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Dev Environment: Lab Package

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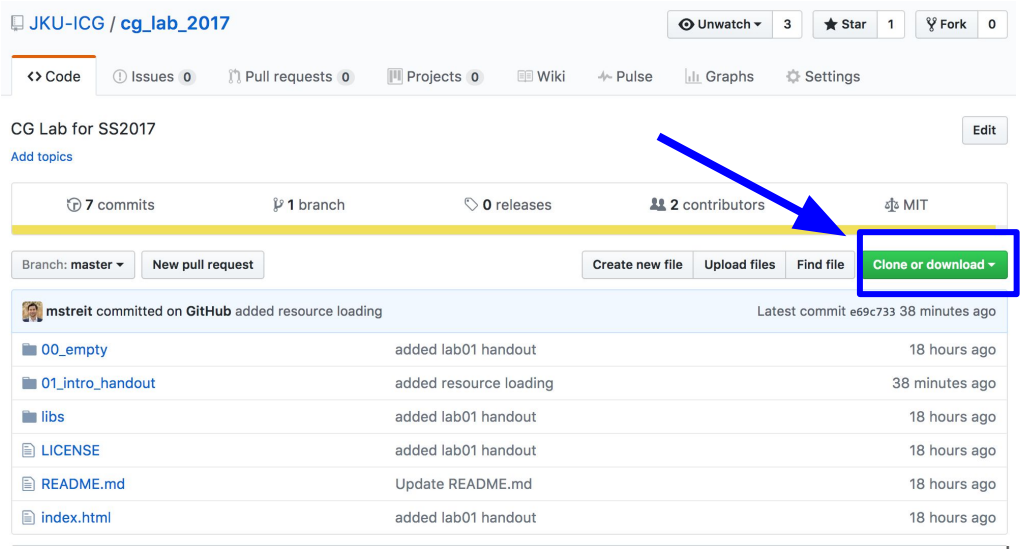
Hosted on GitHub: https://github.com/jku-icg/cg_lab_2017

The repository will be updated during the lab with the new projects.

To get started:

1. Download the zip
2. Extract the folder
3. Open Atom editor
4. Use “Open Folder” in Atom
5. Start server on any port (Packages -> Live Server)



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Lab 5: Texturing

Schedule

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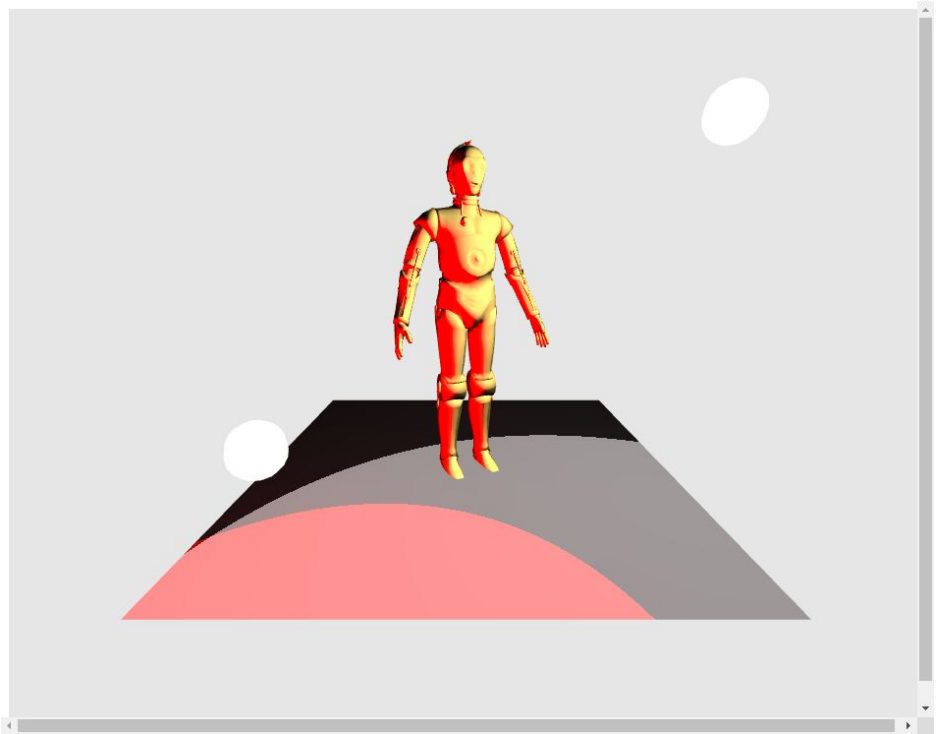
Lab 1	Introduction to WebGL	10.3.2017 / 14.3/2017	-
Lab 2	Transformations and Projections	21.3.2017 / 24.3.2017	Lecture: 14.3.2017
Lab 3	Scene Graphs	28.3.2017 / 31.3.2017	Lecture: 21.3.2017
Lab 4	Illumination and Shading	4.4.2017 / 7.4.2017	Lecture: 28.3.2017
Lab 5	Texturing	25.4.2017 / 28.4.2017	Lecture: 4.4.2017
Lab 6	Advanced Texture Mapping	2.5.2017 / 5.5.2017	Lecture: 26.4.2017
Lab 7a	CUDA	9.5.2017 / 12.5.2017	
Lab 7b	VTK	12.5.2017	

Recap

Lab Project Specification

Illumination

0. Interaction
1. Static Phong Shader
2. New SG Node: Material
3. New SG Node: Light
4. Animated Light
5. Multiple Lights



