Computer Graphics

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Fall 2016

http://www.cs.pdx.edu/~fliu/courses/cs447/

11/09/2016

Last time

- Lighting and Shading

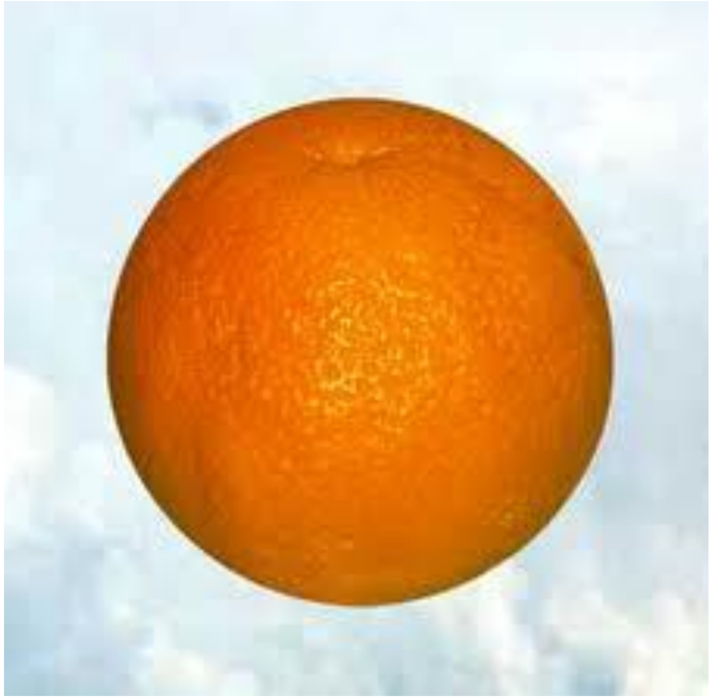
Today

- Texture Mapping
- Homework 4 available, due in class November 21
- Project 2
- Will publicize several times in the final week of classes when you can get your project graded
  - Demo your program to the instructor in person
    - Bring your own laptop or on a CS Windows Lab Machine
  - Latest time to grade
    - 5:00 pm, Friday, December 2, 2016
  - No late submission!

Mapping Techniques

- Consider the problem of rendering a globe
  - The geometry is very simple - a sphere
  - But the color changes rapidly, with sharp edges
  - With the local shading model, so far, the only place to specify color is at the vertices
  - To do a globe, would need thousands of polygons for a simple shape
  - Same thing for an orange: simple shape but complex normal vectors
- Solution: Mapping techniques use *simple geometry* modified by a *detail map* of some type

