CSCI 420 Computer Graphics
Lecture 12

Texture Mapping

Texture Mapping + Shading
Filtering and Mipmaps
Non-color Texture Maps
[Angel Ch. 7]

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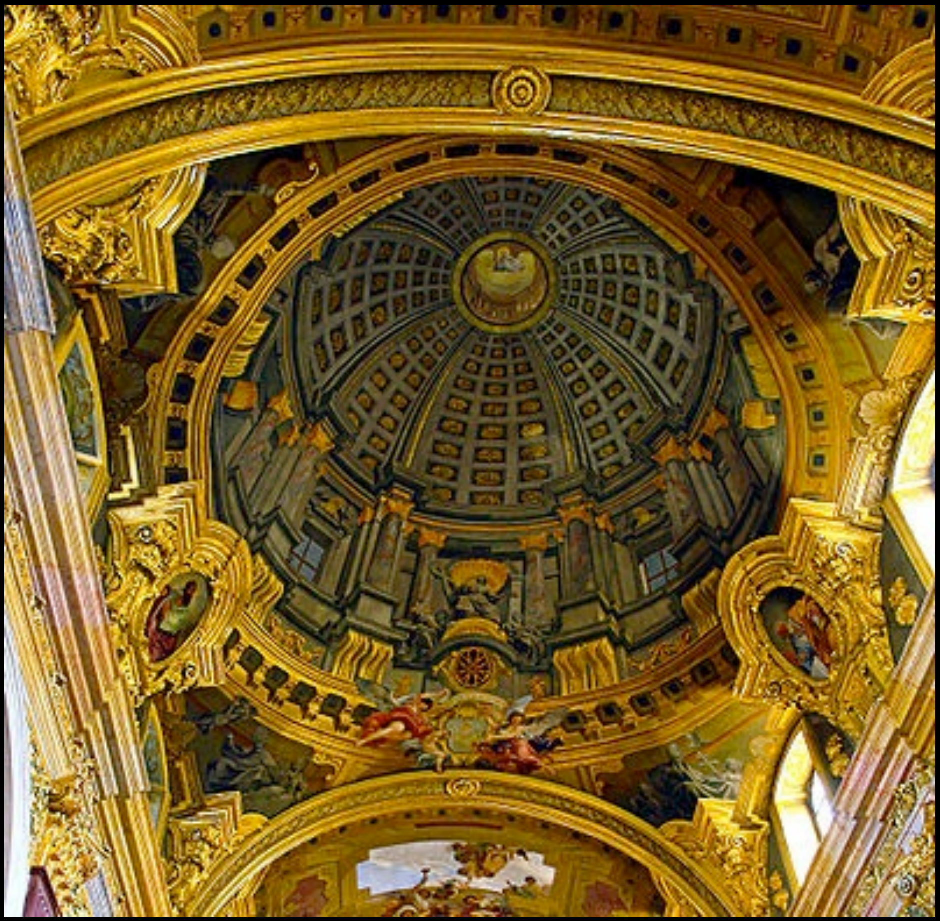
Texture Mapping

- A way of adding surface details
- Two ways can achieve the goal:
  - Model the surface with more polygons
    - » Slows down rendering speed
    - » Hard to model fine features
  - Map a texture to the surface
    - » This lecture
    - » Image complexity does not affect complexity of processing
- Efficiently supported in hardware

I live in my own little world but that's all right, they know me there.

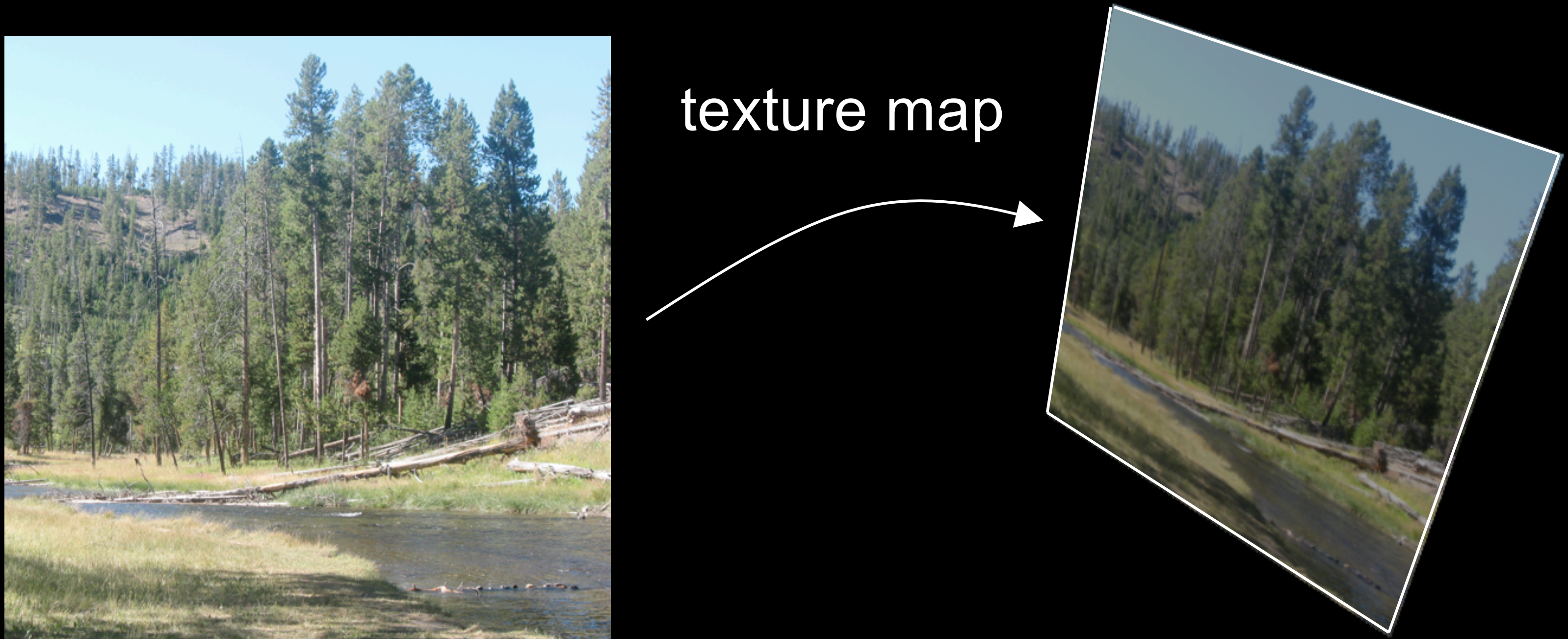
Trompe L’ Oeil (“Deceive the Eye”)


Jesuit Church, Vienna, Austria

- Windows and columns in the dome are painted, not a real 3D object
- Similar idea with texture mapping:

  Rather than modeling the intricate 3D geometry, replace it with an image !

Map textures to surfaces



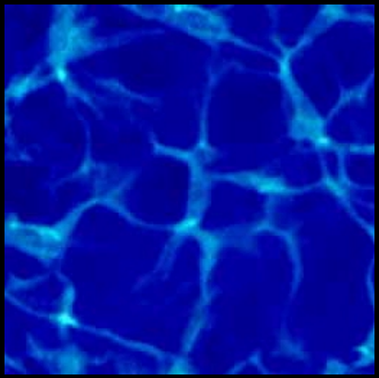
an image

image mapped
to a 3D polygon

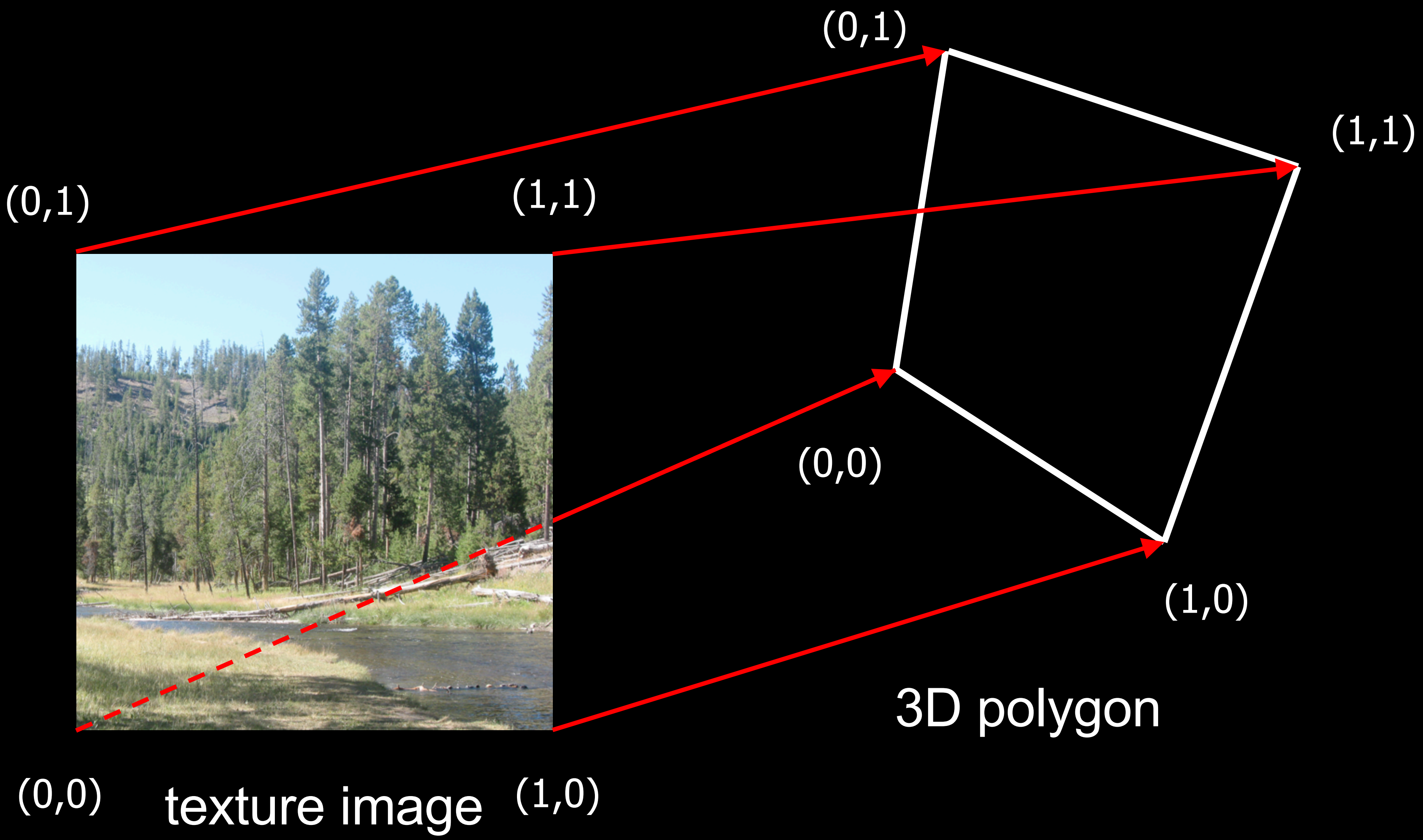
The polygon can have arbitrary size, shape and 3D position