Solution now on GitHub

Agenda for Today

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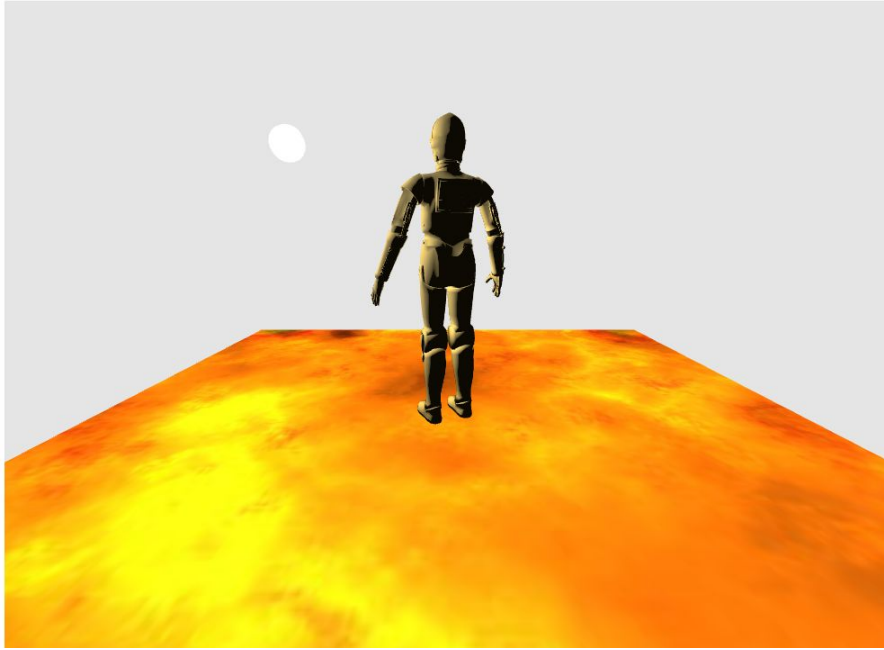
Texturing Basics

- Overview
- Setup Textures
- Texture Coordinates
- Textures in Shader
- Binding Textures
- Task: Simple Texturing
- Task: Integrate Texturing into Phong Shader
- Tasks: Texture Wrapping and Repeating



Rendering to Textures

- Multiple Render Passes
- Setup Framebuffer
- Task: Render to Texture

Extra Task: Animate Texture Coordinates

Texturing - Overview

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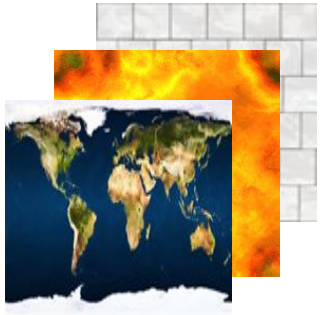
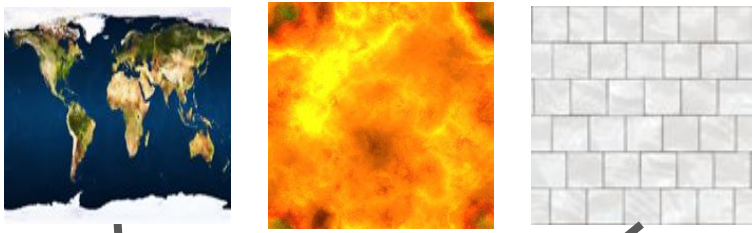
images in main memory



upload to GPU (once)

textures in graphics memory



...

bind textures for current model

vertices + **texture coordinates**

texture units (handle lookup + filtering)

texture unit 0

texture unit 1

…

shader: request texture data (e.g. color) from texture unit at texture coordinates

What Are Texture Units?

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You can think of them as a piece of GPU hardware which performs fast image sampling. (not 100% correct!)

Main jobs:

- Addressing, e.g. compute pixel index (132,12) from texture coordinate (0.342,0.012)
- Filtering, e.g. combine neighboring pixels if pixel index is not an integer

Limited number of texture units!

- Hardware and OpenGL version dependent
- Per shader stage, e.g. 4
- Total, e.g. 4*2=8 (vertex + fragment shader stage)
- Limits number of textures which can be used simultaneously in shader

BUT (almost) unlimited number of textures

- Limited only by graphics memory size

Loading Images

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Done in framework during resource loading!

Basic steps:

Allocate JavaScript “Image” object:

```
var image_1 = new Image();
```

Set image url:

```
image_1.src = "imagefolder/myimage.jpg";
```

Wait until image is loaded:

```
image_1.onload = function () {
    //start OpenGL part
    ...
};
```

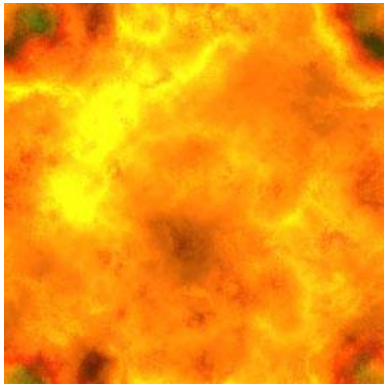
See framework for more details

Recap: Loading Resources

Loading images with our framework is simple:

```
loadResources({
  vs: 'shader/texture.vs.glsl',
  fs: 'shader/texture.fs.glsl',
  vs_single: 'shader/single.vs.glsl',
  fs_single: 'shader/single.fs.glsl',
  floortexture: 'models/lava.jpg',
  model: 'models/C-3PO.obj'
}).then(function (resources) {
  init(resources);
  render(0);
});
```

