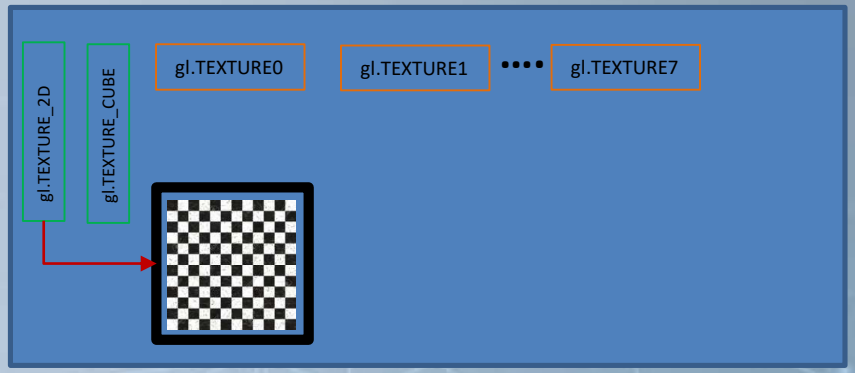


gl.REPEAT
(default)



gl.CLAMP

Example (Ex08-1)

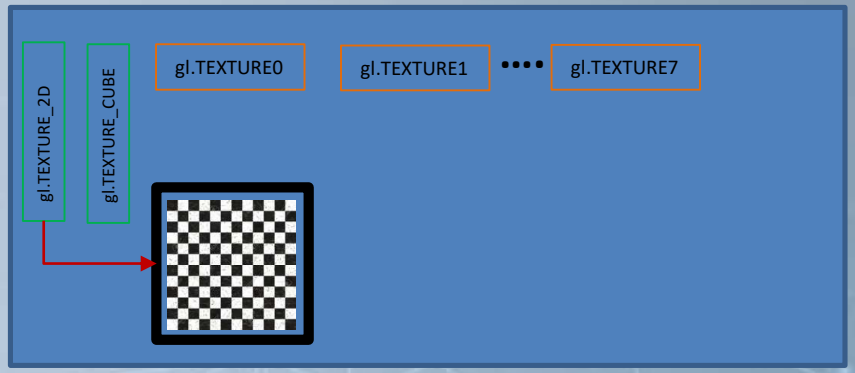


- gl.texImage2D(target, level, internalformat, format, type, image)
  - https://developer.mozilla.org/en-US/docs/Web/API/WebGLRenderingContext/texImage2D
  - target: gl.TEXTURE_2D or gl.TEXTURE_CUBE_MAP
  - level: level of detail
  - internalformat: image's format
  - format: texture format (the same as the internal format)
  - type: type of the texture (per channel)
  - image: input texture image

- Load the texture image
- Prepare texture buffer
  - Create texture buffer: gl.createTexture()
  - Bind texture to a target: gl.bindTexture()
  - Indicate how to interpret the image: gl.pixelStorei()
  - Texture parameters: gl.texParameteri()
  - Assign the texture image to the texture target: gl.texImage2D()
- Assign the texture to the shader
  - Active a texture unit: gl.activeTexture()
  - Bind texture to a target if necessary(): gl.bindTexture()
  - Pass the texture unit to a 'sampler2D' in shader: gl.uniform1i()
- Call shader to draw
  - Get a color from the texture in shader: texture2D()

```
function initTexture(gl, img, texKey){
  var tex = gl.createTexture();
  gl.bindTexture(gl.TEXTURE_2D, tex);

  gl.pixelStorei(gl.UNPACK_FLIP_Y_WEBGL, 1);
  // Set the parameters so we can render any size image.
  gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_MIN_FILTER, gl.LINEAR);
  // Upload the image into the texture.
  gl.texImage2D(gl.TEXTURE_2D, 0, gl.RGBA, gl.RGBA, gl.UNSIGNED_BYTE, img);

  textures[texKey] = tex;

  texCount++;
  if( texCount == numTextures)draw();
}
```

Example (Ex08-1)



Render the first frame
if the loading of all textures is done

Save the texture we create

- Load the texture image
- Prepare texture buffer
  - Create texture buffer: gl.createTexture()
  - Bind texture to a target: gl.bindTexture()
  - Indicate how to interpret the image: gl.pixelStorei()
  - Texture parameters: gl.texParameteri()
  - Assign the texture image to the texture target: gl.texImage2D()
- Assign the texture to the shader
  - Active a texture unit: gl.activeTexture()
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- Call shader to draw
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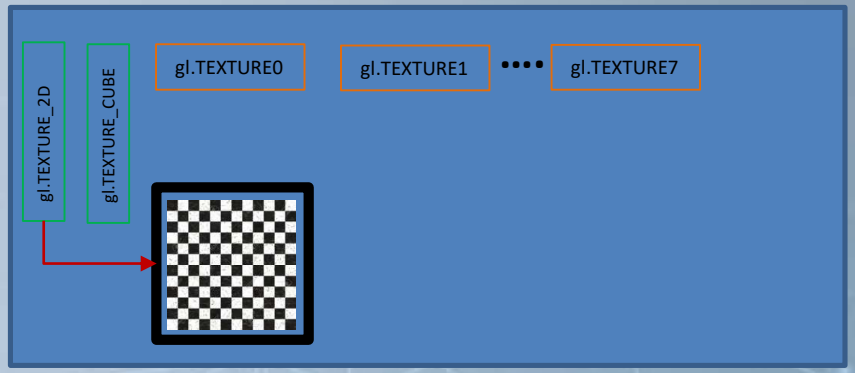
```
function initTexture(gl, img, texKey){
  var tex = gl.createTexture();
  gl.bindTexture(gl.TEXTURE_2D, tex);

  gl.pixelStorei(gl.UNPACK_FLIP_Y_WEBGL, 1);
  // Set the parameters so we can render any size image.
  gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_MIN_FILTER, gl.LINEAR);
  // Upload the image into the texture.
  gl.texImage2D(gl.TEXTURE_2D, 0, gl.RGBA, gl.RGBA, gl.UNSIGNED_BYTE, img);

  textures[texKey] = tex;

  texCount++;
  if( texCount == numTextures)draw();
}
```

Example (Ex08-1)

- draw() in WebGL.js
- Of course, beside pass vertex position and normal vector information, we also have to pass texture coordinates of the object vertices to shader (to an attribute variable)