Globe and Orange



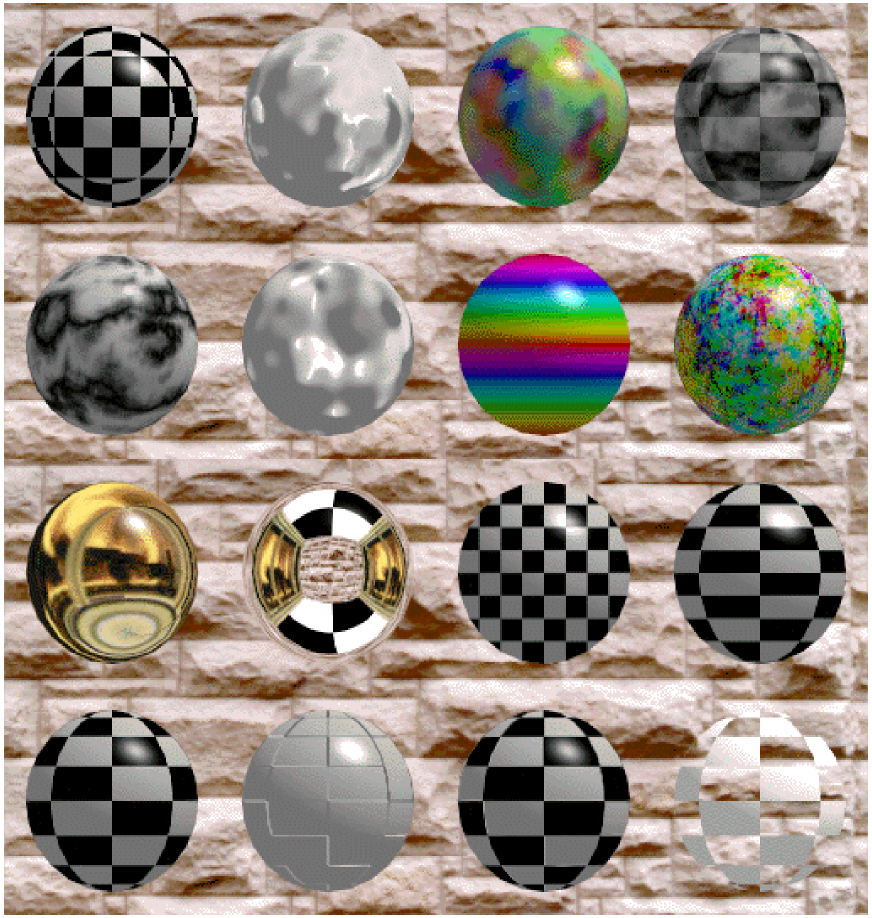
Texture Mapping

3D object Texture Textured object

Texture Mapping

- *Texture mapping* associates the color of a point with the color in an image: the *texture*
- Question to address
  - Which point of the texture do we use for a given point on the surface?
- Establish a *mapping* from surface points to image points
  - Different mappings are common for different shapes
  - We will, for now, just look at triangles (polygons)

Example Mappings

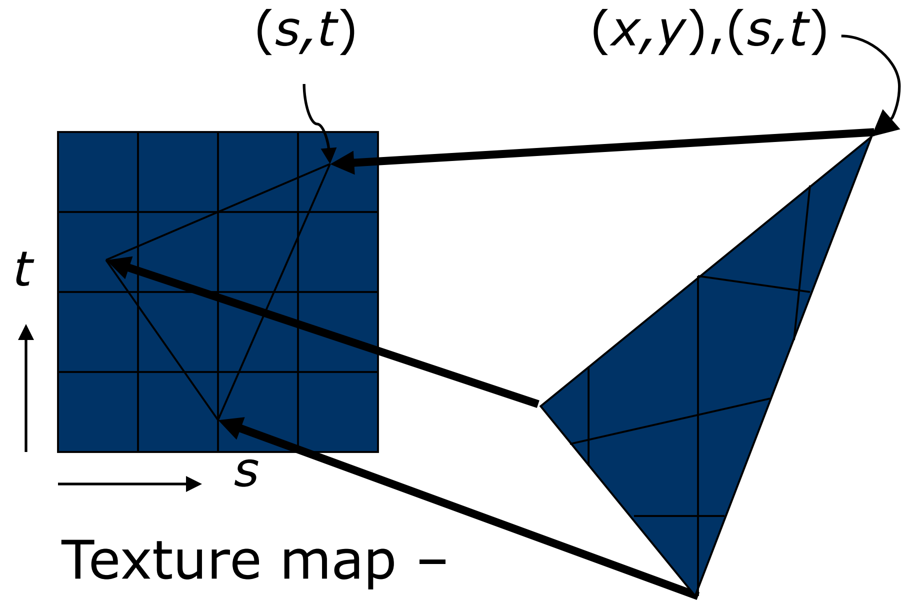


Basic Mapping

- The texture lives in a 2D space
  - Parameterize points in the texture with 2 coordinates: *(s,t)*
  - These are just what we would call *(x,y)* if we were talking about an image, but we wish to avoid confusion with the world *(x,y,z)*
- Define the mapping from *(x,y,z)* in world space to *(s,t)* in texture space
  - To find the color in the texture, take an *(x,y,z)* point on the surface, map it into texture space, and use it to look up the color of the texture
  - Samples in a texture are called ***texels***, to distinguish them from pixels in the final image
- With polygons:
  - Specify *(s,t)* coordinates at vertices
  - Interpolate *(s,t)* for other points based on given vertices