The texture

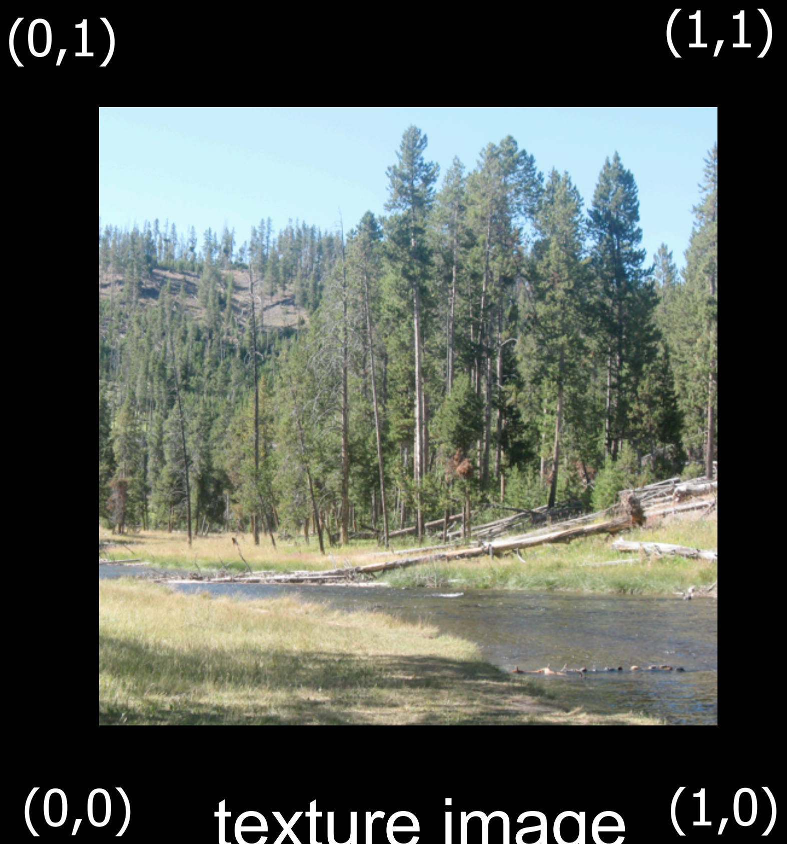
- Texture is a bitmap image
  - Can use an image library to load image into memory
  - Or can create images yourself within the program
- 2D array:
  unsigned char texture[height][width][4]
- Or unrolled into 1D array:
  unsigned char texture[4*height*width]
- Pixels of the texture are called *texels*
- Texel coordinates (s,t) scaled to [0,1] range