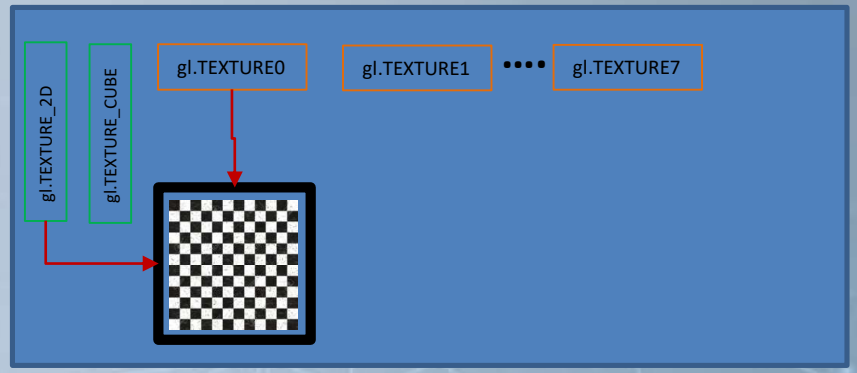

```
function draw(){
    gl.clearColor(0,0,0,1);

    //model Matrix (part of the mvp matrix)
    modelMatrix.setRotate(angleY, 1, 0, 0);//for mouse rotation
    modelMatrix.rotate(angleX, 0, 1, 0);//for mouse rotation
    modelMatrix.scale(objScale, objScale, objScale);
    //mvp: projection * view * model matrix
    mvpMatrix.setPerspective(30, 1, 1, 100);
    mvpMatrix.lookAt(cameraX, cameraY, cameraZ, 0, 0, 0, 0, 1, 0);
    mvpMatrix.multiply(modelMatrix);

    //normal matrix
    normalMatrix.setInverseOf(modelMatrix);
    normalMatrix.transpose();
```

- Load the texture image
- Prepare texture buffer
  - Create texture buffer: gl.createTexture()
  - Bind texture to a target: gl.bindTexture()
  - Indicate how to interpret the image: gl.pixelStorei()
  - Texture parameters: gl.texParameteri()
  - Assign the texture image to the texture target: gl.texImage2D()
- Assign the texture to the shader
  - Active a texture unit: gl.activeTexture()
  - Bind texture to a target if necessary(): gl.bindTexture()
  - Pass the texture unit to a 'sampler2D' in shader: gl.uniform1i()
- Call shader to draw
  - Get a color from the texture in shader: texture2D()

```
    gl.uniform3f(program.u_LightPosition, 0, 0, 3);
    gl.uniform3f(program.u_ViewPosition, cameraX, cameraY, cameraZ);
    gl.uniform1f(program.u_Ka, 0.2);
    gl.uniform1f(program.u_Kd, 0.7);
    gl.uniform1f(program.u_Ks, 1.0);
    gl.uniform1f(program.u_shininess, 10.0);
    gl.uniform1i(program.u_Sampler0, 0);

    gl.uniformMatrix4fv(program.u_MvpMatrix, false, mvpMatrix.elements);
    gl.uniformMatrix4fv(program.u_modelMatrix, false, modelMatrix.elements);
    gl.uniformMatrix4fv(program.u_normalMatrix, false, normalMatrix.elements);

    gl.clear(gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT);

    gl.activeTexture(gl.TEXTURE0);
    gl.bindTexture(gl.TEXTURE_2D, textures["chessTex"]);

    for( let i=0; i < objComponents.length; i ++ ){
      initAttributeVariable(gl, program.a_Position, objComponents[i].vertexBuffer);
      initAttributeVariable(gl, program.a_TexCoord, objComponents[i].texCoordBuffer);
      initAttributeVariable(gl, program.a_Normal, objComponents[i].normalBuffer);
      gl.drawArrays(gl.TRIANGLES, 0, objComponents[i].numVertices);
    }
}
```

Example (Ex08-1)

- draw() in WebGL.js



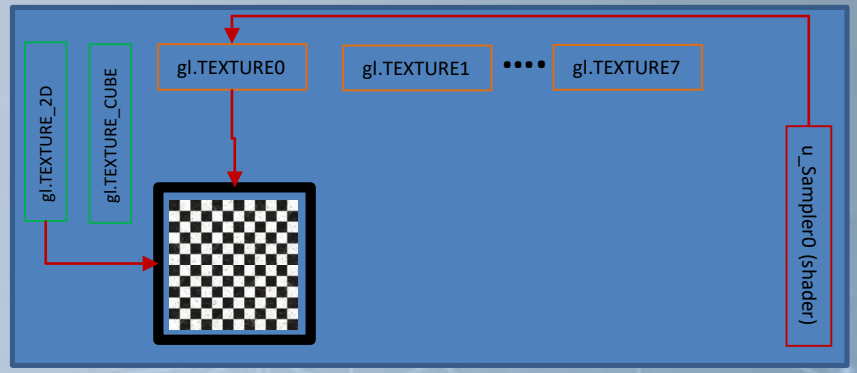

```
function draw(){
    gl.clearColor(0,0,0,1);

    //model Matrix (part of the mvp matrix)
    modelMatrix.setRotate(angleY, 1, 0, 0);//for mouse rotation
    modelMatrix.rotate(angleX, 0, 1, 0);//for mouse rotation
    modelMatrix.scale(objScale, objScale, objScale);
    //mvp: projection * view * model matrix
    mvpMatrix.setPerspective(30, 1, 1, 100);
    mvpMatrix.lookAt(cameraX, cameraY, cameraZ, 0, 0, 0, 0, 1, 0);
    mvpMatrix.multiply(modelMatrix);

    //normal matrix
    normalMatrix.setInverseOf(modelMatrix);
    normalMatrix.transpose();
```

- Load the texture image
- Prepare texture buffer
  - Create texture buffer: gl.createTexture()
  - Bind texture to a target: gl.bindTexture()
  - Indicate how to interpret the image: gl.pixelStorei()
  - Texture parameters: gl.texParameteri()
  - Assign the texture image to the texture target: gl.texImage2D()
- Assign the texture to the shader
  - Active a texture unit: gl.activeTexture()
  - Bind texture to a target if necessary(): gl.bindTexture()
  - Pass the texture unit to a 'sampler2D' in shader: gl.uniform1i()
- Call shader to draw
  - Get a color from the texture in shader: texture2D()

```
    gl.uniform3f(program.u_LightPosition, 0, 0, 3);
    gl.uniform3f(program.u_ViewPosition, cameraX, cameraY, cameraZ);
    gl.uniform1f(program.u_Ka, 0.2);
    gl.uniform1f(program.u_Kd, 0.7);
    gl.uniform1f(program.u_Ks, 1.0);
    gl.uniform1f(program.u_shininess, 10.0);
    gl.uniform1i(program.u_Sampler0, 0);

    gl.uniformMatrix4fv(program.u_MvpMatrix, false, mvpMatrix.elements);
    gl.uniformMatrix4fv(program.u_modelMatrix, false, modelMatrix.elements);
    gl.uniformMatrix4fv(program.u_normalMatrix, false, normalMatrix.elements);

    gl.clear(gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT);

    gl.activeTexture(gl.TEXTURE0);
    gl.bindTexture(gl.TEXTURE_2D, textures["chessTex"]);

    for( let i=0; i < objComponents.length; i ++ ){
      initAttributeVariable(gl, program.a_Position, objComponents[i].vertexBuffer);
      initAttributeVariable(gl, program.a_TexCoord, objComponents[i].texCoordBuffer);
      initAttributeVariable(gl, program.a_Normal, objComponents[i].normalBuffer);
      gl.drawArrays(gl.TRIANGLES, 0, objComponents[i].numVertices);
    }
}
```

Example (Ex08-1)