Texture Interpolation

- Specify where the vertices in world space are mapped to in texture space
- A *texture coordinate* is the location in texture space that corresponds to the vertex
- Linearly interpolate the mapping for other points in world space
  - Straight lines in world space go to straight lines in texture space



Texture map – texture coordinates

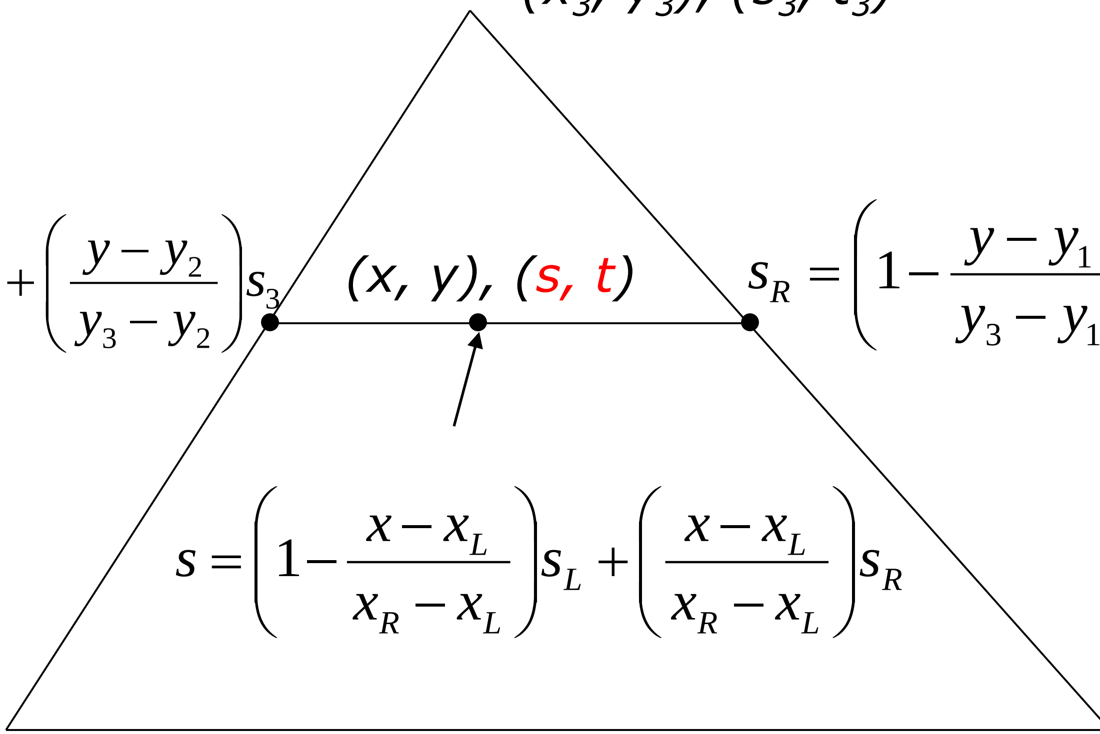
Triangle in world space – vertex coordinates

Linear Interpolation

Linear Interpolation

$$s = s1\left(1 - \frac{x-x1}{x2-x1}\right) + s2\,\frac{x-x1}{x2-x1}$$

Interpolating Coordinates



$$s_L = \left(1 - \frac{y - y_2}{y_3 - y_2}\right) s_2 + \left(\frac{y - y_2}{y_3 - y_2}\right) s_3$$

$$s_R = \left(1 - \frac{y - y_1}{y_3 - y_1}\right) s_1 + \left(\frac{y - y_1}{y_3 - y_1}\right) s_3$$

$$s = \left(1 - \frac{x - x_L}{x_R - x_L}\right) s_L + \left(\frac{x - x_L}{x_R - x_L}\right) s_R$$