Access: `resources.floortexture`



`lava.jpg`

Code: Initialize Textures

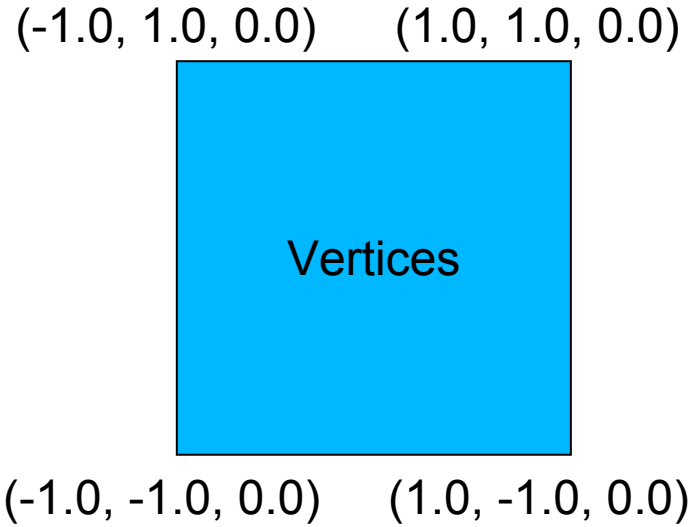
1. create texture object
2. choose any texture unit
3. bind to texture unit
4. set sampling parameters
5. upload data to GPU
6. unbind texture

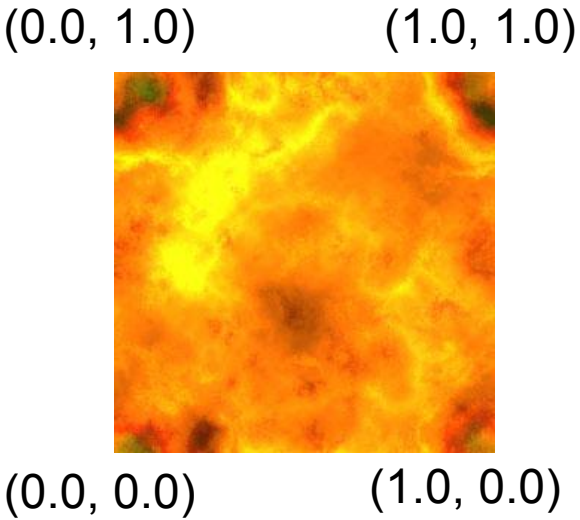
```
function initTextures(resources)
{
  //create texture reference
  floorTexture = gl.createTexture();
  //select a texture unit
  gl.activeTexture(gl.TEXTURE0);
  //bind texture to active texture unit
  gl.bindTexture(gl.TEXTURE_2D, floorTexture);
  //set sampling parameters
  gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_MAG_FILTER, gl.LINEAR);
  gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_MIN_FILTER, gl.LINEAR);
  gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_WRAP_S, gl.CLAMP_TO_EDGE);
  gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_WRAP_T, gl.CLAMP_TO_EDGE);
  //upload texture data
  gl.texImage2D(gl.TEXTURE_2D, //texture unit target == texture type
    0, //level of detail level (default 0)
    gl.RGBA, //internal format of the data in memory
    gl.RGBA, //image format (should match internal format)
    gl.UNSIGNED_BYTE, //image data type
    resources.floortexture); //actual image data
  //clean up/unbind texture
  gl.bindTexture(gl.TEXTURE_2D, null);
}
```

Texture Coordinates

Mapping a texture onto a shape will be done by providing texture coordinates for every vertex

Texture coordinates for a simple quad:





Recap: Buffers and Attributes

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Texture coordinates are defined per vertex via buffer

Same as vertex position, color, normal, …

Define coordinates + buffer:

```
texturcoordinates = [0, 0,   1, 0,   1, 1,   0, 1]; //4x 2D coordinates
texCoordBuffer = gl.createBuffer();
gl.bindBuffer(gl.ARRAY_BUFFER, texCoordBuffer);
gl.bufferData(gl.ARRAY_BUFFER, new Float32Array(texturcoordinates), gl.STATIC_DRAW);
```

Pass buffer to shader attribute (`a_texCoord`):

```
var texCoordLoc = gl.getAttribLocation(shader, 'a_texCoord');
gl.bindBuffer(gl.ARRAY_BUFFER, texCoordBuffer);
gl.enableVertexAttribArray(texCoordLoc);
gl.vertexAttribPointer(texCoordLoc, 2, gl.FLOAT, false, 0, 0);
```

remember? 2 == 2D vectors

See framework for more details

Code: Texture Coordinates for Floor

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Define texture coordinates using our framework:

```
function makeFloor() {
  var width = 2;
  var height = 2;
  var position = [-width, -height, 0,   width, -height, 0,   width, height, 0,   -width, height, 0];
  var normal = [0, 0, 1,   0, 0, 1,   0, 0, 1,   0, 0, 1];
  var texturecoordinates = [0, 0,   1, 0,   1, 1,   0, 1];
  var index = [0, 1, 2,   2, 3, 0];
  return {
    position: position,
    normal: normal,
    texture: texturecoordinates,
    index: index
  };
}
```

Assign to render node:

```
new RenderSGNode(makeFloor())
```

Texture Coordinates in Shader

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Texture coordinates are bound to shader attributes:

```
//given texture coordinates per vertex
attribute vec2 a_texCoord;
```

Note: Our framework assigns texture coordinates to the attribute named `a_texCoord`.