- draw() in WebGL.js




```
function draw(){
    gl.clearColor(0,0,0,1);

    //model Matrix (part of the mvp matrix)
    modelMatrix.setRotate(angleY, 1, 0, 0);//for mouse rotation
    modelMatrix.rotate(angleX, 0, 1, 0);//for mouse rotation
    modelMatrix.scale(objScale, objScale, objScale);
    //mvp: projection * view * model matrix
    mvpMatrix.setPerspective(30, 1, 1, 100);
    mvpMatrix.lookAt(cameraX, cameraY, cameraZ, 0, 0, 0, 0, 1, 0);
    mvpMatrix.multiply(modelMatrix);

    //normal matrix
    normalMatrix.setInverseOf(modelMatrix);
    normalMatrix.transpose();
```

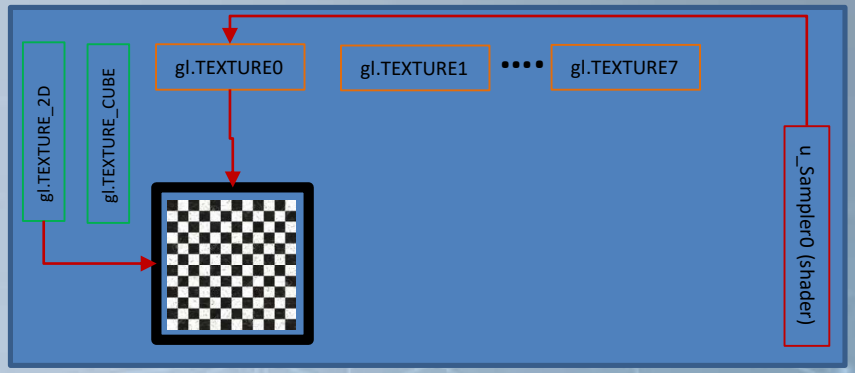
- Load the texture image
- Prepare texture buffer
  - Create texture buffer: gl.createTexture()
  - Bind texture to a target: gl.bindTexture()
  - Indicate how to interpret the image: gl.pixelStorei()
  - Texture parameters: gl.texParameteri()
  - Assign the texture image to the texture target: gl.texImage2D()
- Assign the texture to the shader
  - Active a texture unit: gl.activeTexture()
  - Bind texture to a target if necessary(): gl.bindTexture()
  - Pass the texture unit to a 'sampler2D' in shader: gl.uniform1i()
- Call shader to draw
  - Get a color from the texture in shader: texture2D()

```
    gl.uniform3f(program.u_LightPosition, 0, 0, 3);
    gl.uniform3f(program.u_ViewPosition, cameraX, cameraY, cameraZ);
    gl.uniform1f(program.u_Ka, 0.2);
    gl.uniform1f(program.u_Kd, 0.7);
    gl.uniform1f(program.u_Ks, 1.0);
    gl.uniform1f(program.u_shininess, 10.0);
    gl.uniform1i(program.u_Sampler0, 0);
```

0? Because we bind the texture to **TEXTURE0**

```
    gl.uniformMatrix4fv(program.u_MvpMatrix, false, mvpMatrix.elements);
    gl.uniformMatrix4fv(program.u_modelMatrix, false, modelMatrix.elements);
    gl.uniformMatrix4fv(program.u_normalMatrix, false, normalMatrix.elements);

    gl.clear(gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT);

    gl.activeTexture(gl.TEXTURE0);
    gl.bindTexture(gl.TEXTURE_2D, textures["chessTex"]);

    for( let i=0; i < objComponents.length; i ++ ){
      initAttributeVariable(gl, program.a_Position, objComponents[i].vertexBuffer);
      initAttributeVariable(gl, program.a_TexCoord, objComponents[i].texCoordBuffer);
      initAttributeVariable(gl, program.a_Normal, objComponents[i].normalBuffer);
      gl.drawArrays(gl.TRIANGLES, 0, objComponents[i].numVertices);
    }
}
```

Example (Ex08-1)



- Shader in WebGL.js

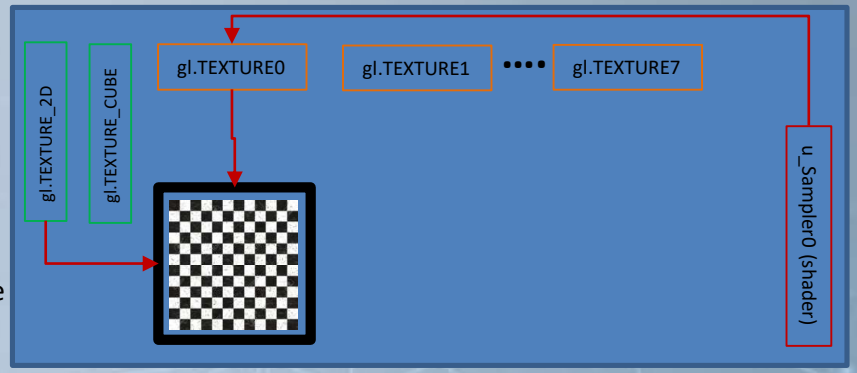
```
var VSHADER_SOURCE =
    attribute vec4 a_Position;
    attribute vec4 a_Normal;
    attribute vec2 a_TexCoord;
    uniform mat4 u_MvpMatrix;
    uniform mat4 u_modelMatrix;
    uniform mat4 u_normalMatrix;
    varying vec3 v_Normal;
    varying vec3 v_PositionInWorld;
    varying vec2 v_TexCoord;
    void main(){
        gl_Position = u_MvpMatrix * a_Position;
        v_PositionInWorld = (u_modelMatrix * a_Position).xyz;
        v_Normal = normalize(vec3(u_normalMatrix * a_Normal));
        v_TexCoord = a_TexCoord;
    }
`;
```

Texture coordinate of a fragment is calculated from the texture coordinates of vertices of the triangle by interpolation

```
var FSHADER_SOURCE =
    precision mediump float;
    uniform vec3 u_LightPosition;
    uniform vec3 u_ViewPosition;
    uniform float u_Ka;
    uniform float u_Kd;
    uniform float u_Ks;
    uniform float u_shininess;
    uniform sampler2D u_Sampler0;
    varying vec3 v_Normal;
    varying vec3 v_PositionInWorld;
    varying vec2 v_TexCoord;
    void main(){
        // let ambient and diffuse color are u_Color
        // (you can also input them from ouside and make them different)
        vec3 texColor = texture2D( u_Sampler0, v_TexCoord ).rgb;
        vec3 ambientLightColor = texColor;
        vec3 diffuseLightColor = texColor;
        // assume white specular light (you can also input it from ouside)
        vec3 specularLightColor = vec3(1.0, 1.0, 1.0);

        vec3 ambient = ambientLightColor * u_Ka;
```

- Load the texture image
- Prepare texture buffer
  - Create texture buffer: gl.createTexture()
  - Bind texture to a target: gl.bindTexture()
  - Indicate how to interpret the image: gl.pixelStorei()
  - Texture parameters: gl.texParameteri()
  - Assign the texture image to the texture target: gl.texImage2D()
- Assign the texture to the shader
  - Active a texture unit: gl.activeTexture()
  - Bind texture to a target if necessary(): gl.bindTexture()
  - Pass the texture unit to a ‘sampler2D’ in shader: gl.uniform1i()
- Call shader to draw
  - Get a color from the texture in shader: texture2D()

Example (Ex08-1)