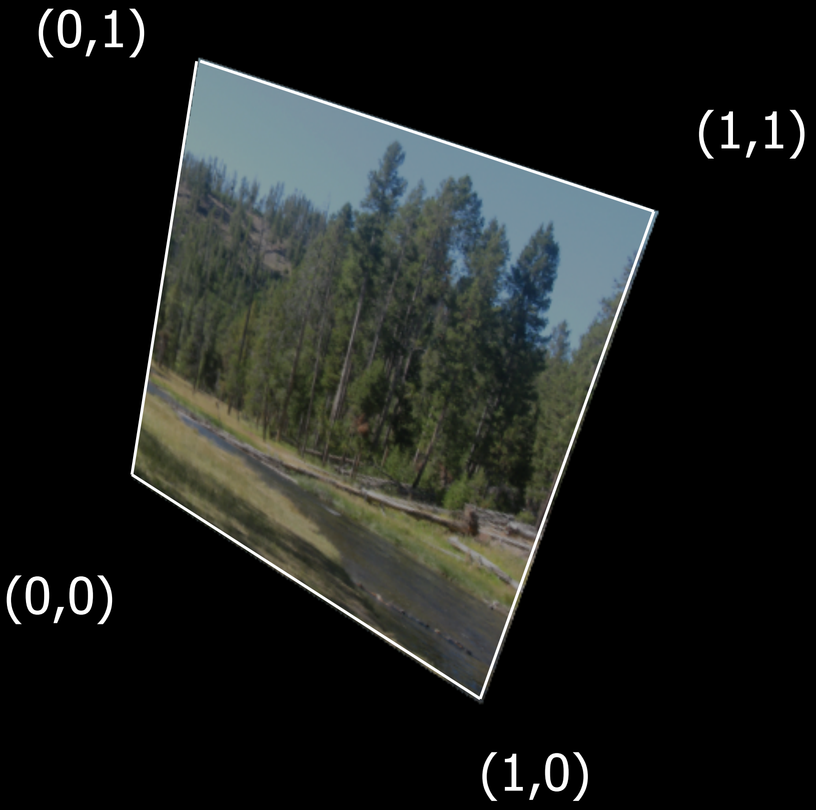
Texture map



Texture map

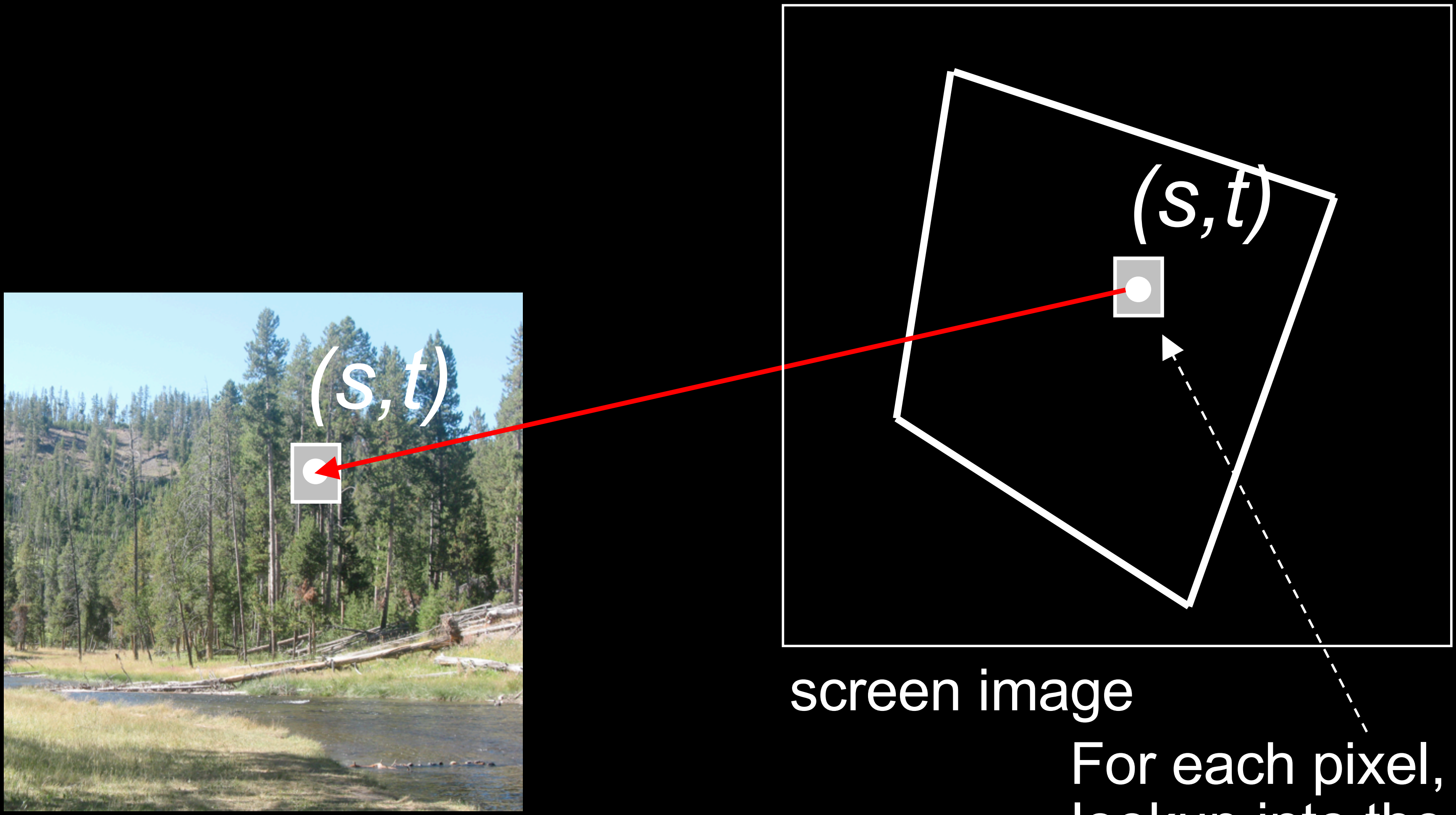


texture image



3D polygon

Texture coordinates

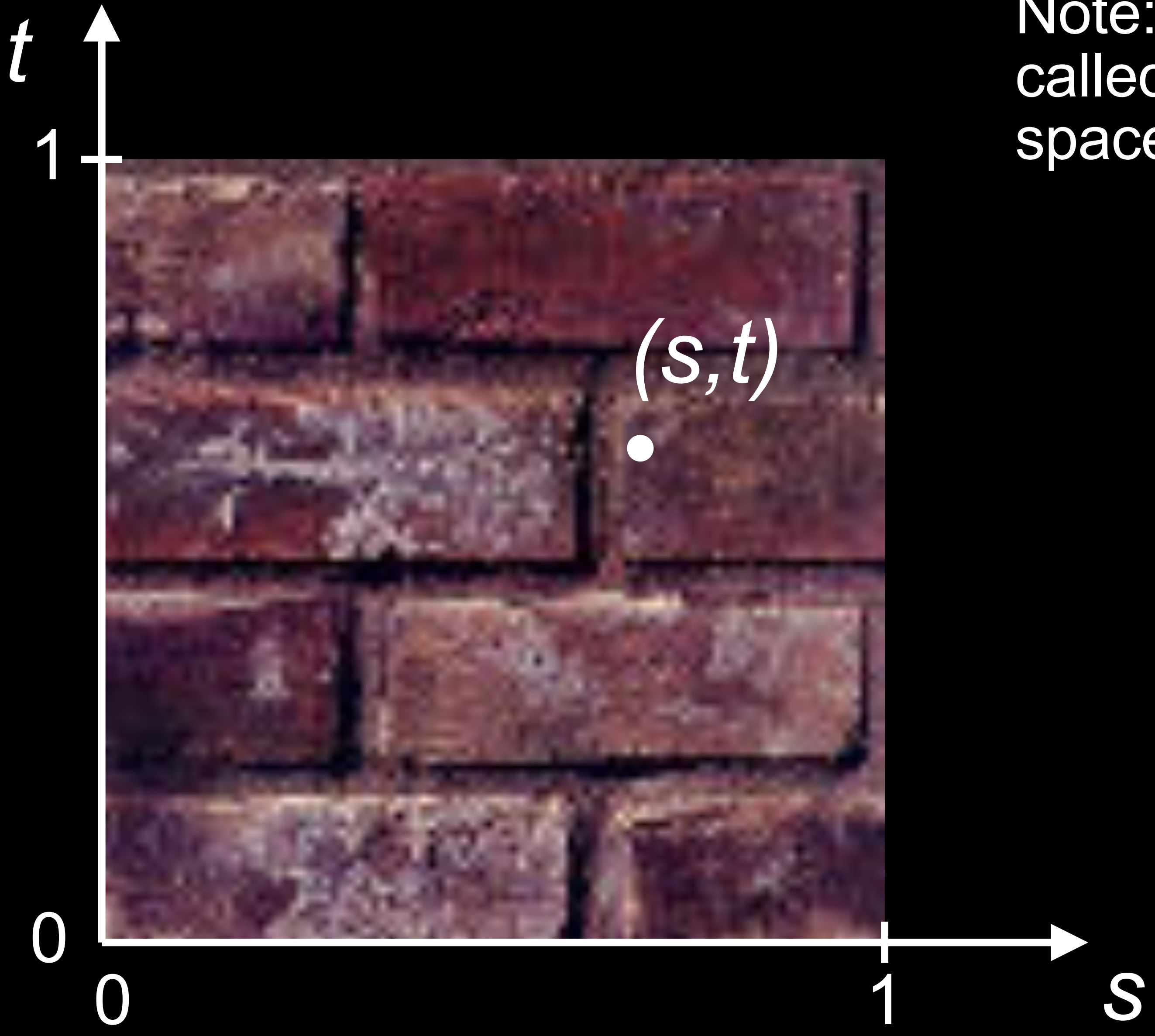


screen image

texture image

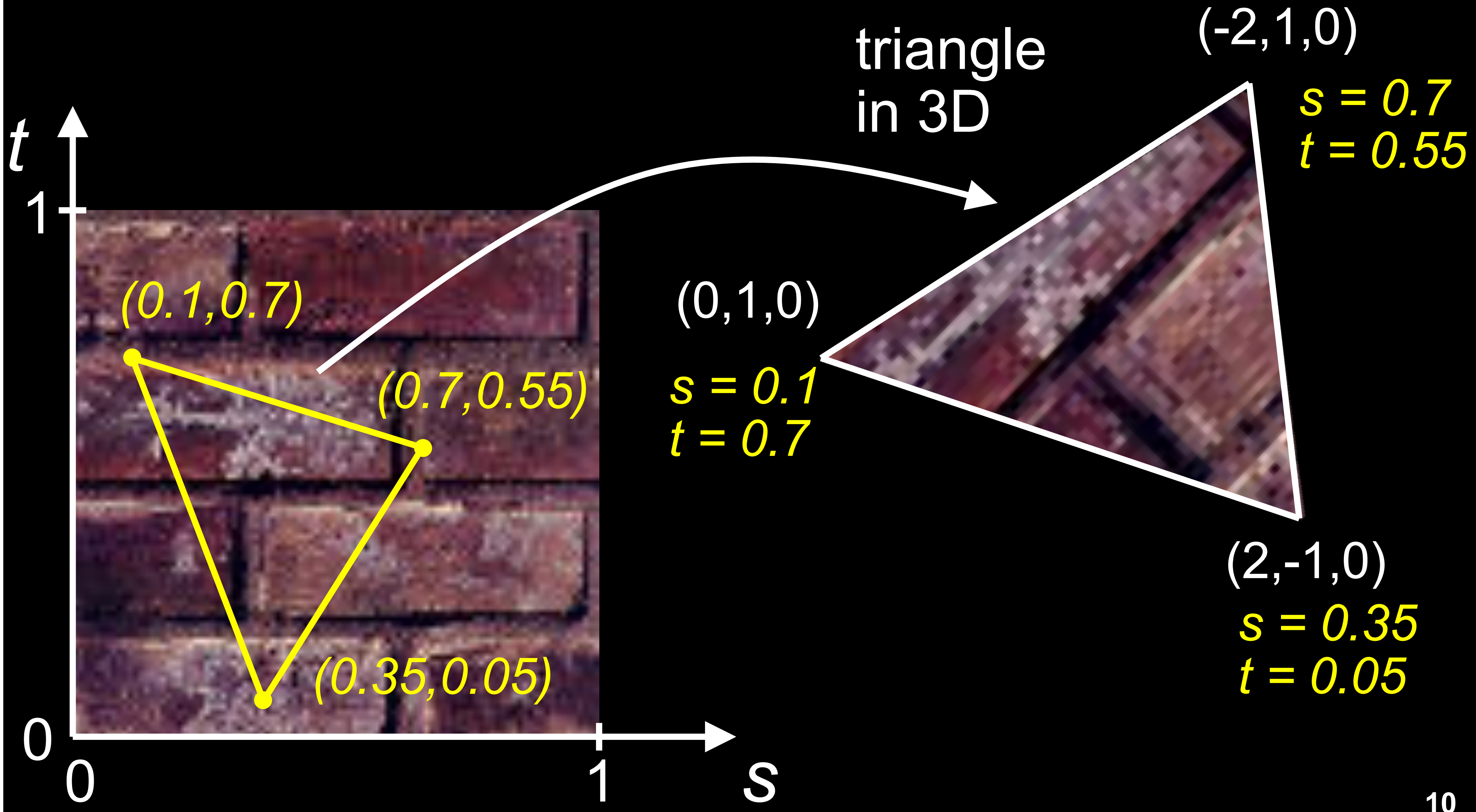
For each pixel, lookup into the texture image to obtain color.

The “st” coordinate system



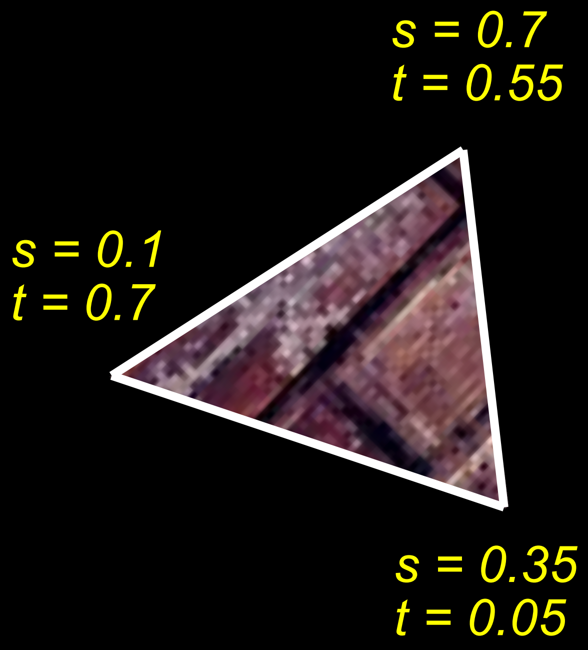
Note: also called “uv” space

Texture mapping: key slide

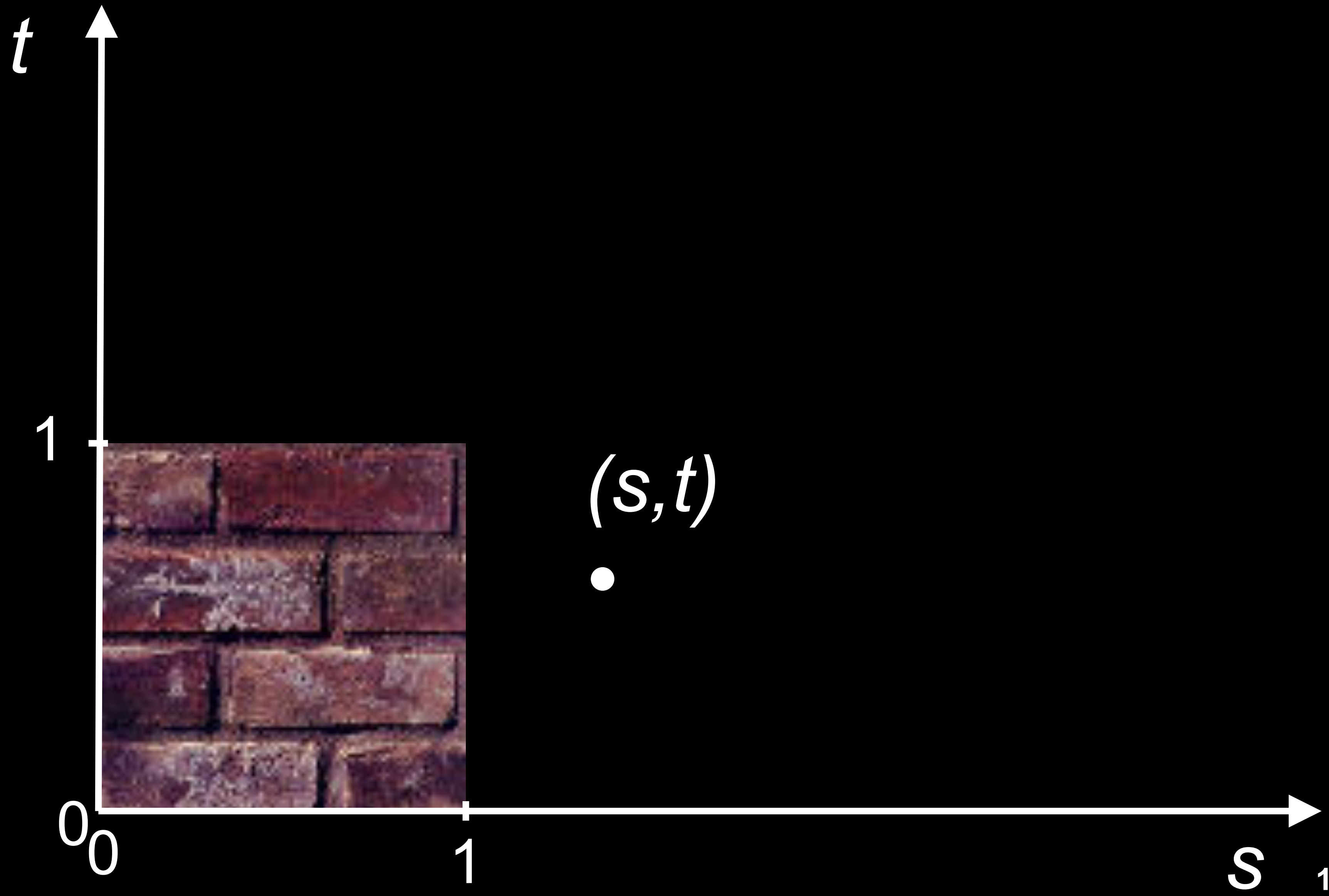


Specifying texture coordinates in OpenGL (core profile)

- Use VBO
- Either create a separate VBO for texture coordinates, or put them with vertex positions into one VBO

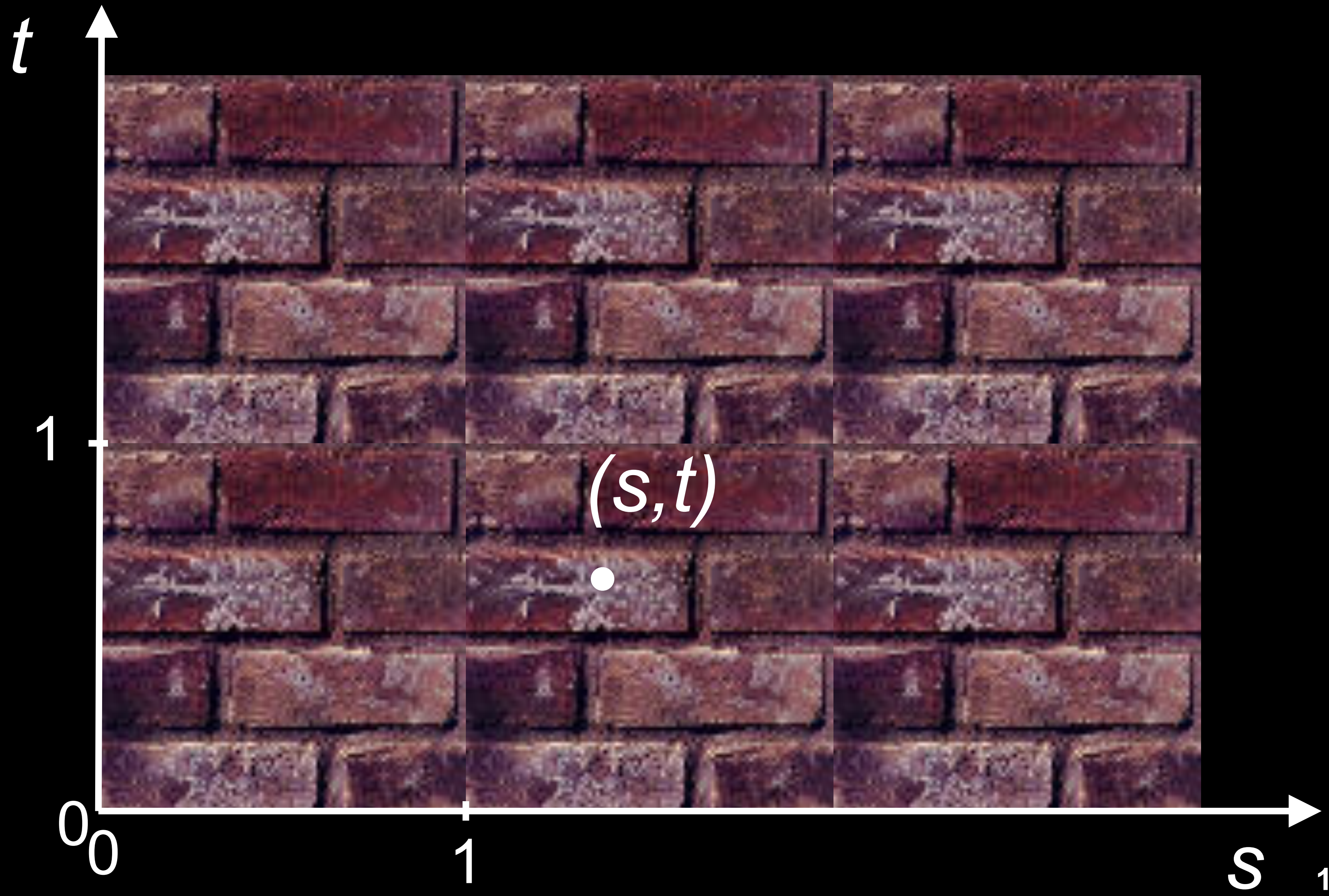


What if texture coordinates are outside of [0,1] ?