Remember: Attributes are only available in vertex shader.
Have to be passed on via “varying” variables to fragment shader if required!

Texture Unit in Shader

Access to texture units via sampler variables

They don't change per vertex ⟶ `uniform`

Different sampler type for each texture type: 2D ⟶ `sampler2D`

Define sampler for 2D textures:

```
uniform sampler2D u_tex;
```

Texture Lookup in Shader

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Texture Lookup:

Get color of texture bound to sampler at defined coordinates.

Function:

```
texture2D(sampler,texture coordinates)
```

Input:

sampler (type: sampler2D)

texture coordinates (type: vec2)

Returns:

color (type: vec4)

Bind Texture to Texture Unit

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Before rendering a textured object we have to:

1. Select/activate a texture unit:

```
gl.activeTexture(gl.TEXTURE0);
```

Hint: Add texture unit number to `gl.TEXTURE0` to select a different unit!

2. Bind desired texture to selected texture unit:

```
gl.bindTexture(gl.TEXTURE_2D, mytexture);
```

Note: `gl.TEXTURE_2D` specifies the texture target = texture type

3. Assign texture unit number to sampler variable in shader.

Use `gl.uniform1i(...)` to set an integer to a uniform shader variable.

Hint: Do NOT use the texture unit constant (e.g. `gl.TEXTURE0`) in this case.

These are the duties of our `TextureSGNode` scene graph node!

Task 1 - Simple Texturing

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Goal:

Put texture on floor

Given:

Floor scenegraph node (`floor`)

Partially implemented texture node (`TextureSGNode`)

Partially implemented shaders (`texture.vs.glsl, texture.fs.glsl`)

Texture coordinates in vertex shader (`a_texCoord`)

Loaded and initialized texture (`floorTexture`)

Have a look at those code parts! Ask if you don’t understand them.

Task 1 - Simple Texturing

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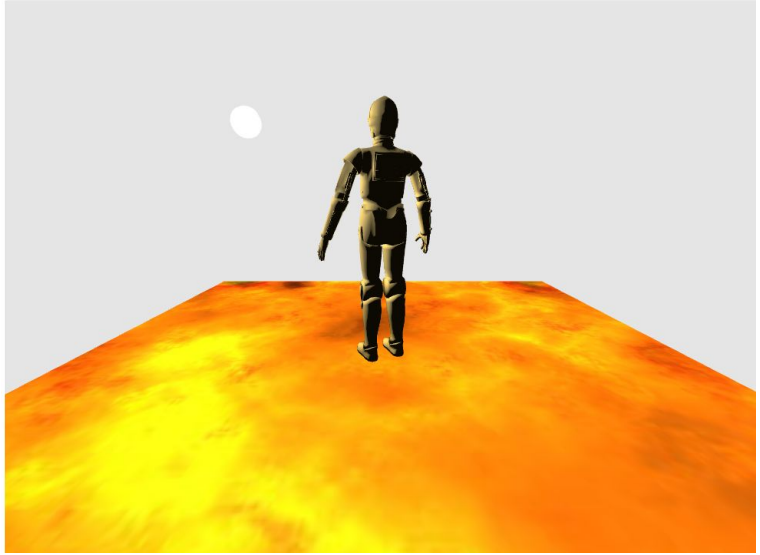
Tasks in shaders:

- Pass texture coordinates as varying to fragment shader
- Define sampler variable
- Do texture lookup in fragment shader (main)
  - Assign result to `gl_FragColor`

Tasks in main.js:

- Finish `TextureSGNode` implementation
  - Pass texture unit number to shader
  - Bind texture to texture unit
  - Clean up texture unit assignment
- Apply `TextureSGNode` to floor in scene graph
  - Use texture `floorTexture`
  - Use texture unit number 2



Solution: Simple Texturing (main.js)

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```
render(context)
{
  //tell shader to use our texture
  gl.uniform1i(gl.getUniformLocation(context.shader, 'u_enableObjectTexture'), 1);

  //set additional shader parameters
  //TASK 1: set texture unit
  gl.uniform1i(gl.getUniformLocation(context.shader, 'u_tex'), this.textureunit);

  //activate and bind texture
  //TASK 1: activate/select texture unit and bind texture
  gl.activeTexture(gl.TEXTURE0 + this.textureunit);
  gl.bindTexture(gl.TEXTURE_2D, this.texture);

  //render children
  super.render(context);

  //clean up
  //TASK 1: activate texture unit and bind null as texture
  gl.activeTexture(gl.TEXTURE0 + this.textureunit);
  gl.bindTexture(gl.TEXTURE_2D, null);

  //disable texturing in shader
  gl.uniform1i(gl.getUniformLocation(context.shader, 'u_enableObjectTexture'), 0);
}
```

```
let floor = new MaterialSGNode(
            new TextureSGNode(floorTexture,2,
            new RenderSGNode(makeFloor())
            ));
```

Solution: Simple Texturing (shader)

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vertex shader:

```
varying vec2 v_texCoord;
```

```
  //TASK 1: pass on texture coordinates to fragment shader
  v_texCoord = a_texCoord;

  gl_Position = u_projection * eyePosition;
}
```

fragment shader:

```
varying vec2 v_texCoord;
uniform sampler2D u_tex;
```

```
if(u_enableObjectTexture)
{
  gl_FragColor = texture2D(u_tex,v_texCoord);
  return;
}
```

Task 2: Phong Shader Integration

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Goal:

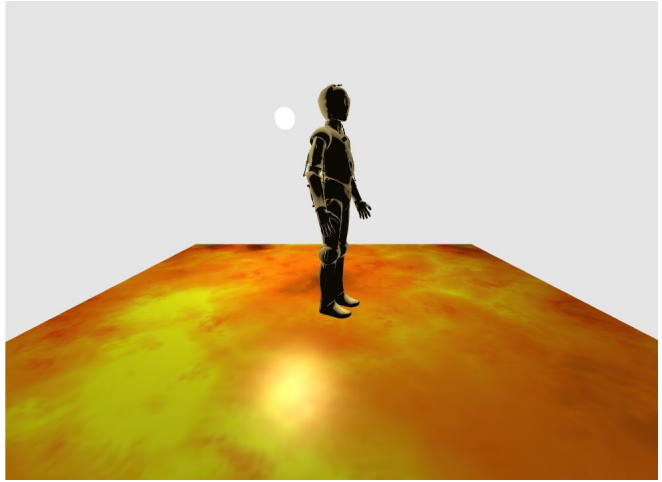
The light should influence our textured object.

Tasks:

Pass texture color to `calculateSimplePointLight` function (instead of setting `gl_FragColor`)

Hint: use `textureColor` variable

Replace diffuse and ambient material color with texture color



Solution: Phong Shader Integration

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`main` shader function:

```
vec4 textureColor = vec4(0,0,0,1);
if(u_enableObjectTexture)
{
  textureColor = texture2D(u_tex,v_texCoord);
}
gl_FragColor = calculateSimplePointLight(u_light, u_material, v_lightVec, v_normalVec, v_eyeVec, textureColor);
```

`calculateSimplePointLight` function:

```
if(u_enableObjectTexture)
{
  //TASK 2: replace diffuse and ambient material color with texture color
  material.diffuse = textureColor;
  material.ambient = textureColor;
  //Note: an alternative to replacing the material color is to multiply it with the texture color
}
```

Task 3: Modify Texture Coordinates

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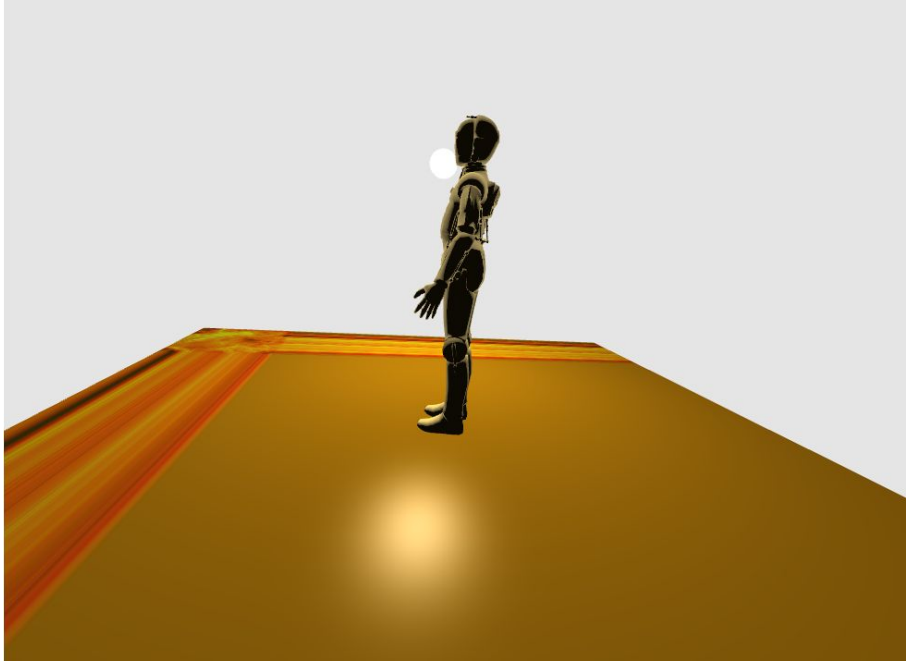
Goal:

The texture should only be visible on ⅕ of the floor.
(Any corner is fine)

Task:

Modify the texture coordinates of the floor to achieve this.



Solution: Modify Texture Coordinates

```
function makeFloor() {
  var floor = makeRect(2, 2);
  //TASK 3: adapt texture coordinates
  //floor.texture = [0, 0,   1, 0,   1, 1,   0, 1];
  floor.texture = [0, 0,   5, 0,   5, 5,   0, 5];
  return floor;
}
```

Task 4: Modify Sampling Parameters

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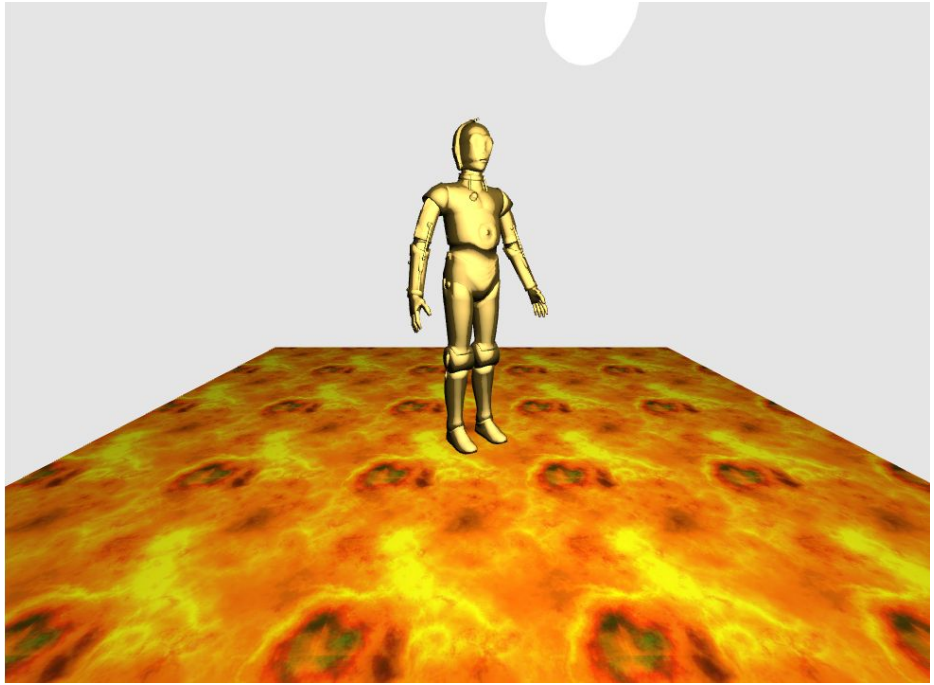
Goal:

The texture should be visible 5x5 times on the floor

Task:

Modify the texture wrapping parameters to achieve this.

Look up alternative wrapping parameters on the Internet.



Solution: Modify Sampling Parameters