- Shader in WebGL.js
  - sampler2D is the variable type to hold a 2D texture
  - Use "**texture2D()**" to get a texture color (RGBA) from a sampler2D variable
    - First parameter: the texture
    - Second parameter: a texture coordinate
    - Return: a RGBA color

```
var FSHADER_SOURCE =
    precision mediump float;
    uniform vec3 u_LightPosition;
    uniform vec3 u_ViewPosition;
    uniform float u_Ka;
    uniform float u_Kd;
    uniform float u_Ks;
    uniform float u_shininess;
    uniform sampler2D u_Sampler0;
    varying vec3 v_Normal;
    varying vec3 v_PositionInWorld;
    varying vec2 v_TexCoord;
    void main(){
        // let ambient and diffuse color are u_Color
        // (you can also input them from ouside and make them different)
        vec3 texColor = texture2D( u_Sampler0, v_TexCoord ).rgb;
        vec3 ambientLightColor = texColor;
        vec3 diffuseLightColor = texColor;
        // assume white specular light (you can also input it from ouside)
        vec3 specularLightColor = vec3(1.0, 1.0, 1.0);

        vec3 ambient = ambientLightColor * u_Ka;
```

- Load the texture image
- Prepare texture buffer
  - Create texture buffer: gl.createTexture()
  - Bind texture to a target: gl.bindTexture()
  - Indicate how to interpret the image: gl.pixelStorei()
  - Texture parameters: gl.texParameteri()
  - Assign the texture image to the texture target: gl.texImage2D()
- Assign the texture to the shader
  - Active a texture unit: gl.activeTexture()
  - Bind texture to a target if necessary(): gl.bindTexture()
  - Pass the texture unit to a 'sampler2D' in shader: gl.uniform1i()
- Call shader to draw
  - Get a color from the texture in shader: texture2D()

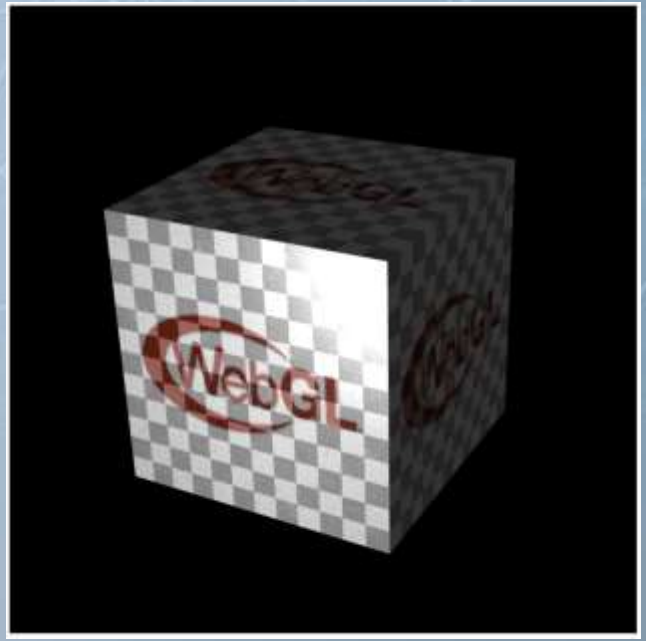
Let’s try (5mins)

- Make sure you know the step to use a texture and how to pass it to shader
- Change gl.uniform1i(program.u_Sampler0, 0) to gl.uniform1i(program.u_Sampler0, 2), does it work?
- What if you also modify gl.activeTexture(gl.TEXTURE0) to gl.activeTexture(gl.TEXTURE2), does it work?
- Try any thing you want.

Example (Ex08-2)

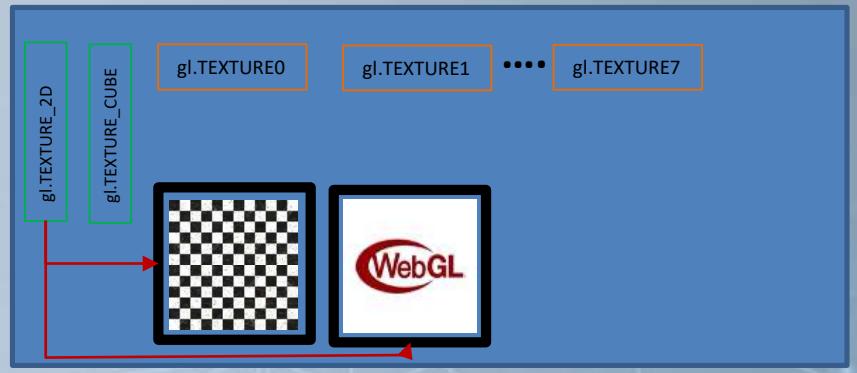
- **Mix multiple textures to color the cube**
  - Use multiple textures

- Files
  - Index.html
  - WebGL.js
  - cuon-matrix.js
  - cube.obj
  - chess.jpg
  - webglIcon.jpg



Example (Ex08-2)

- main(): load one more texture
- Also call initTexture to initialize each texture
- Store each texture in a dictionary, “textures”



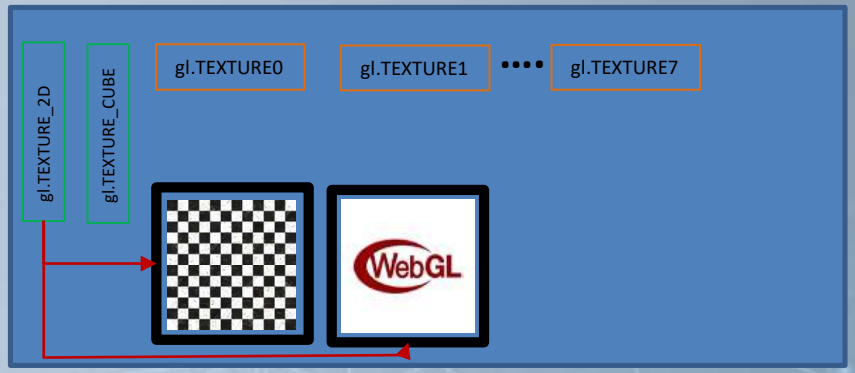

```
var textures = {};
var texCount = 0;
var numTextures = 2; //brick, grass

async function main(){
    canvas = document.getElementById('webgl');
```

```
function initTexture(gl, img, texKey){
  var tex = gl.createTexture();
  gl.pixelStorei(gl.UNPACK_FLIP_Y_WEBGL, 1);
  gl.bindTexture(gl.TEXTURE_2D, tex);

  // Set the parameters so we can render any size image.
  gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_MIN_FILTER, gl.LINEAR);

  // Upload the image into the texture.
  gl.texImage2D(gl.TEXTURE_2D, 0, gl.RGBA, gl.RGBA, gl.UNSIGNED_BYTE, img);

  textures[texKey] = tex;

  texCount++;
  if( texCount == numTextures)draw();
}
```

```
    var imageChess = new Image();
    imageChess.onload = function(){initTexture(gl, imageChess, "chessTex");};
    imageChess.src = "chess.jpg";

    var imageBk = new Image();
    imageBk.onload = function(){initTexture(gl, imageBk, "webGLTex");};
    imageBk.src = "webglIcon.jpg";

    mvpMatrix = new Matrix4();
    modelMatrix = new Matrix4();
    normalMatrix = new Matrix4();

    gl.enable(gl.DEPTH_TEST);

    canvas.onmousedown = function(ev){mouseDown(ev)};
    canvas.onmousemove = function(ev){mouseMove(ev)};
    canvas.onmouseup = function(ev){mouseUp(ev)};
}
```