Barycentric Coordinates

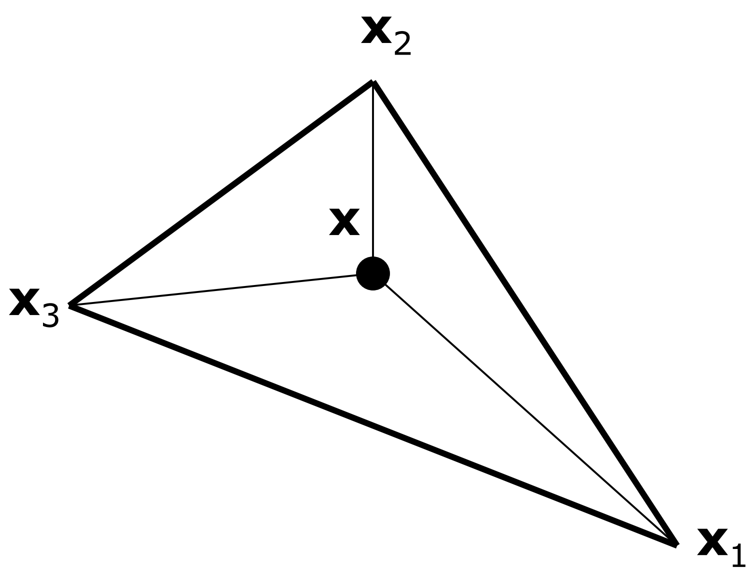
- An alternate way of describing points in triangles
- These can be used to interpolate texture coordinates
  - Gives the same result as previous slide
  - Method in textbook (Shirley)

$$\mathbf{x} = \alpha\mathbf{x}_1 + \beta\mathbf{x}_2 + \gamma\mathbf{x}_3$$

$$\alpha = \frac{\text{Area}(\mathbf{x}, \mathbf{x}_2, \mathbf{x}_3)}{\text{Area}(\mathbf{x}_1, \mathbf{x}_2, \mathbf{x}_3)}$$

$$\beta = \frac{\text{Area}(\mathbf{x}_1, \mathbf{x}, \mathbf{x}_3)}{\text{Area}(\mathbf{x}_1, \mathbf{x}_2, \mathbf{x}_3)}$$

$$\delta = 1 - \alpha - \beta$$



Steps in Texture Mapping

- Polygons (triangles) are specified with texture coordinates at the vertices
  - A modeling step, but some ways to automate it for common shapes
- When rasterizing, interpolate the texture coordinates to get the texture coordinate at the current pixel
  - Previous slides
- Look up the texture map using those coordinates
  - Just round the texture coordinates to integers and index the image
- Take the color from the map and put it in the pixel
  - Many ways to put it into a pixel (more later)

Basic OpenGL Texturing

- Specify texture coordinates for the polygon:
  - Use `glTexCoord2f(s,t)` before each vertex:
    - Eg: `glTexCoord2f(0,0); glVertex3f(x,y,z);`
- Create a texture object and fill it with texture data:
  - `glGenTextures(num,&identifier)` to get identifiers for the objects
  - `glBindTexture(GL_TEXTURE_2D, identifier)` to bind the texture
    - Following texture commands refer to the bound texture
  - `glTexParameteri(GL_TEXTURE_2D, …, …)` to specify parameters for use when applying the texture
  - `glTexImage2D(GL_TEXTURE_2D, ….)` to specify the texture data (the image itself)

MORE…

Basic OpenGL Texturing (cont)

- Enable texturing: `glEnable(GL_TEXTURE_2D)`
- State how the texture will be used:
  - `glTexEnvf(…)`
- **Texturing is done *after* lighting**
- You’re ready to go…

Nasty Details

- There are a large range of functions that control the layout of texture data:
  - You must state how the data in your image is arranged
  - Eg: `glPixelStorei(GL_UNPACK_ALIGNMENT, 1)` tells OpenGL not to skip bytes at the end of a row
  - You must state how you want the texture to be put in memory: how many bits per "pixel", which channels,…
- Textures must be square with width/height a power of 2
  - Common sizes are 32x32, 64x64, 256x256
  - Smaller uses less memory, and there is a finite amount of texture memory on graphics cards
  - Some extensions to OpenGL allow arbitrary textures