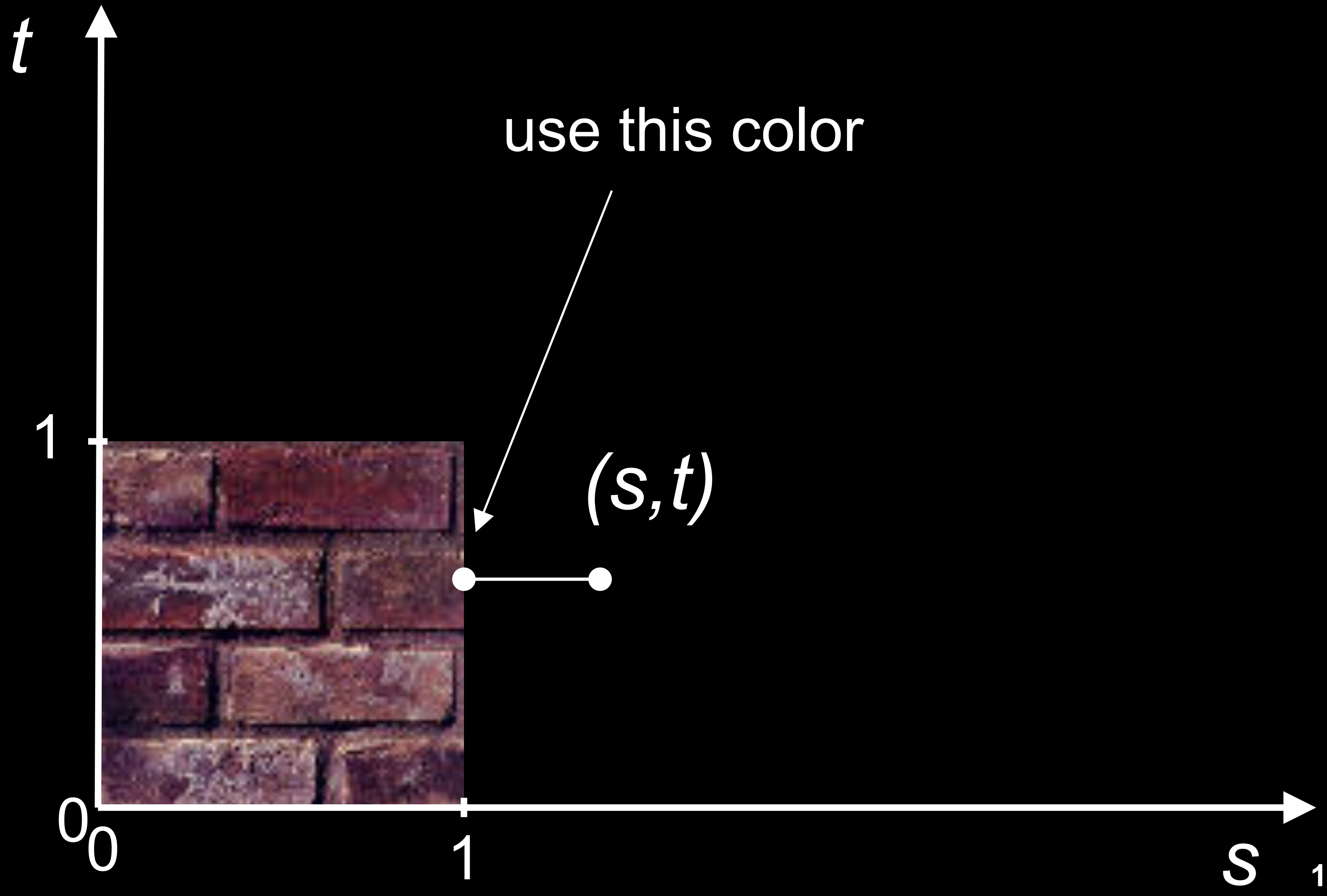
Solution 1: Repeat texture

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

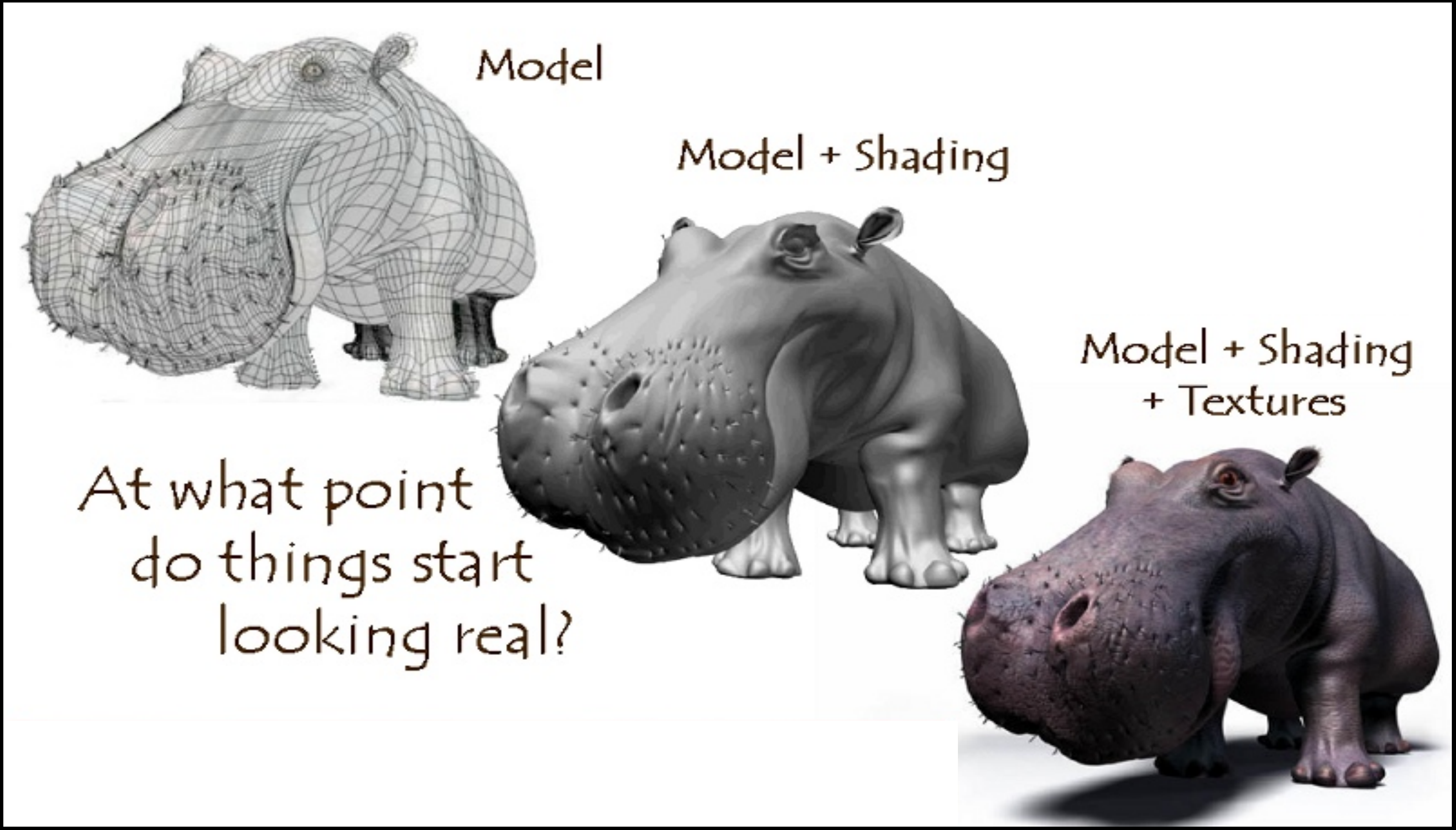


Solution 2: Clamp to [0,1]

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



Combining texture mapping and shading


Model
Model + Shading
Model + Shading + Textures
At what point do things start looking real?

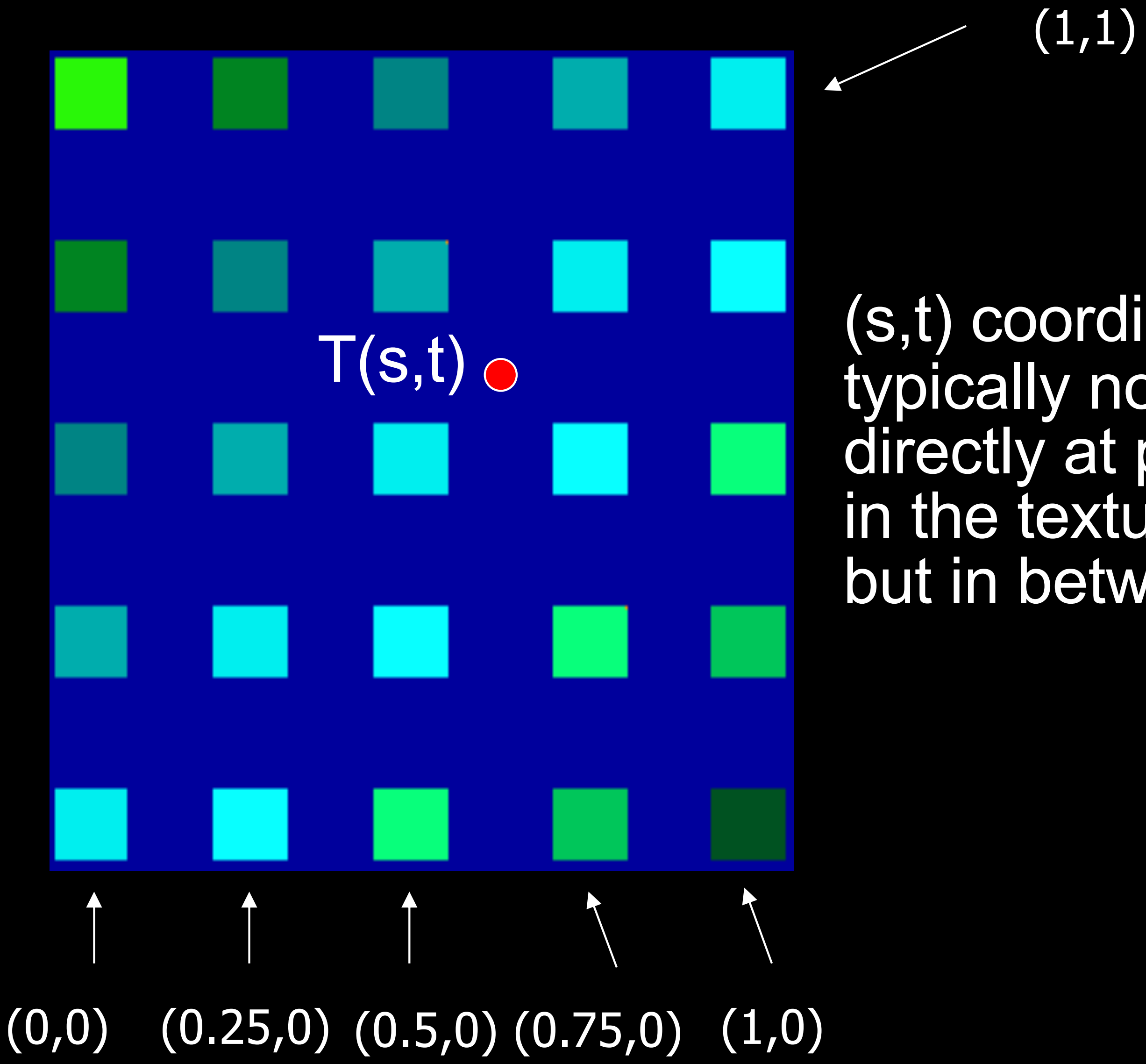
Source: Jeremy Birn

Outline

- Introduction
- Filtering and Mipmaps
- Non-color texture maps
- Texture mapping in OpenGL