Example (Ex08-2)

- draw the first frame if all texture loading is done



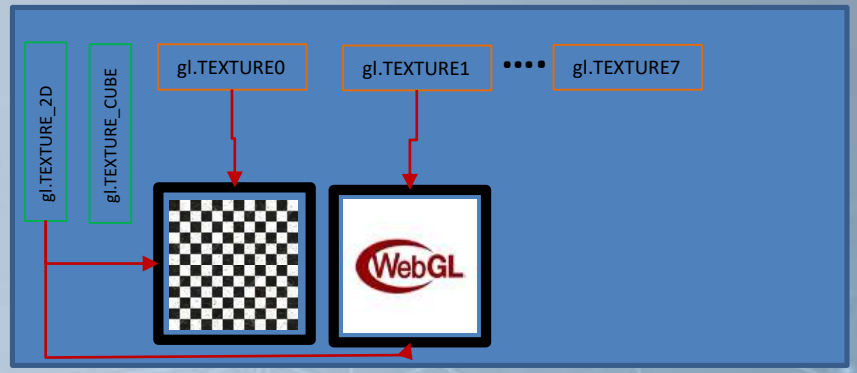

```
var textures = {};
var texCount = 0;
var numTextures = 2; //brick, grass

async function main(){
    canvas = document.getElementById('webgl');
```

```
function initTexture(gl, img, texKey){
  var tex = gl.createTexture();
  gl.pixelStorei(gl.UNPACK_FLIP_Y_WEBGL, 1);
  gl.bindTexture(gl.TEXTURE_2D, tex);

  // Set the parameters so we can render any size image.
  gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_MIN_FILTER, gl.LINEAR);

  // Upload the image into the texture.
  gl.texImage2D(gl.TEXTURE_2D, 0, gl.RGBA, gl.RGBA, gl.UNSIGNED_BYTE, img);

  textures[texKey] = tex;

  texCount++;
  if( texCount == numTextures)draw();
}
```

```
    var imageChess = new Image();
    imageChess.onload = function(){initTexture(gl, imageChess, "chessTex");};
    imageChess.src = "chess.jpg";

    var imageBk = new Image();
    imageBk.onload = function(){initTexture(gl, imageBk, "webGLTex");};
    imageBk.src = "webglIcon.jpg";

    mvpMatrix = new Matrix4();
    modelMatrix = new Matrix4();
    normalMatrix = new Matrix4();

    gl.enable(gl.DEPTH_TEST);

    canvas.onmousedown = function(ev){mouseDown(ev)};
    canvas.onmousemove = function(ev){mouseMove(ev)};
    canvas.onmouseup = function(ev){mouseUp(ev)};
}
```

Example (Ex08-2)

- **Bind textures to texture units**
- Assign texture units to sampler2D variables in shader

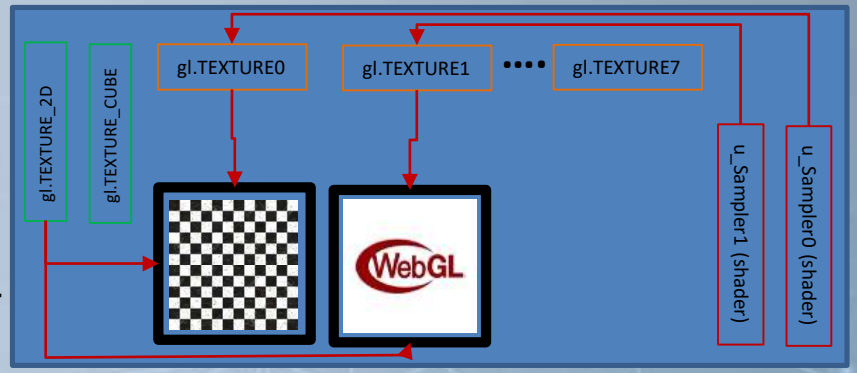



```
function draw(){
    gl.clearColor(0,0,0,1);

    //model Matrix (part of the mvp matrix)
    modelMatrix.setRotate(angleY, 1, 0, 0);//for mouse rotation
    modelMatrix.rotate(angleX, 0, 1, 0);//for mouse rotation
    modelMatrix.scale(objScale, objScale, objScale);
    // modelMatrix.translate(0.0, 0.0, -1.0);
    // modelMatrix.scale(1.0, 0.5, 2.0);
    //mvp: projection * view * model matrix
    mvpMatrix.setPerspective(30, 1, 1, 100);
    mvpMatrix.lookAt(cameraX, cameraY, cameraZ, 0, 0, 0, 0, 1, 0);
    mvpMatrix.multiply(modelMatrix);

    //normal matrix
    normalMatrix.setInverseOf(modelMatrix);
    normalMatrix.transpose();
```

```
    gl.uniform3f(program.u_LightPosition, 0, 0, 3);
    gl.uniform3f(program.u_ViewPosition, cameraX, cameraY, cameraZ);
    gl.uniform1f(program.u_Ka, 0.2);
    gl.uniform1f(program.u_Kd, 0.7);
    gl.uniform1f(program.u_Ks, 1.0);
    gl.uniform1f(program.u_shininess, 10.0);
    gl.uniform1i(program.u_Sampler0, 0);
    gl.uniform1i(program.u_Sampler1, 1);

    gl.uniformMatrix4fv(program.u_MvpMatrix, false, mvpMatrix.elements);
    gl.uniformMatrix4fv(program.u_modelMatrix, false, modelMatrix.elements);
    gl.uniformMatrix4fv(program.u_normalMatrix, false, normalMatrix.elements);

    gl.clear(gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT);

    gl.activeTexture(gl.TEXTURE0);
    gl.bindTexture(gl.TEXTURE_2D, textures["chessTex"]);

    gl.activeTexture(gl.TEXTURE1);
    gl.bindTexture(gl.TEXTURE_2D, textures["webGLTex"]);

    for( let i=0; i < objComponents.length; i ++ ){
      initAttributeVariable(gl, program.a_Position, objComponents[i].vertexBuffer);
      initAttributeVariable(gl, program.a_TexCoord, objComponents[i].texCoordBuffer);
      initAttributeVariable(gl, program.a_Normal, objComponents[i].normalBuffer);
      gl.drawArrays(gl.TRIANGLES, 0, objComponents[i].numVertices);
    }
}
```

Example (Ex08-2)