Controlling Different Parameters

- The “pixels” in the texture map may be interpreted as many different things. For example:
  - As colors in RGB or RGBA format
  - As grayscale intensity
  - As alpha values only
- The data can be applied to the polygon in many different ways:
  - Replace: Replace the polygon color with the texture color
  - Modulate: Multiply the polygon color with the texture color or intensity
  - Similar to compositing: Composite texture with base color using operator

Example: Diffuse shading and texture

- Say you want to have an object textured and have the texture appear to be diffusely lit
- Problem: Texture is applied after lighting, so how do you adjust the texture's brightness?
- Solution:
  - Make the polygon white and light it normally
  - Use `glTexEnvi(GL_TEXTURE_2D, GL_TEXTURE_ENV_MODE, GL_MODULATE)`
  - Use GL_RGB for internal format
  - Then, texture color is multiplied by surface color, and alpha is taken from fragment

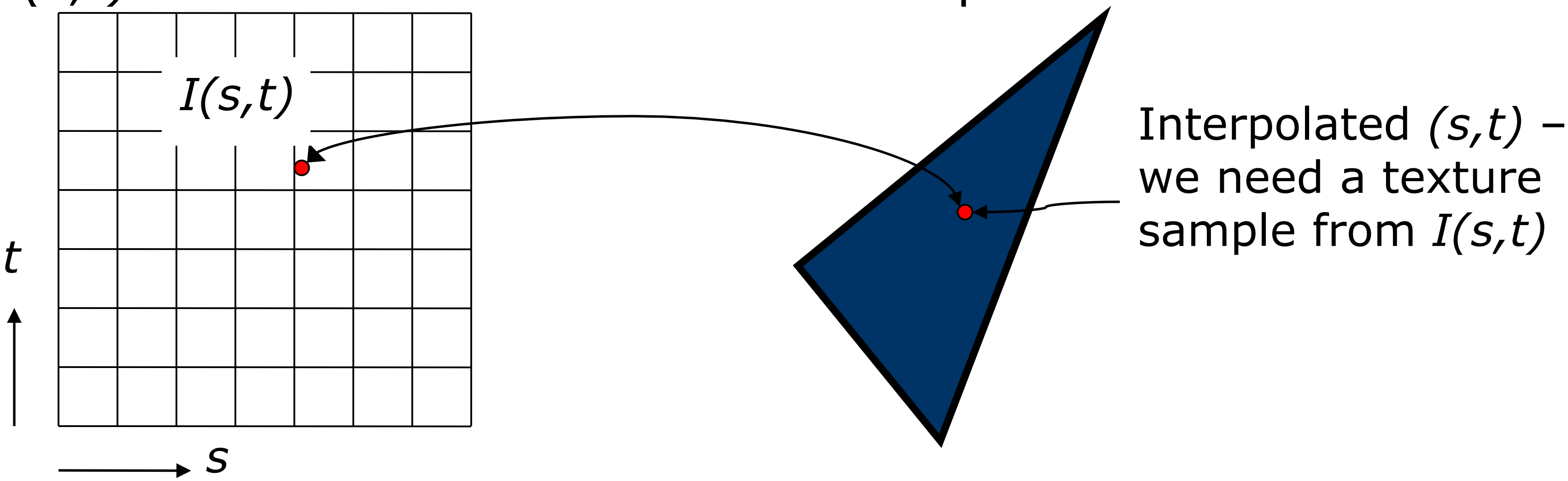
Specular Color

- Typically, texture mapping happens *after* lighting
  - More useful in general
- Recall plastic surfaces and specularities: the highlight should be the color of the light
- But if texturing happens after the lighting, the color of the specularity will be modified by the texture – the wrong thing
- OpenGL lets you do the specular lighting after the texture
  - Use glLightModel ()