Texture interpolation

5 x 5 texture



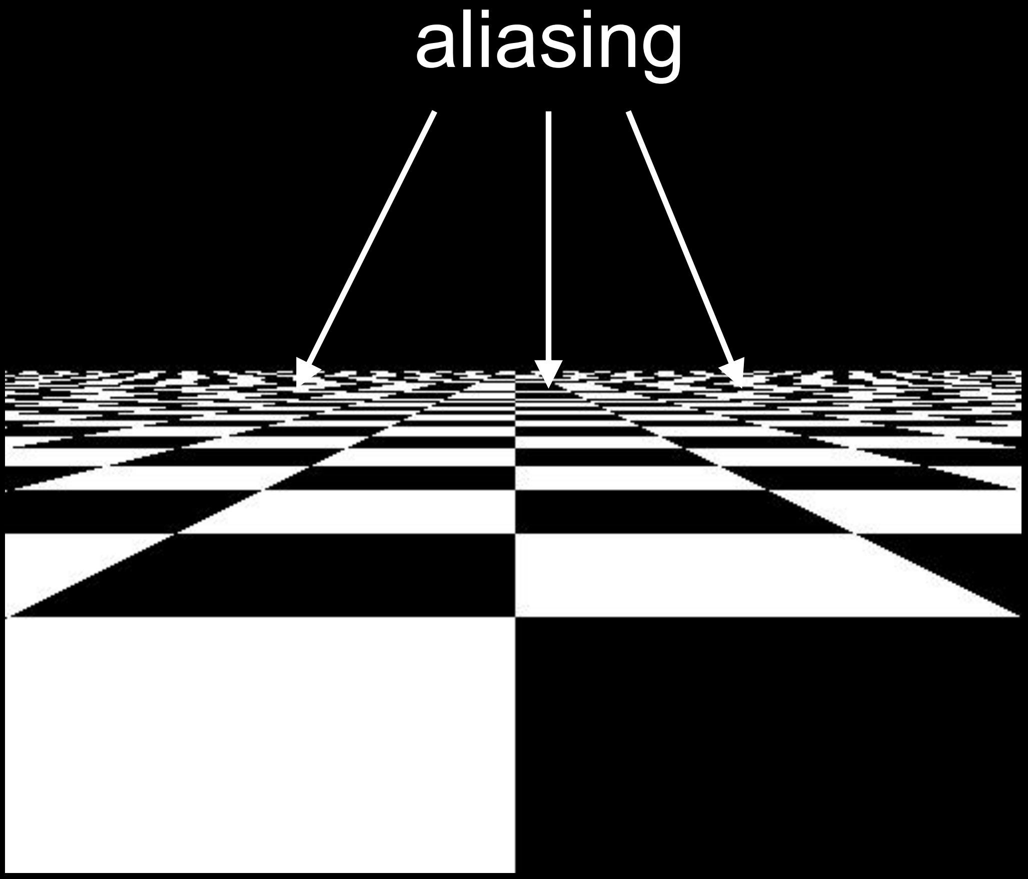
(s,t) coordinates typically not directly at pixel in the texture, but in between

Texture interpolation

- (s,t) coordinates typically not directly at pixel in the texture, but in between
- Solutions:
  - Use the nearest neighbor to determine color
    - Faster, but worse quality
    - glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_NEAREST);
  - Linear interpolation
    - Incorporate colors of several neighbors to determine color
    - Slower, better quality
    - glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR)

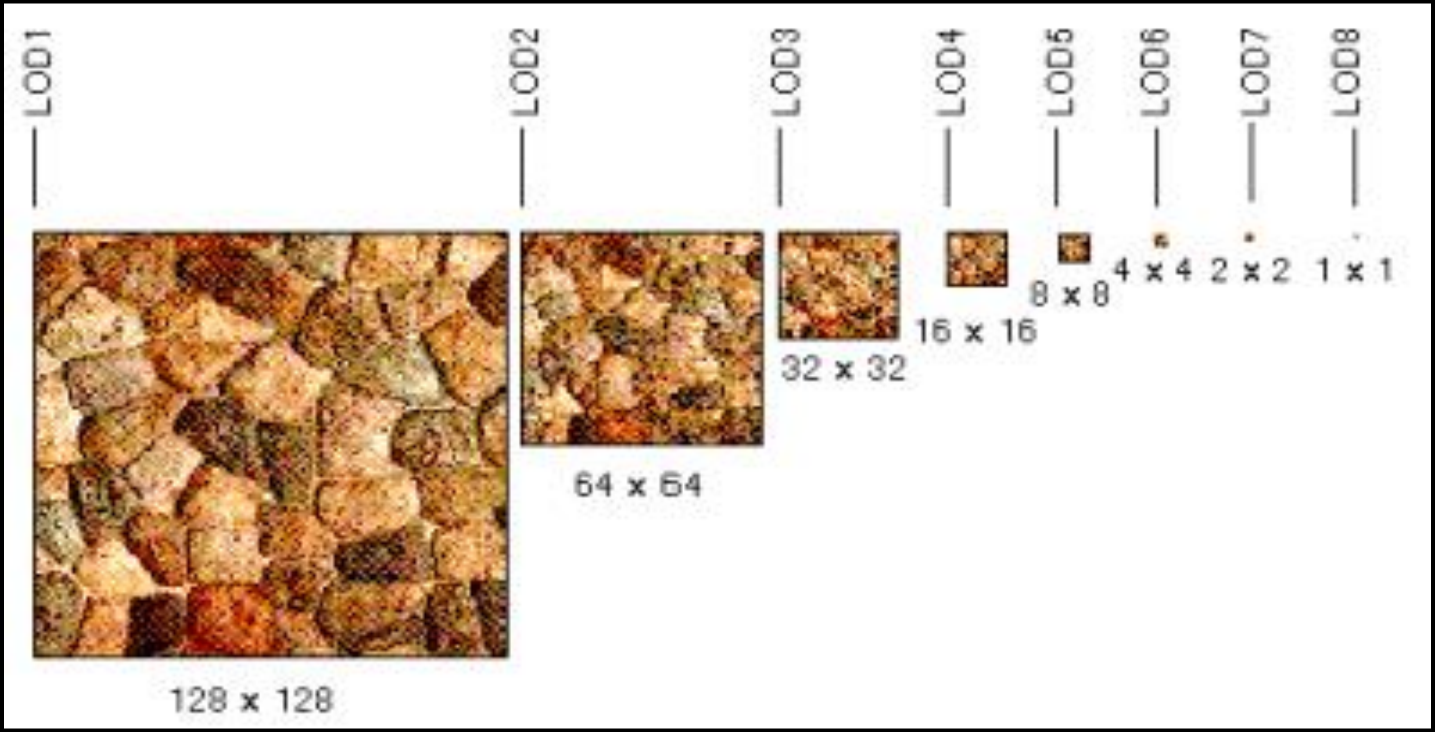
Filtering

- Texture image is shrunk in distant parts of the image
- This leads to aliasing
- Can be fixed with *filtering*
  - bilinear in space
  - trilinear in space and level of detail (mipmapping)



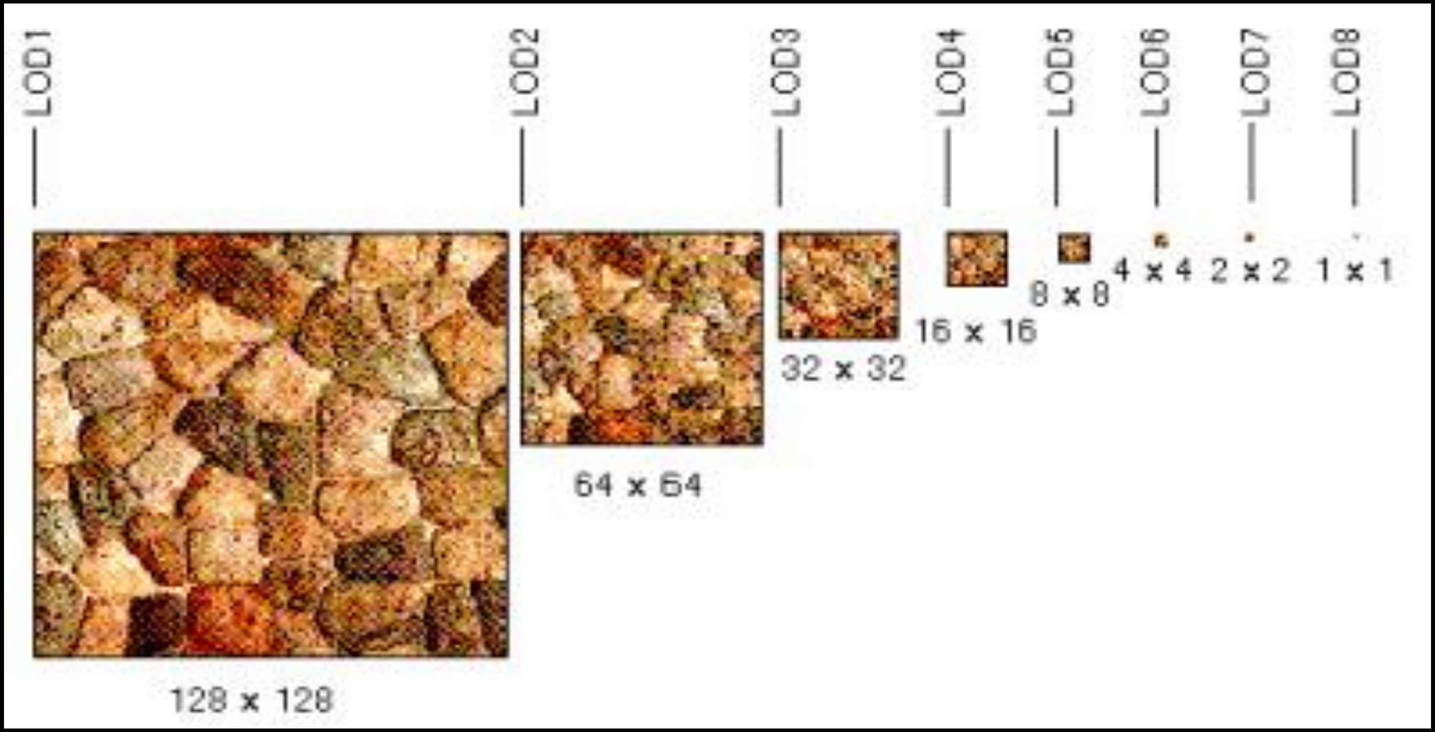
Mipmapping

- Pre-calculate how the texture should look at various distances, then use the appropriate texture at each distance
- Reduces / fixes the aliasing problem