```
//TASK 4: change texture sampling behaviour
gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_WRAP_S, gl.REPEAT);
gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_WRAP_T, gl.REPEAT);
```

Render to Texture

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Multiple render passes

First render pass: render into framebuffer/texture

Enable framebuffer:

```
gl.bindFramebuffer(gl.FRAMEBUFFER, renderTargetFramebuffer);
```

Setup viewport + camera + clear buffers + render scene graph

Disable framebuffer:

```
gl.bindFramebuffer(gl.FRAMEBUFFER, null);
```

Framebuffer has attached textures to render into.

Nothing will be shown on screen!

Second render pass:

Render scene normally

Texture objects with textures of framebuffer

Setup Framebuffer

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Create framebuffer object:

```
renderTargetFramebuffer = gl.createFramebuffer();
```

Bind framebuffer to use it (and for setup):

```
gl.bindFramebuffer(gl.FRAMEBUFFER, renderTargetFramebuffer);
```

Create empty textures to render into (setup similar as learned before)

Color texture: format: `gl.RGBA`, image data type: `gl.UNSIGNED_BYTE`

Depth texture: format: `gl.DEPTH_COMPONENT`, image data type: `gl.UNSIGNED_SHORT`

Depth texture required to allow doing depth test!

Attach textures to framebuffer

specify texture usage

```
gl.framebufferTexture2D(gl.FRAMEBUFFER, gl.COLOR_ATTACHMENT0, gl.TEXTURE_2D, renderTargetColorTexture, 0);
gl.framebufferTexture2D(gl.FRAMEBUFFER, gl.DEPTH_ATTACHMENT, gl.TEXTURE_2D, renderTargetDepthTexture ,0);
```

Unbind framebuffer

Setup Empty Textures

Same as for previous tasks but extended texImage2D:

```
gl.texImage2D(
  ?, //texture unit target == texture type
  ?, //level of detail level (default 0)
  ?, //internal format of the data in memory
  ?, //texture width
  ?, //texture height
  ?, //border (enable (1) or disable (0) setting a border color for clamping)
  ?, //image format (should match internal format)
  ?, //image data type
  ?); //actual image data (null if texture should be empty)
```

new

Texture width and height define framebuffer size

Border can be disabled in our case (0)

Image data is empty (null)

Task 5: Render to Texture

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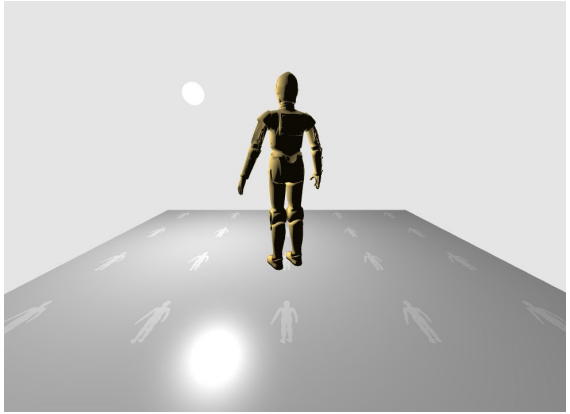
Goal:

Render C3PO into texture and put result on floor.



Given:

Partial framebuffer initialization (`initRenderToTexture`)

Scene graph without floor and simple shader (`rootnofloor`)

Tasks:

Initialize textures for color and depth (`initRenderToTexture`)

- Use `framebufferWidth`, `framebufferHeight` and texture types as in comments
- Attach those textures to framebuffer and call `initRenderToTexture` function

Render scene without floor to the texture/framebuffer (`renderToTexture`)

- Setup projection and view matrix as in normal scene but without mouse rotation

Put color texture of framebuffer on the floor (`createSceneGraph`)

Solution: Render to Texture

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`initRenderToTexture` function

```
//TASK 5: Setup color and depth texture and bind them to the framebuffer
//create color texture
renderTargetColorTexture = gl.createTexture();
gl.bindTexture(gl.TEXTURE_2D, renderTargetColorTexture);
gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_MAG_FILTER, gl.LINEAR);
gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_MIN_FILTER, gl.LINEAR);
gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_WRAP_S, gl.REPEAT);
gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_WRAP_T, gl.REPEAT);
gl.texImage2D(gl.TEXTURE_2D, 0, gl.RGBA, framebufferWidth, framebufferHeight, 0, gl.RGBA, gl.UNSIGNED_BYTE, null);