- Bind textures to texture units
- **Assign texture units to sampler2D variables in shader**




```
function draw(){
    gl.clearColor(0,0,0,1);

    //model Matrix (part of the mvp matrix)
    modelMatrix.setRotate(angleY, 1, 0, 0);//for mouse rotation
    modelMatrix.rotate(angleX, 0, 1, 0);//for mouse rotation
    modelMatrix.scale(objScale, objScale, objScale);
    // modelMatrix.translate(0.0, 0.0, -1.0);
    // modelMatrix.scale(1.0, 0.5, 2.0);
    //mvp: projection * view * model matrix
    mvpMatrix.setPerspective(30, 1, 1, 100);
    mvpMatrix.lookAt(cameraX, cameraY, cameraZ, 0, 0, 0, 0, 1, 0);
    mvpMatrix.multiply(modelMatrix);

    //normal matrix
    normalMatrix.setInverseOf(modelMatrix);
    normalMatrix.transpose();
```

```
    gl.uniform3f(program.u_LightPosition, 0, 0, 3);
    gl.uniform3f(program.u_ViewPosition, cameraX, cameraY, cameraZ);
    gl.uniform1f(program.u_Ka, 0.2);
    gl.uniform1f(program.u_Kd, 0.7);
    gl.uniform1f(program.u_Ks, 1.0);
    gl.uniform1f(program.u_shininess, 10.0);
    gl.uniform1i(program.u_Sampler0, 0);
    gl.uniform1i(program.u_Sampler1, 1);

    gl.uniformMatrix4fv(program.u_MvpMatrix, false, mvpMatrix.elements);
    gl.uniformMatrix4fv(program.u_modelMatrix, false, modelMatrix.elements);
    gl.uniformMatrix4fv(program.u_normalMatrix, false, normalMatrix.elements);

    gl.clear(gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT);

    gl.activeTexture(gl.TEXTURE0);
    gl.bindTexture(gl.TEXTURE_2D, textures["chessTex"]);

    gl.activeTexture(gl.TEXTURE1);
    gl.bindTexture(gl.TEXTURE_2D, textures["webGLTex"]);

    for( let i=0; i < objComponents.length; i ++ ){
      initAttributeVariable(gl, program.a_Position, objComponents[i].vertexBuffer);
      initAttributeVariable(gl, program.a_TexCoord, objComponents[i].texCoordBuffer);
      initAttributeVariable(gl, program.a_Normal, objComponents[i].normalBuffer);
      gl.drawArrays(gl.TRIANGLES, 0, objComponents[i].numVertices);
    }
}
```

Example (Ex08-2)

- Fragment shader
  - Mix color from two textures

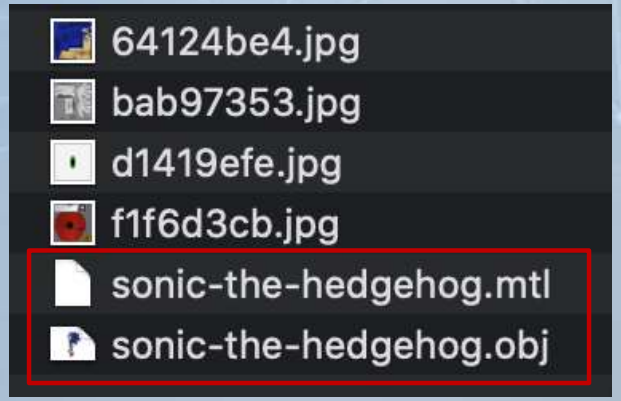
```
var FSHADER_SOURCE =
    precision mediump float;
    uniform vec3 u_LightPosition;
    uniform vec3 u_ViewPosition;
    uniform float u_Ka;
    uniform float u_Kd;
    uniform float u_Ks;
    uniform float u_shininess;
    uniform sampler2D u_Sampler0;
    uniform sampler2D u_Sampler1;
    varying vec3 v_Normal;
    varying vec3 v_PositionInWorld;
    varying vec2 v_TexCoord;
    void main(){
        // let ambient and diffuse color are u_Color
        // (you can also input them from ouside and make them different)
        vec3 texColor0 = texture2D( u_Sampler0, v_TexCoord ).rgb;
        vec3 texColor1 = texture2D( u_Sampler1, v_TexCoord ).rgb;
        vec3 texColor = texColor0 * 0.4 + texColor1 * 0.6;
        vec3 ambientLightColor = texColor;
        vec3 diffuseLightColor = texColor;
        // assume white specular light (you can also input it from ouside)
        vec3 specularLightColor = vec3(1.0, 1.0, 1.0);
```

Let’s try (5mins)

- Try to modify this line, “vec3 texColor = texColor0 *0.4 + texColor1 *0.6”;, to vec3 texColor = texColor0 *0.7 + texColor1 *0.3
  - Change this line to other weight factors to mix them, make sure you understand it
- If you want to pass the third textures to shader, try to think what you should do?
- Try any thing you want

Color an Obj File Object by Texture Images

- The obj file from clara.io usually includes texture images for the object
- The metadata is in *.mtl file



Color an Obj File Object by Texture Images

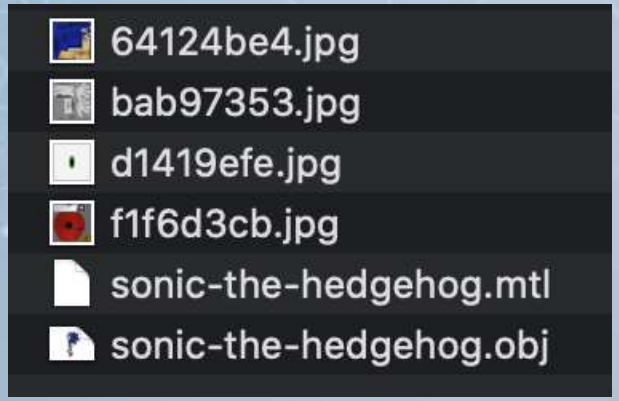
- Review the obj files
  - use sonic as an example (it consist of 13 components)

Tell you where the material metadata file is

```
# Blender v2.74 (sub 0) OBJ File: ''
# www.blender.org
mtllib sonic-the-hedgehog.mtl
o DrawCall_0277
v -1.861972 22.695541 2.067917
v -1.814528 22.398708 2.033974
v -1.594641 22.407452 2.108498
v -1.620953 22.704561 2.146652
v -1.897370 23.060692 2.074585
v -1.645572 23.072294 2.154800
v -1.923574 23.475042 2.060799
v -1.663958 23.490108 2.144958
v -1.939530 23.931679 2.025650
v -1.673995 23.948975 2.113655
v -1.674102 24.439888 2.057426
v -1.943755 24.423717 1.968201
v -1.659837 24.990534 1.969383
v -1.933084 24.975704 1.879944
v -1.627081 25.628675 1.842583
v -1.903709 25.612173 1.752319
v -1.545297 26.311020 1.632172
v -1.823511 26.294573 1.540985
v -1.384264 26.994339 1.293381
v -1.660048 26.984308 1.201553
v -1.183500 27.678129 0.890373
v -1.455058 27.677729 0.798042
v -0.911733 27.651968 0.975662
```