Mipmapping

- Each mipmap (each image below) represents a level of depth (LOD).
- Decrease image 2x at each level



Mipmapping in OpenGL

- Generate mipmaps automatically
  (for the currently bound texture):

  Core profile:
  ```
  glGenerateMipmap(GL_TEXTURE_2D);
  ```

  Compatibility profile:
  ```
  gluBuild2DMipmaps(GL_TEXTURE_2D,
    components, width, height, format, type, data)
  ```

- Must also instruct OpenGL to use mipmaps:

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

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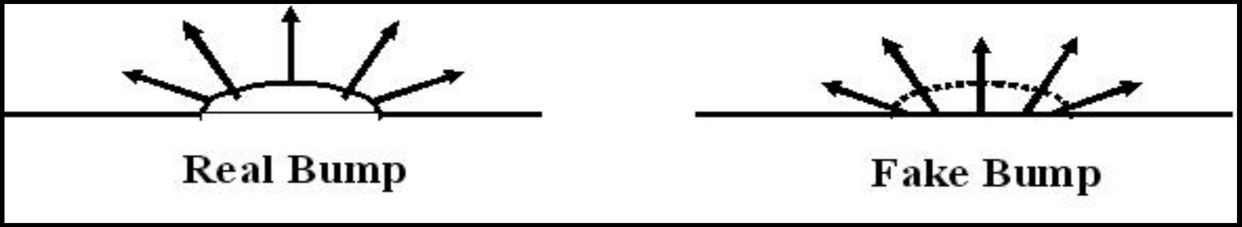
Textures do not have to represent color

- Specularity (patches of shininess)
- Transparency (patches of clearness)
- Normal vector changes (bump maps)
- Reflected light (environment maps)
- Shadows
- Changes in surface height (displacement maps)

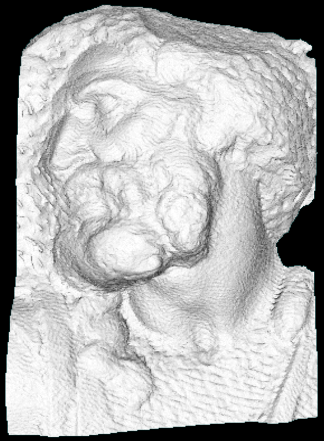
Bump mapping

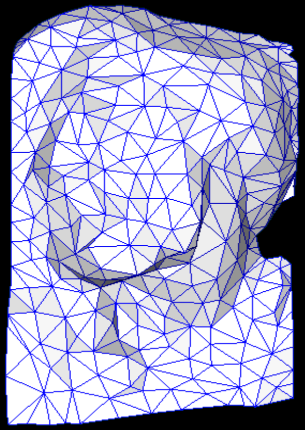
- How do you make a surface look *rough*?
  - Option 1: model the surface with many small polygons
  - Option 2: perturb the normal vectors before the shading calculation
    - » Fakes small displacements above or below the true surface
    - » The surface doesn't actually change, but shading makes it look like there are irregularities!
    - » A texture stores information about the "fake" height of the surface

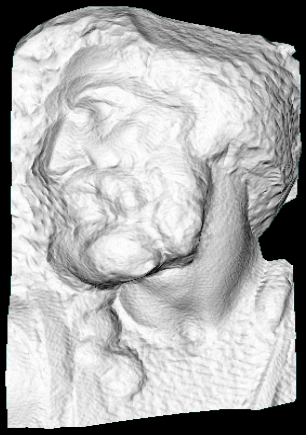


Bump mapping

- We can perturb the normal vector without having to make any actual change to the shape.
- This illusion can be seen through—how?

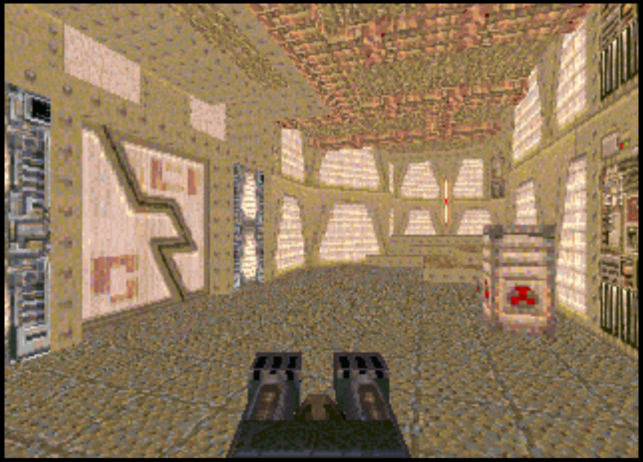

Original model (5M)

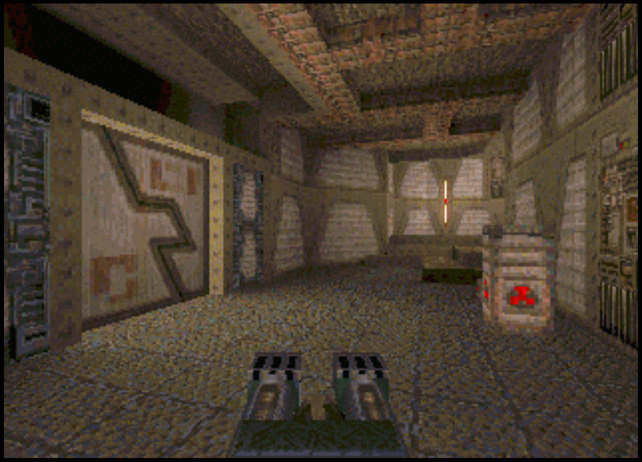

Simplified (500)

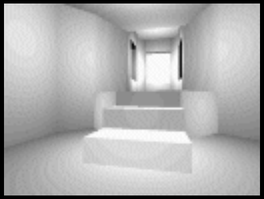

Simple model with bump map

Light Mapping

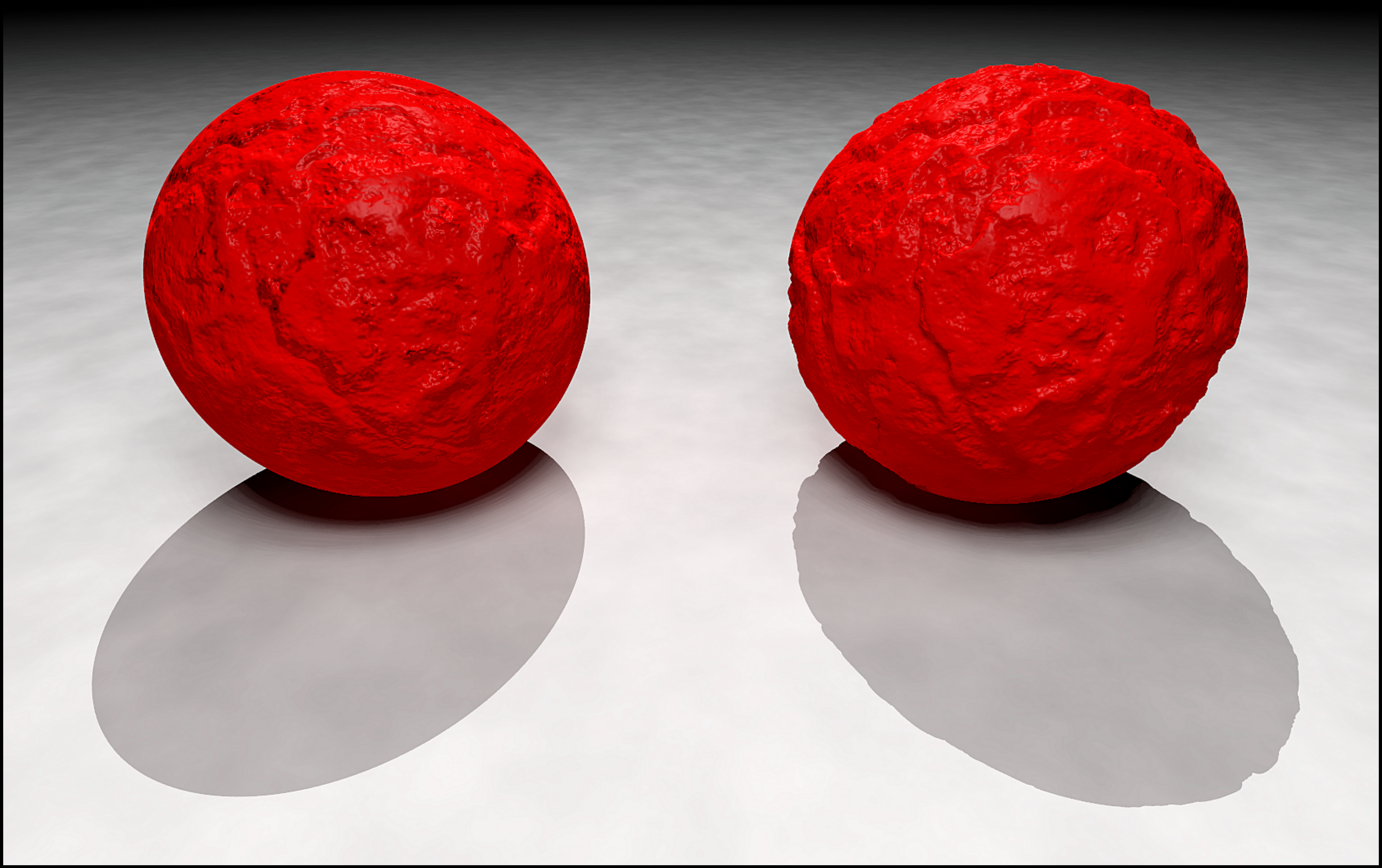
- *Quake* uses *light maps* in addition to texture maps. Texture maps are used to add detail to surfaces, and light maps are used to store pre-computed illumination. The two are multiplied together at run-time, and cached for efficiency.