Texture Recap

Triangle in 8x8 Texture Map, *I(s,t)*

Triangle in world space

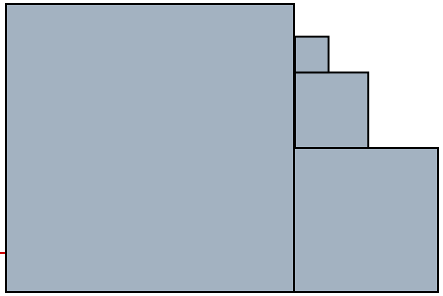


- We must reconstruct the texture image at the point *(s,t)*
- Time to apply the theory of sampling and reconstruction

Textures and Aliasing

- Textures are subject to aliasing:
  - A polygon pixel maps into a texture image, essentially sampling the texture at a point
  - The situation is essentially an image warp, with the warp defined by the mapping and projection
- Standard approaches:
  - Pre-filtering: Filter the texture down before applying it
    - Useful when the texture has multiple texels per output image pixel
  - Post-filtering: Take multiple pixels from the texture and filter them before applying to the polygon fragment
    - Useful in all situations

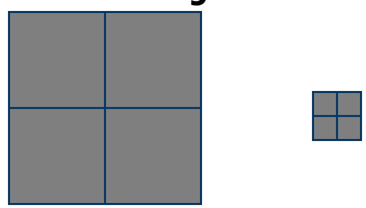
Mipmapping (Pre-filtering)

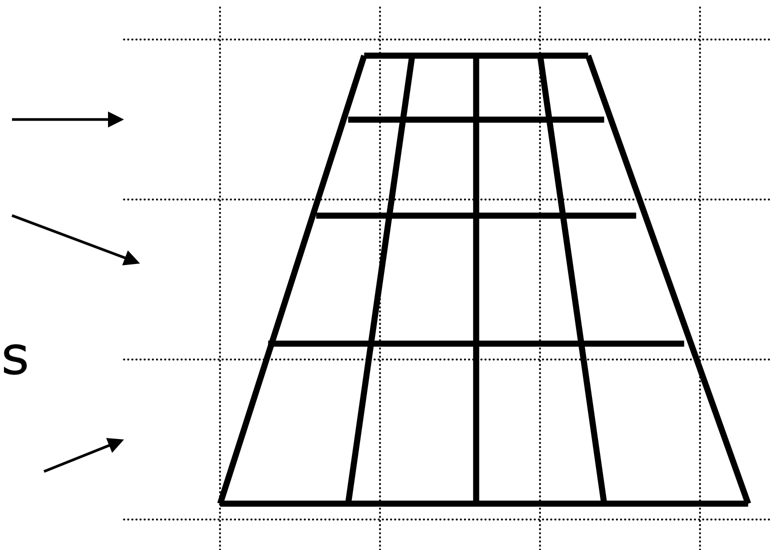


- If a textured object is far away, one screen pixel (on an object) may map to many texture pixels
  - The problem is: how to combine them
- A mipmap is a low resolution version of a texture
  - Texture is filtered down as a pre-processing step:
    - `gluBuild2DMipmaps(…)`
  - When the textured object is far away, use the mipmap chosen so that one image pixel maps to at most four mipmap pixels
  - Full set of mipmaps requires at most 1.3333 the storage of the original texture (in the limit)
    - 1+0.25+.25*.25+0.25*0.25*0.25+…