Color an Obj File Object by Texture Images

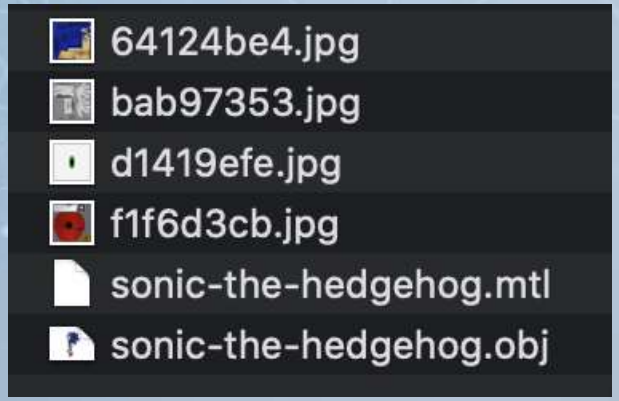
- sonic-the-hedgehog.mtl
- Although sonic consist of 13 components
- It only has 4 different materials
  - Each material has its own illumination parameters (ka, kd, ks…) and texture image




```
# Blender MTL File: 'None'
# Material Count: 4

newmtl 64124be4_dds
Ns 96.078431
Ka 0.000000 0.000000 0.000000
Kd 0.700000 0.700000 0.700000
Ks 0.010000 0.010000 0.010000
Ni 1.000000
d 1.000000
illum 2
map_Kd 64124be4.jpg

newmtl bab97353_dds
Ns 96.078431
Ka 0.000000 0.000000 0.000000
Kd 0.700000 0.700000 0.700000
Ks 0.010000 0.010000 0.010000
Ni 1.000000
d 1.000000
illum 2
map_Kd bab97353.jpg

newmtl d1419efe_dds
Ns 96.078431
Ka 0.000000 0.000000 0.000000
Kd 0.700000 0.700000 0.700000
Ks 0.010000 0.010000 0.010000
Ni 1.000000
d 1.000000
illum 2
map_Kd d1419efe.jpg

newmtl f1f6d3cb_dds
Ns 96.078431
Ka 0.000000 0.000000 0.000000
Kd 0.700000 0.700000 0.700000
Ks 0.010000 0.010000 0.010000
Ni 1.000000
d 1.000000
illum 2
map_Kd f1f6d3cb.jpg
```

Color an Obj File Object by Texture Images

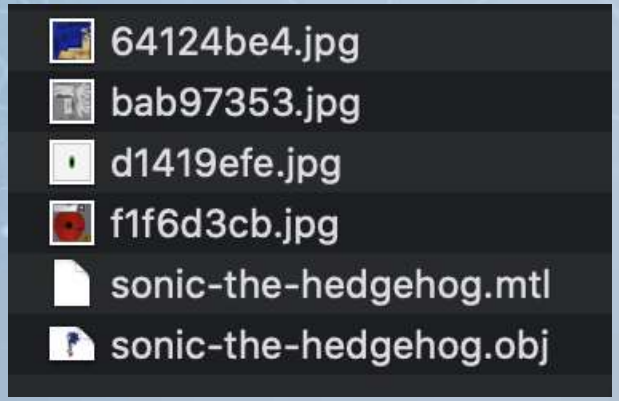
- Material IDs




```
# Blender MTL File: 'None'
# Material Count: 4

newmtl 64124be4_dds
Ns 96.078431
Ka 0.000000 0.000000 0.000000
Kd 0.700000 0.700000 0.700000
Ks 0.010000 0.010000 0.010000
Ni 1.000000
d 1.000000
illum 2
map_Kd 64124be4.jpg

newmtl bab97353_dds
Ns 96.078431
Ka 0.000000 0.000000 0.000000
Kd 0.700000 0.700000 0.700000
Ks 0.010000 0.010000 0.010000
Ni 1.000000
d 1.000000
illum 2
map_Kd bab97353.jpg

newmtl d1419efe_dds
Ns 96.078431
Ka 0.000000 0.000000 0.000000
Kd 0.700000 0.700000 0.700000
Ks 0.010000 0.010000 0.010000
Ni 1.000000
d 1.000000
illum 2
map_Kd d1419efe.jpg

newmtl f1f6d3cb_dds
Ns 96.078431
Ka 0.000000 0.000000 0.000000
Kd 0.700000 0.700000 0.700000
Ks 0.010000 0.010000 0.010000
Ni 1.000000
d 1.000000
illum 2
map_Kd f1f6d3cb.jpg
```

Color an Obj File Object by Texture Images

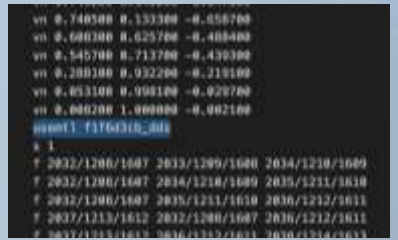
- Texture image of each material

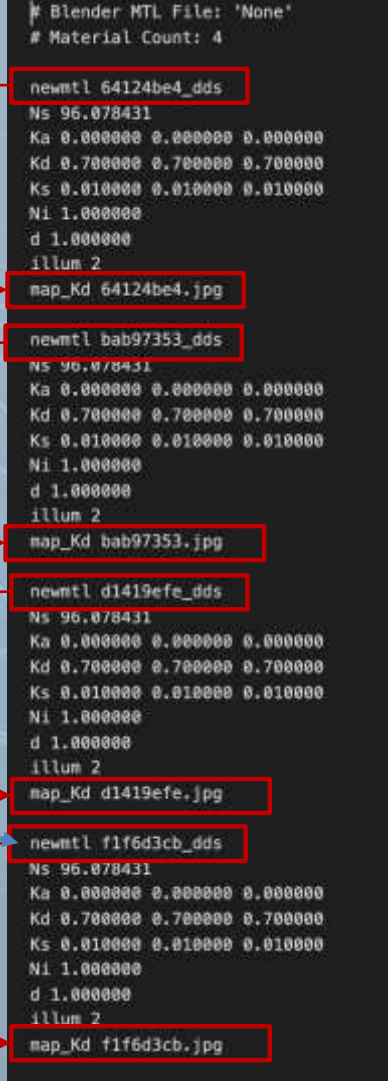



```
# Blender MTL File: 'None'
# Material Count: 4

newmtl 64124be4_dds
Ns 96.078431
Ka 0.000000 0.000000 0.000000
Kd 0.700000 0.700000 0.700000
Ks 0.010000 0.010000 0.010000
Ni 1.000000
d 1.000000
illum 2
map_Kd 64124be4.jpg

newmtl bab97353_dds
Ns 96.078431
Ka 0.000000 0.000000 0.000000
Kd 0.700000 0.700000 0.700000
Ks 0.010000 0.010000 0.010000
Ni 1.000000
d 1.000000
illum 2
map_Kd bab97353.jpg

newmtl d1419efe_dds
Ns 96.078431
Ka 0.000000 0.000000 0.000000
Kd 0.700000 0.700000 0.700000
Ks 0.010000 0.010000 0.010000
Ni 1.000000
d 1.000000
illum 2
map_Kd d1419efe.jpg

newmtl f1f6d3cb_dds
Ns 96.078431
Ka 0.000000 0.000000 0.000000
Kd 0.700000 0.700000 0.700000
Ks 0.010000 0.010000 0.010000
Ni 1.000000
d 1.000000
illum 2
map_Kd f1f6d3cb.jpg
```

Color an Obj File Object by Texture Images

- Back to the obj file again
- If you search the keyword “usemtl”, you will realize that each component has one “usemtl” line (usually right before ”face” section).
- It tells you what the material information is of this component
  - Ex: usemtl f1f6d3cb_dds (so the texture image for this component is “f1f6d3cb.jpg”)
  - So, you can find 13 usemtl lines in the sonic obj file