Texture Map Only


Texture + Light Map

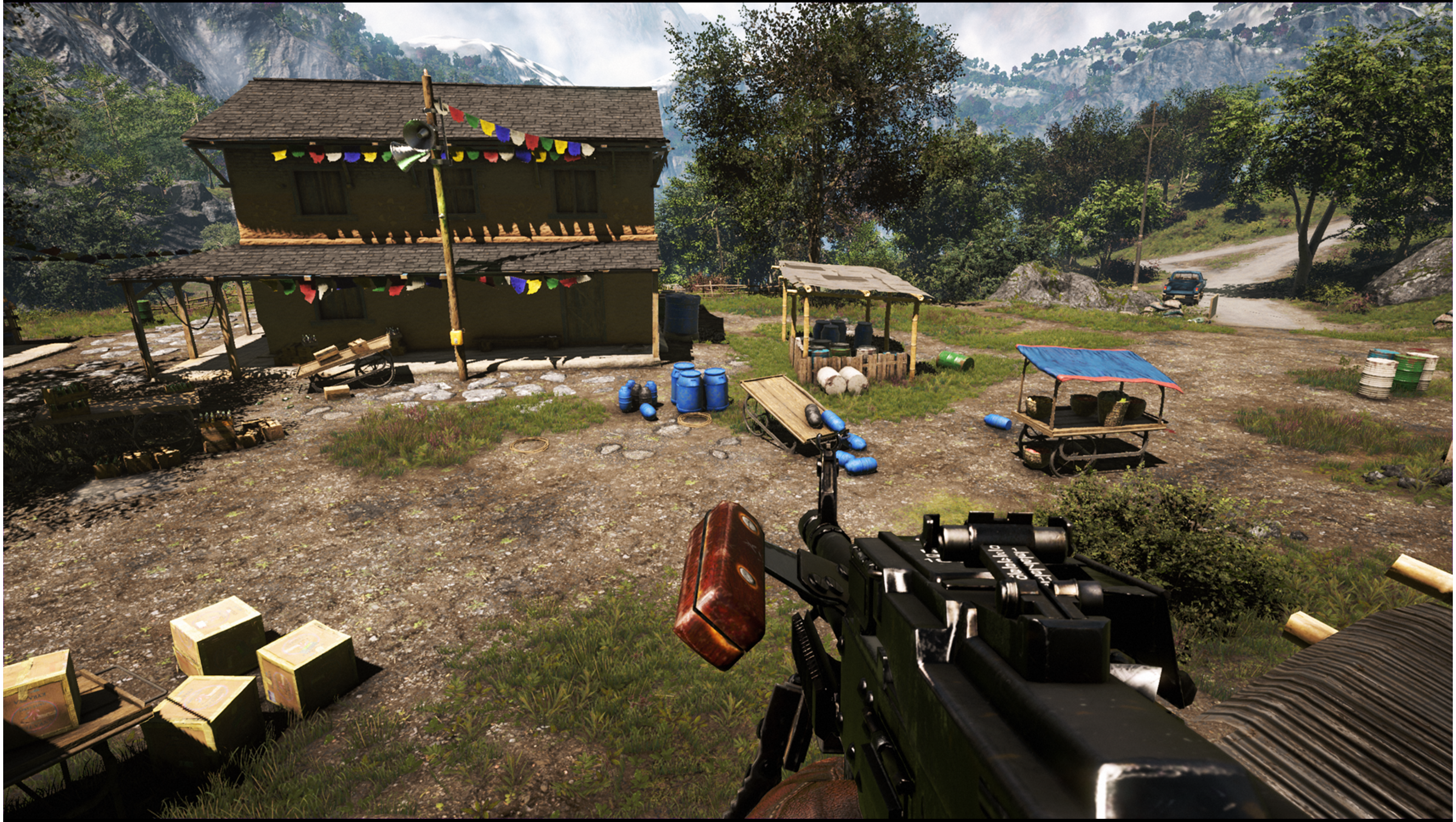

Light Map

Bump vs Displacement Mapping



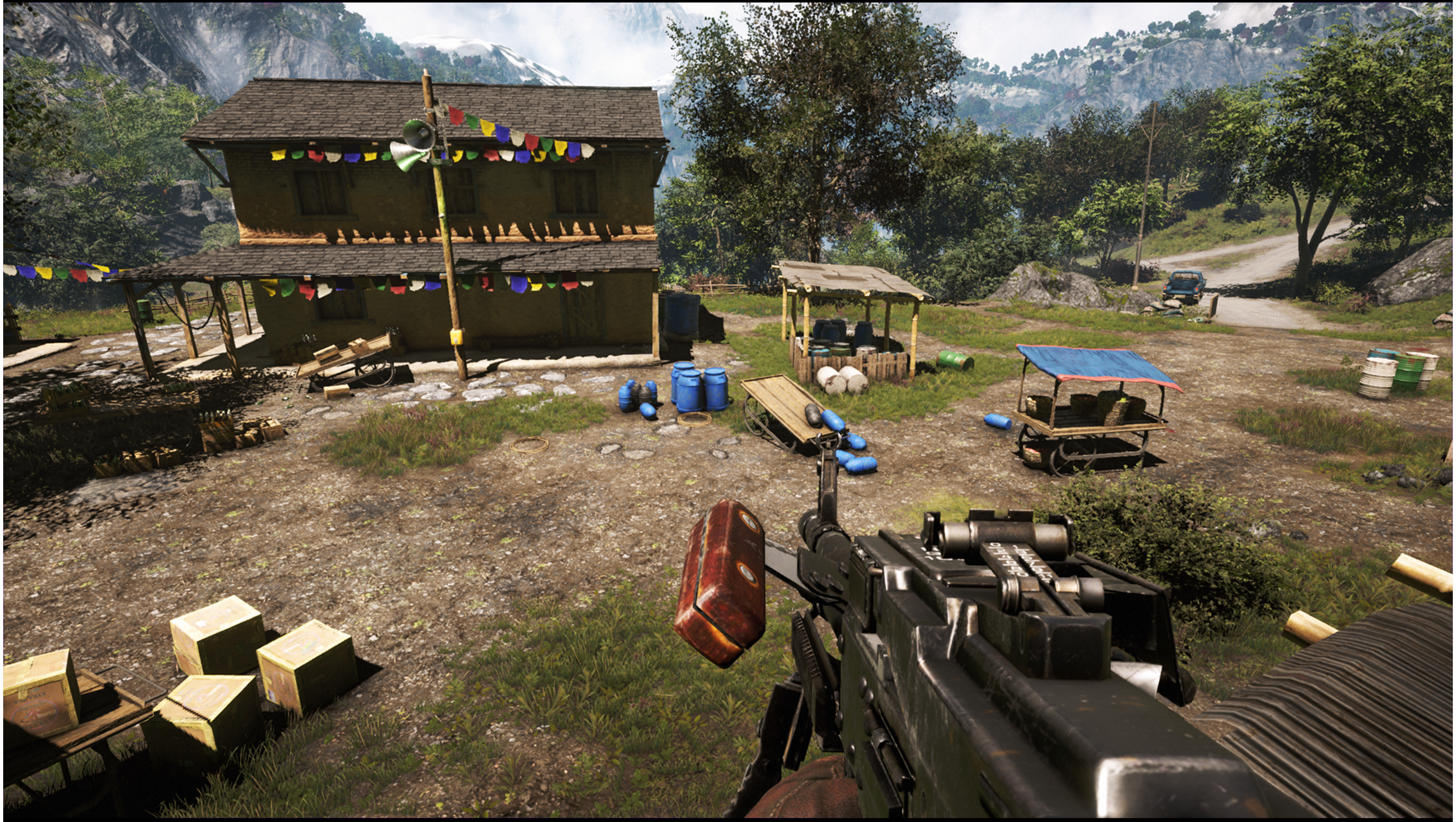
Left: bump mapping Right: displacement mapping

Example: Far Cry 4 (low mapping setting)



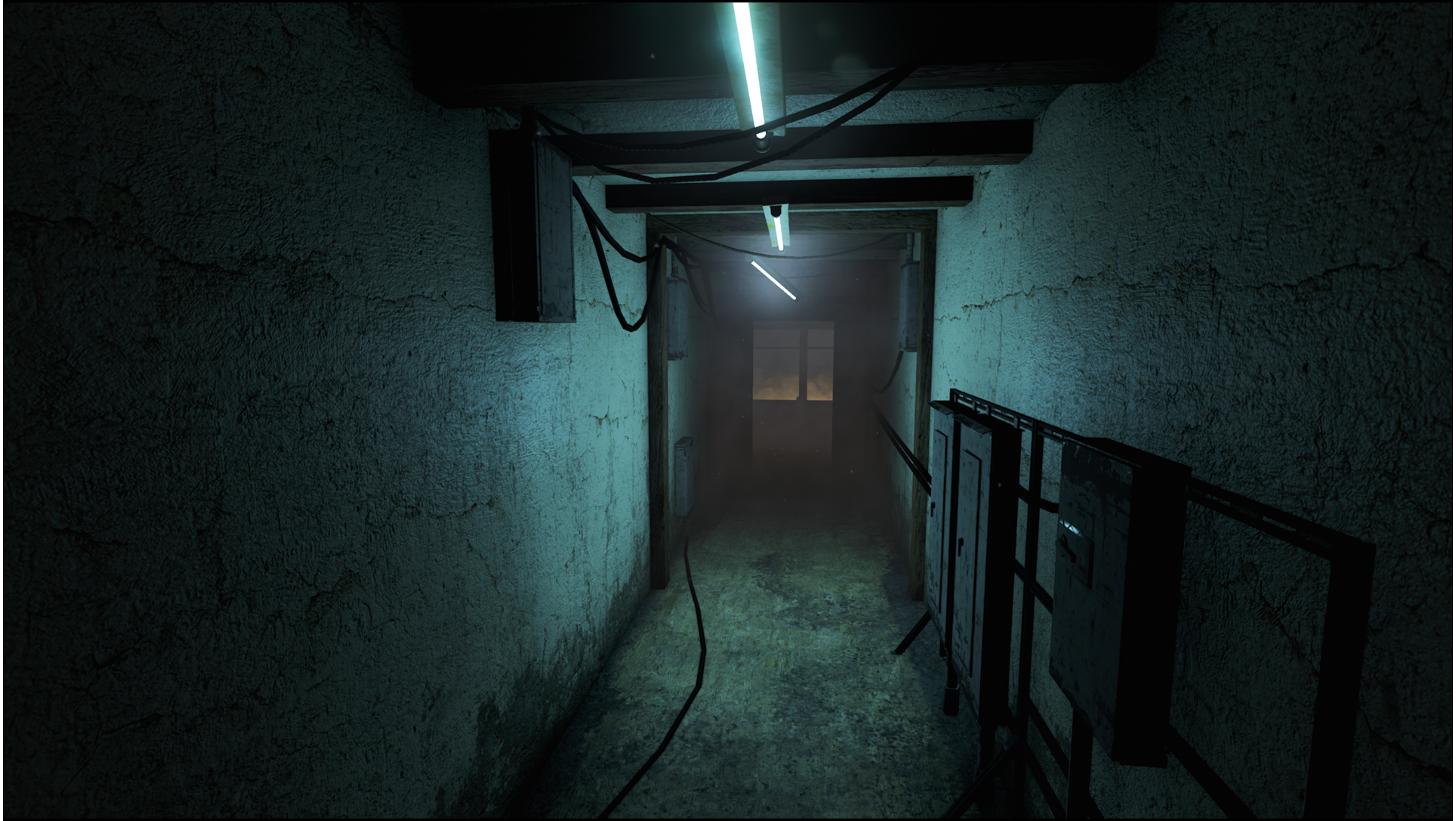
Note the low detail on the weapon.