//create depth texture
renderTargetDepthTexture = gl.createTexture();
gl.bindTexture(gl.TEXTURE_2D, renderTargetDepthTexture);
gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_MAG_FILTER, gl.LINEAR);
gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_MIN_FILTER, gl.LINEAR);
gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_WRAP_S, gl.CLAMP_TO_EDGE);
gl.texParameteri(gl.TEXTURE_2D, gl.TEXTURE_WRAP_T, gl.CLAMP_TO_EDGE);
gl.texImage2D(gl.TEXTURE_2D, 0, gl.DEPTH_COMPONENT, framebufferWidth, framebufferHeight, 0, gl.DEPTH_COMPONENT, gl.UNSIGNED_SHORT, null);

//attach textures to framebuffer
gl.framebufferTexture2D(gl.FRAMEBUFFER, gl.COLOR_ATTACHMENT0, gl.TEXTURE_2D, renderTargetColorTexture, 0);
gl.framebufferTexture2D(gl.FRAMEBUFFER, gl.DEPTH_ATTACHMENT, gl.TEXTURE_2D, renderTargetDepthTexture ,0);
```

Solution: Render to Texture

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```
function renderToTexture(timeInMilliseconds)
{
  //TASK 5: Render C3PO to framebuffer/texture
  //bind framebuffer to draw scene into texture
  gl.bindFramebuffer(gl.FRAMEBUFFER, renderTargetFramebuffer);

  //setup viewport
  gl.viewport(0, 0, framebufferWidth, framebufferHeight);
  gl.clearColor(0.9, 0.9, 0.9, 1.0);
  gl.clear(gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT);

  //setup context and camera matrices
  const context = createSGContext(gl);
  context.projectionMatrix = mat4.perspective(mat4.create(), 30, framebufferWidth / framebufferHeight, 0.01, 100);
  context.viewMatrix = mat4.lookAt(mat4.create(), [0,-1,-4], [0,0,0], [0,1,0]);

  //render scenegraph
  rootnofloor.render(context);

  //disable framebuffer (to render to screen again)
  gl.bindFramebuffer(gl.FRAMEBUFFER, null);
}
```

Don’t forget to change the texture that you provide as parameter to the texture node!

Extra Task: Animate Texture Coordinates

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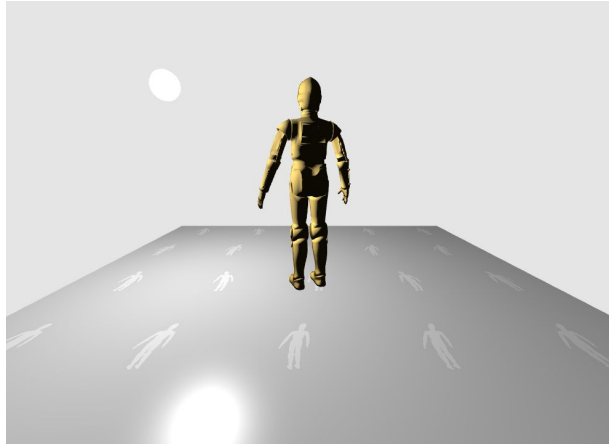
Goal:

Achieve wobble effect by animating the texture coordinates in the shader.



No task numbers! Think by yourself ;-)

Hints:

Pass time to shader

Use `sin()` function (e.g. x = x+sin(y+time))

Copy texture coordinates to local variable before modification

Solution: Animate Texture Coordinates

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main.js render functions:

```
//EXTRA TASK: animate texture coordinates
context.timeInMilliseconds = timeInMilliseconds;
```

main.js TextureSGNode:

```
//EXTRA TASK: animate texture coordinates
gl.uniform1f(gl.getUniformLocation(context.shader, 'u_wobbleTime'), context.timeInMilliseconds);
```

fragment shader:

```
//EXTRA TASK: define uniform for time variable
uniform float u_wobbleTime;
```

fragment shader main function:

```
//EXTRA TASK: animate texture coordinates
vec2 wobblecoords = v_texCoord;
wobblecoords.s = wobblecoords.s + sin(wobblecoords.t*3.14+u_wobbleTime/100.0)*0.1;
textureColor = texture2D(u_tex,wobblecoords);
```

Recap

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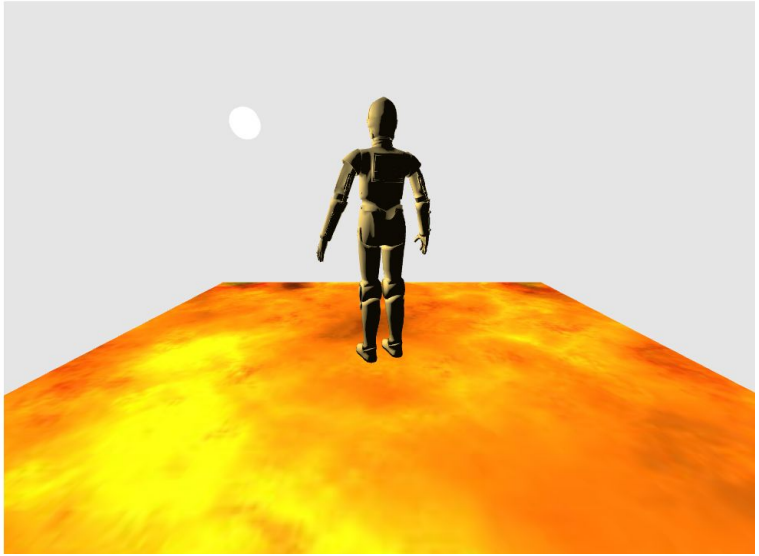
Texturing Basics