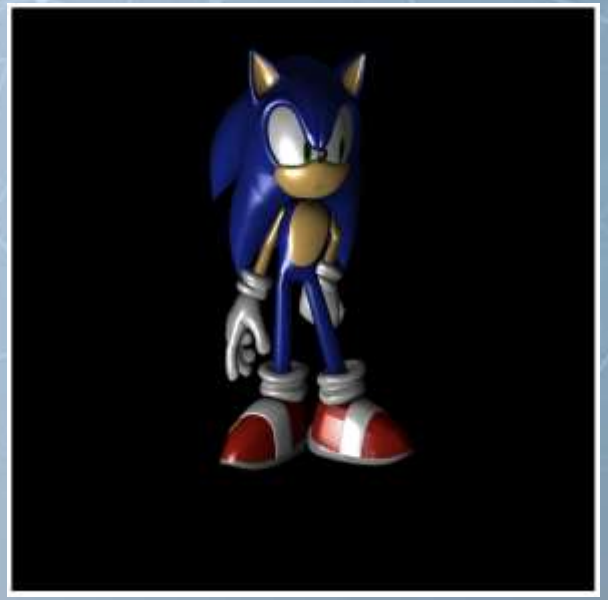




Example (Ex08-3)

- Use texture images to color the sonic

- Files



Example (Ex08-3)

- main() in WebGL.js
  - I do not write a parser to parse the mtl file. So, I manually create and hardcode the mapping between object components and texture images
  - It is better if you write a parser for mtl file.

```
var cameraX = 3, cameraY = 3, cameraZ = 7;
var objScale = 0.1;
var objComponents = [];
var textures = [];
var imgNames = ["64124be4.jpg", "bab97353.jpg", "d1419efe.jpg", "f1f6d3cb.jpg"];
var objCompImgIndex = ["d1419efe.jpg", "64124be4.jpg", "64124be4.jpg", "f1f6d3cb.jpg",
                       "bab97353.jpg", "64124be4.jpg", "64124be4.jpg", "64124be4.jpg",
                       "f1f6d3cb.jpg", "64124be4.jpg", "bab97353.jpg", "f1f6d3cb.jpg",
                       "d1419efe.jpg"];
var texCount = 0;
var numTextures = imgNames.length;

async function main(){
    canvas = document.getElementById('webgl');
    gl = canvas.getContext('webgl2');
    if(!gl){
        console.log('Failed to get the rendering context for WebGL');
        return ;
    }

    program = compileShader(gl, VSHADER_SOURCE, FSHADER_SOURCE);

    gl.useProgram(program);
```

```
program.a_Position = gl.getAttribLocation(program, 'a_Position');
program.a_TexCoord = gl.getAttribLocation(program, 'a_TexCoord');
program.a_Normal = gl.getAttribLocation(program, 'a_Normal');
program.u_MvpMatrix = gl.ge any rmLocation(program, 'u_MvpMatrix');
program.u_modelMatrix = gl.getUniformLocation(program, 'u_modelMatrix');
program.u_normalMatrix = gl.getUniformLocation(program, 'u_normalMatrix');
program.u_LightPosition = gl.getUniformLocation(program, 'u_LightPosition');
program.u_ViewPosition = gl.getUniformLocation(program, 'u_ViewPosition');
program.u_Ka = gl.getUniformLocation(program, 'u_Ka');
program.u_Kd = gl.getUniformLocation(program, 'u_Kd');
program.u_Ks = gl.getUniformLocation(program, 'u_Ks');
program.u_shininess = gl.getUniformLocation(program, 'u_shininess');
program.u_Sampler = gl.getUniformLocation(program, "u_Sampler")

response = await fetch('sonic.obj');
text = await response.text();
obj = parseOBJ(text);

for( let i=0; i < obj.geometries.length; i ++ ){
  let o = initVertexBufferForLaterUse(gl,
                                      obj.geometries[i].data.position,
                                      obj.geometries[i].data.normal,
                                      obj.geometries[i].data.texcoord);
  objComponents.push(o);
}
```

load and setup components and texture images

```
for( let i=0; i < imgNames.length; i ++ ){
  let image = new Image();
  image.onload = function(){initTexture(gl, image, imgNames[i]);};
  image.src = imgNames[i];
}

mvpMatrix = new Matrix4();
modelMatrix = new Matrix4();
normalMatrix = new Matrix4();

gl.enable(gl.DEPTH_TEST);

canvas.onmousedown = function(ev){mouseDown(ev)};
canvas.onmousemove = function(ev){mouseMove(ev)};
canvas.onmouseup = function(ev){mouseUp(ev)};
}
```

Example (Ex08-3)

- draw() in WebGL.js

Before drawing a component bind the corresponding texture image to TEXTURE0, and tell u_Sampler to use the texture unit 0

```
function draw(){
    gl.clearColor(0,0,0,1);

    //model Matrix (part of the mvp matrix)
    modelMatrix.setRotate(angleY, 1, 0, 0);//for mouse rotation
    modelMatrix.rotate(angleX, 0, 1, 0);//for mouse rotation
    modelMatrix.translate(0, -1.2, 0);
    modelMatrix.scale(objScale, objScale, objScale);
    //mvp: projection * view * model matrix
    mvpMatrix.setPerspective(30, 1, 1, 100);
    mvpMatrix.lookAt(cameraX, cameraY, cameraZ, 0, 0, 0, 0, 1, 0);
    mvpMatrix.multiply(modelMatrix);

    //normal matrix
    normalMatrix.setInverseOf(modelMatrix);
    normalMatrix.transpose();

    gl.uniform3f(program.u_LightPosition, 0, 0, 3);
    gl.uniform3f(program.u_ViewPosition, cameraX, cameraY, cameraZ);
    gl.uniform1f(program.u_Ka, 0.2);
    gl.uniform1f(program.u_Kd, 0.7);
    gl.uniform1f(program.u_Ks, 1.0);
    gl.uniform1f(program.u_shininess, 10.0);

    gl.uniformMatrix4fv(program.u_MvpMatrix, false, mvpMatrix.elements);
    gl.uniformMatrix4fv(program.u_modelMatrix, false, modelMatrix.elements);
    gl.uniformMatrix4fv(program.u_normalMatrix, false, normalMatrix.elements);
```

Draw components one by one

```
    gl.clear(gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT);

    for( let i=0; i < objComponents.length; i ++ ){
      gl.activeTexture(gl.TEXTURE0);
      gl.bindTexture(gl.TEXTURE_2D, textures[objCompImgIndex[i]]);
      gl.uniform1i(program.u_Sampler, 0);

      initAttributeVariable(gl, program.a_Position, objComponents[i].vertexBuffer);
      initAttributeVariable(gl, program.a_TexCoord, objComponents[i].texCoordBuffer);
      initAttributeVariable(gl, program.a_Normal, objComponents[i].normalBuffer);

      gl.drawArrays(gl.TRIANGLES, 0, objComponents[i].numVertices);
    }
}
```

Let’s try

- Make sure you know .mtl file and you know an object component should map to which texture image