Example: Far Cry 4 (high mapping setting)



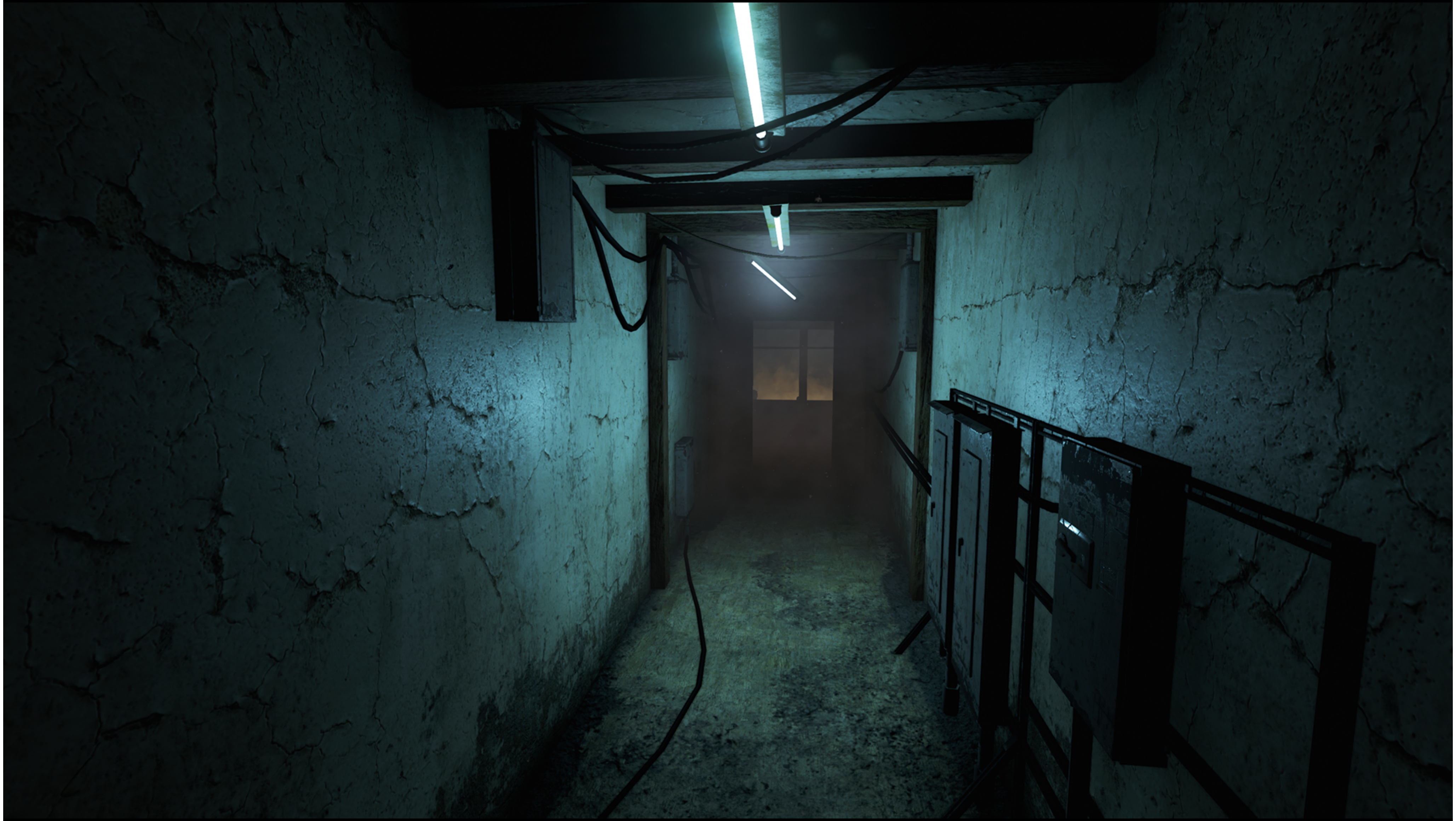
Note the high detail on the weapon, due to specular mapping.

Example: Far Cry 4 (low mapping setting)



Note the low detail on the walls, due to low-resolution displacement mapping.

Example: Far Cry 4 (high mapping setting)



Note the high detail on the walls, due to high-resolution displacement mapping.

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OpenGL Texture Mapping (Core Profile)

- During initialization:
  1. Read texture image from file into an array in memory, or generate the image using your program
  2. Initialize the texture (glTexImage2D)
  3. Specify texture mapping parameters:
     - » Repeat/clamp, filtering, mipmapping, etc.
  4. Make VBO for the texture coordinates
  5. Create VAO
- In display():
  1. Bind VAO
  2. Select the texture unit, and texture (using glBindTexture)
  3. Render (e.g., glDrawArrays)

Read texture image from file into an array in memory

- Can use our ImageIO library

-
  ```
  ImageIO * imageIO = new ImageIO();
  if (imageIO->loadJPEG(imageFilename) != ImageIO::OK)
  {
    cout << “Error reading image “ << imageFilename << “.” << endl;
    exit(EXIT_FAILURE);
  }
  ```

- See starter code for hw2

Initializing the texture

- Do once during initialization, for each texture image in the scene, by calling glTexImage2D
- The dimensions of texture images must be a multiple of 4 (Note: they do NOT have to be a power of 2)
- Can load textures dynamically if GPU memory is scarce:

  Delete a texture (if no longer needed) using glDeleteTextures

glTexImage2D

- glTexImage2D(GL_TEXTURE_2D, level, internalFormat, width, height, border, format, type, data)

- GL_TEXTURE_2D: specifies that it is a 2D texture
- Level: used for specifying levels of detail for mipmapping (default: 0)
- InternalFormat
  - Often: GL_RGB or GL_RGBA
  - Determines how the texture is stored internally
- Width, Height
  - The size of the texture must be a multiple of 4
- Border (often set to 0)
- Format, Type
  - Specifies what the input data is (GL_RGB, GL_RGBA, …)
  - Specifies the input data type (GL_UNSIGNED_BYTE, GL_BYTE, …)
  - Regardless of Format and Type, OpenGL converts the data to internalFormat
- Data: pointer to the image buffer

Texture Initialization

Global variable:

```
GLUint texHandle;
```

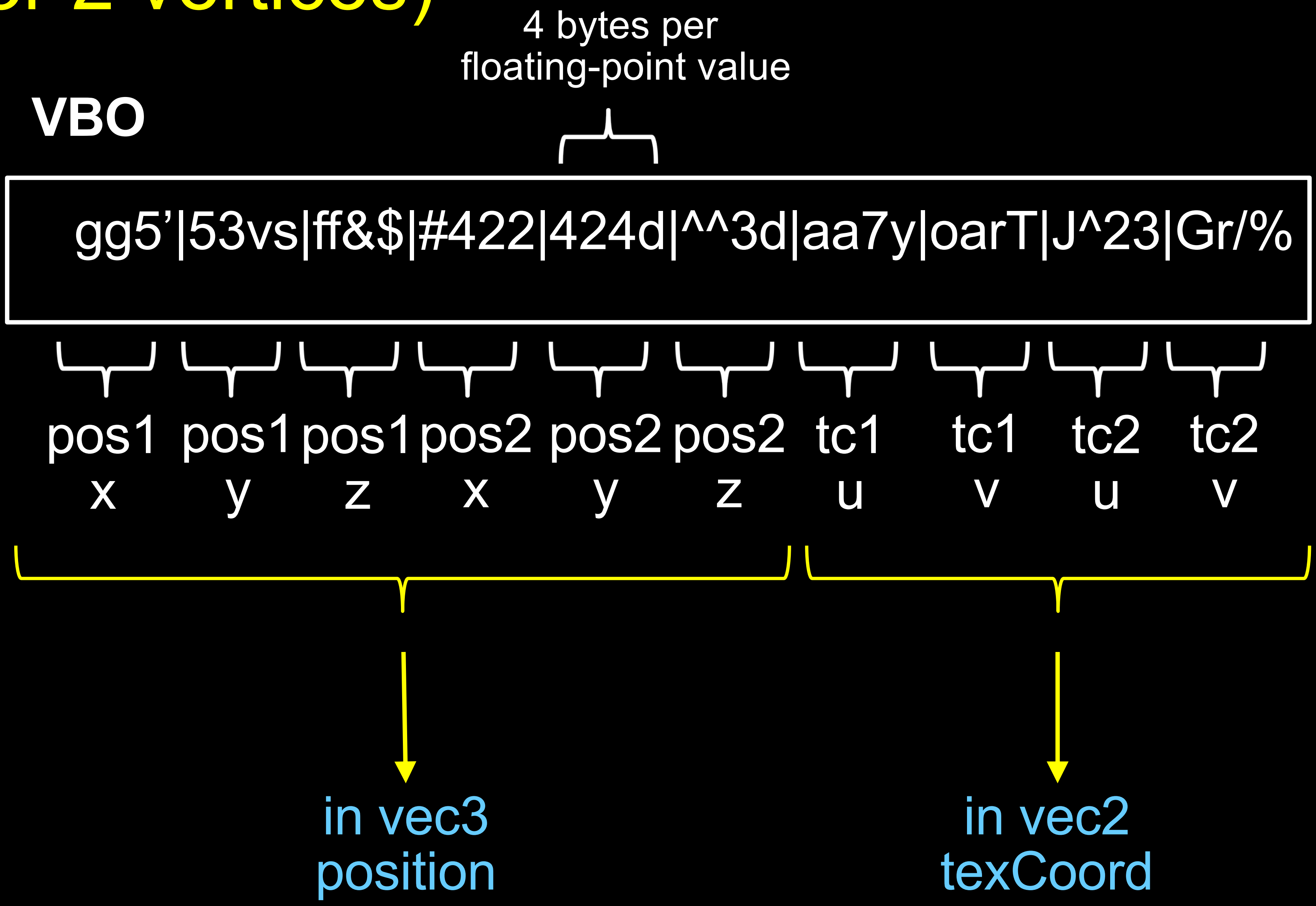
During initialization:

```
// create an integer handle for the texture
glGenTextures(1, &texHandle);

int code = initTexture("sky.jpg", texHandle);
if (code != 0)
{
  printf("Error loading the texture image.\n");
  exit(EXIT_FAILURE);
}
```

Function initTexture() is given in the starter code for hw2.

VBO Layout: positions, texture coordinates (for 2 vertices)



Texture Shader: Vertex Program

```
#version 150

in vec3 position;
in vec2 texCoord;
```

$\Big\}$ input vertex position and texture coordinates

```
out vec2 tc;
```

$\Big\}$ output texture coordinates; they will be passed to the fragment program (interpolated by hardware)

```
uniform mat4 modelViewMatrix;
uniform mat4 projectionMatrix;
```

$\Big\}$ transformation matrices

```
void main()
{
  // compute the transformed and projected vertex position (into gl_Position)
  gl_Position = projectionMatrix * modelViewMatrix * vec4(position, 1.0f);
  // pass-through the texture coordinate
  tc = texCoord;
}
```

Texture Shader: Fragment Program

```
#version 150

in vec2 tc; // input tex coordinates (computed by the interpolator)
out vec4 c; // output color (the final fragment color)
uniform sampler2D textureImage; // the texture image

void main()
{
  // compute the final fragment color,
  // by looking up into the texture map
  c = texture(textureImage, tc);
}
```

VAO code (“texCoord” shader variable)

During initialization:

```
glBindVertexArray(vao); // bind the VAO

// bind the VBO “buffer” (must be previously created)
glBindBuffer(GL_ARRAY_BUFFER, buffer);

// get location index of the “texCoord” shader variable
GLuint loc = glGetAttribLocation(program, “texCoord”);
glEnableVertexAttribArray(loc); // enable the “texCoord” attribute

// set the layout of the “texCoord” attribute data
const void * offset = (const void*) sizeof(positions);  GLsizei stride = 0;
glVertexAttribPointer(loc, 2, GL_FLOAT, GL_FALSE, stride, offset);
```

Multitexturing

- The ability to use *multiple* textures simultaneously in a shader
- Useful for bump mapping, displacement mapping, etc.
- The different texture units are denoted by GL_TEXTURE0, GL_TEXTURE1, GL_TEXTURE2, etc.
- In simple applications (our homework), we only need one unit

```
void setTextureUnit(GLint unit)
{
  glActiveTexture(unit); // select texture unit affected by subsequent texture calls
  // get a handle to the “textureImage” shader variable
  GLint h_textureImage = glGetUniformLocation(program, “textureImage”);
  // deem the shader variable “textureImage” to read from texture unit “unit”
  glUniform1i(h_textureImage, unit - GL_TEXTURE0);
}
```

The display function

```
void display()
{
   // put all the usual code here (clear screen, set up camera, upload
   //   the modelview matrix and projection matrix to GPU, etc.)
   // …

  // select the active texture unit
  setTextureUnit(GL_TEXTURE0); // it is safe to always use GL_TEXTURE0
  // select the texture to use (“texHandle” was generated by glGenTextures)
  glBindTexture(GL_TEXTURE_2D, texHandle);

  // here, bind the VAO and render the object using the VAO (as usual)
  // …

  glutSwapBuffers();
}
```

Summary

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