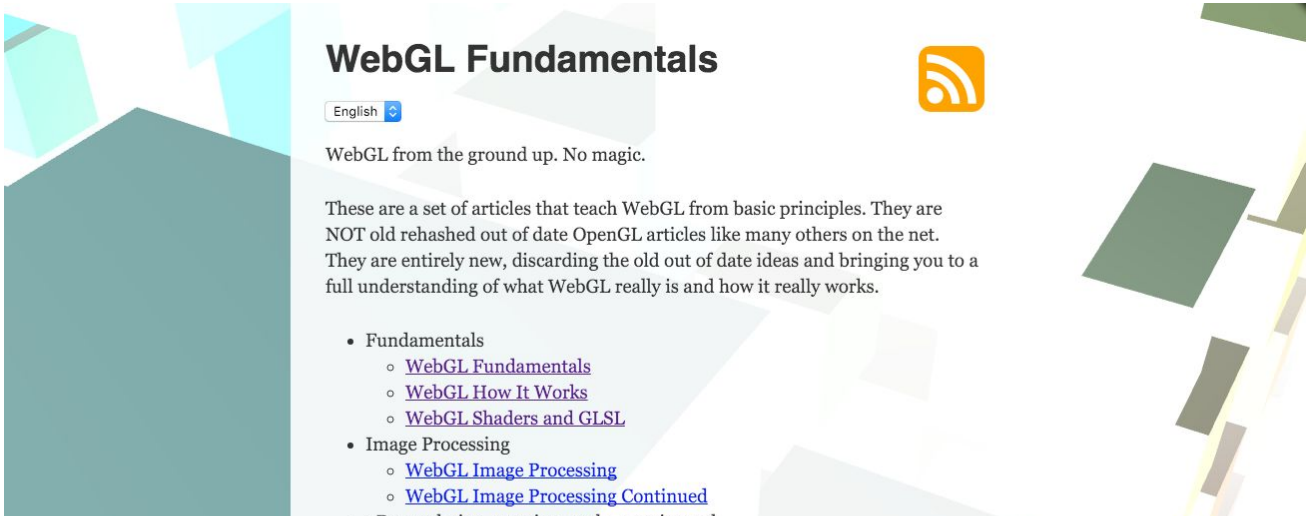
- Setup Textures
- Texture Coordinates
- Textures in Shader
- Binding Textures
- Integrate Texturing into Phong Shader
- Texture Wrapping and Repeating

Rendering to Textures

- Framebuffer
- Multiple Render Passes



Useful Resource: http://webglfundamentals.org



Useful summary of functions and parameters:

https://www.khronos.org/files/webgl/webgl-reference-card-1_0.pdf

Next Time

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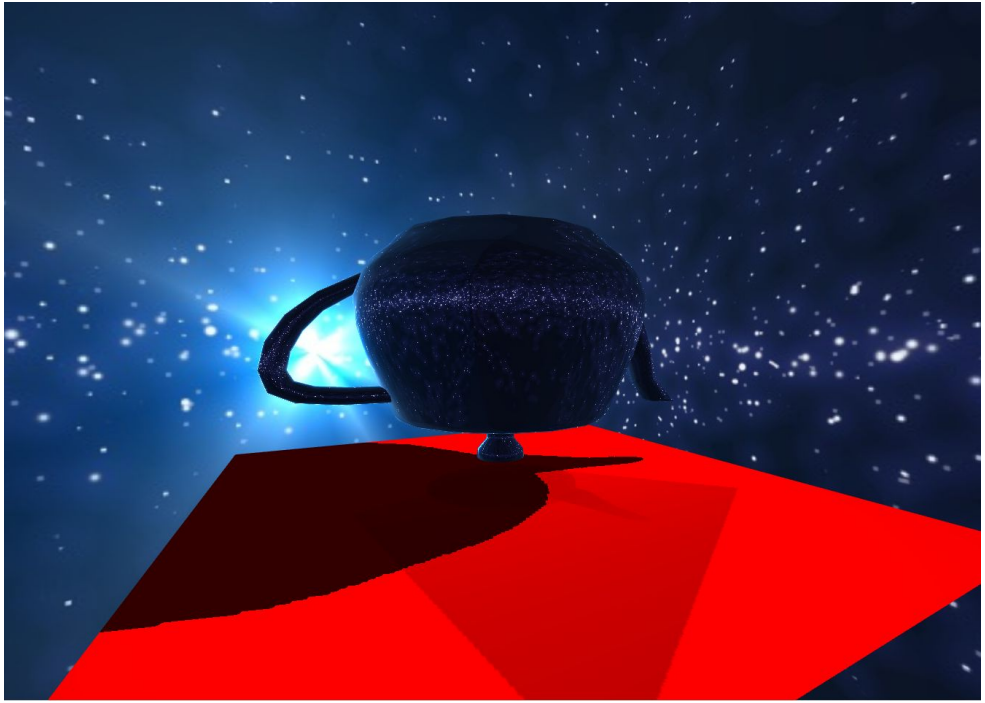
Advanced Texture Mapping

- Environment Mapping
- Shadow Mapping



Last CG Lab

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In 2 weeks (one more regular lab next week)!

Choose between:

- Introduction to CUDA
- The Visualization Toolkit (VTK)

We will send out email with Doodle link

Practice at Home!