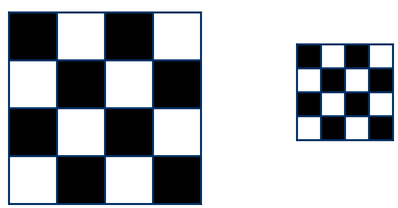
Mipmaps

For far objects

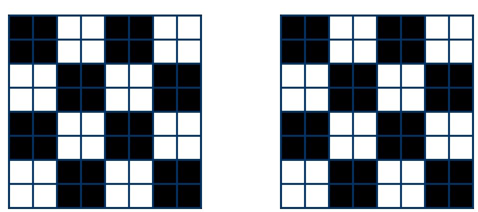




For middle objects



For near objects



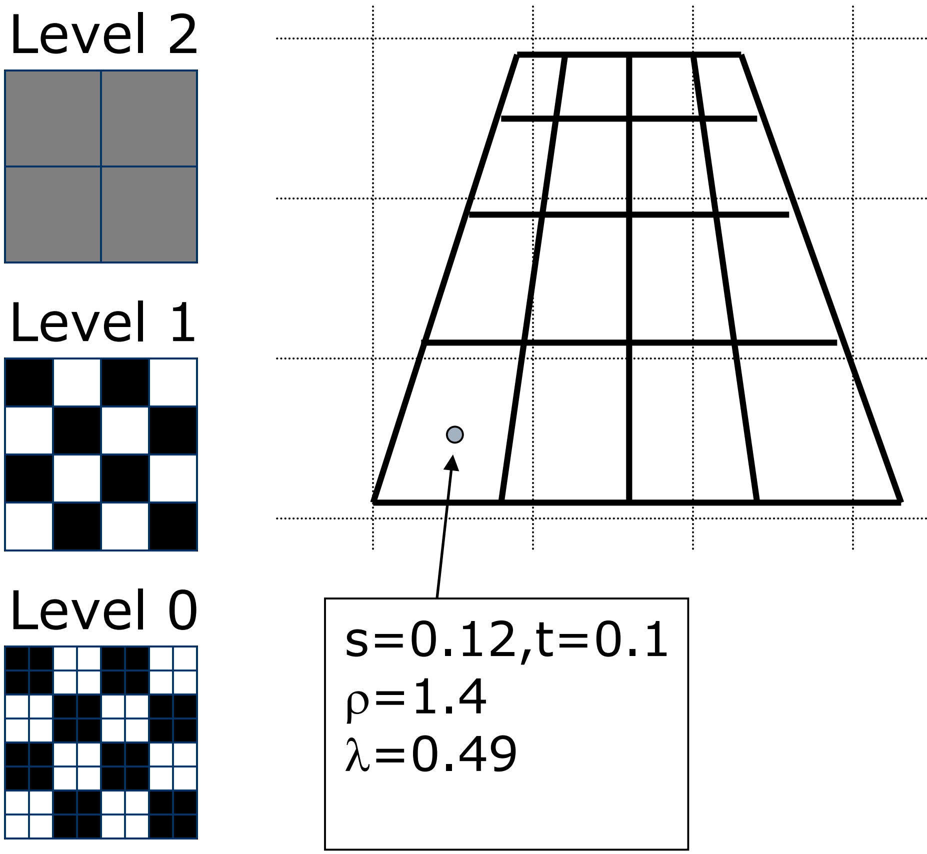
Mipmap Math

- Define a scale factor, ρ=texels/pixel
  - A texel is a pixel from a texture
  - ρ is actually the maximum from x and y
  - The scale factor may vary over a polygon
  - It can be derived from the transformation matrices
- Define $\lambda=\log_2 \rho$
- λ tells you which mipmap level to use
  - Level 0 is the original texture, level 1 is the next smallest texture, and so on
  - If $\lambda<0$, then multiple pixels map to one texel: magnification

Post-Filtering

- You tell OpenGL what sort of post-filtering to do
- Magnification: When λ<0 the image pixel is smaller than the texel:
  - `glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, type)`
  - Type is `GL_LINEAR` or `GL_NEAREST`
- Minification: When λ>0 the image pixel is bigger than the texel:
  - `GL_TEX_MIN_FILTER`
  - Can choose to:
    - Take nearest point in base texture, `GL_NEAREST`
    - Linearly interpolate nearest 4 pixels in base texture, `GL_LINEAR`
    - Take the nearest mipmap and then take nearest or interpolate in that mipmap, `GL_NEAREST_MIPMAP_LINEAR`
    - Interpolate between the two nearest mipmaps using nearest or interpolated points from each, `GL_LINEAR_MIPMAP_LINEAR`

Filtering Example



NEAREST_MIPMAP_NEAREST:
level 0, texel (0,0)

LINEAR_MIPMAP_NEAREST:
texel 0, texel (0,0) * 0.51
+ level 1, texel (0,0) * 0.49

NEAREST_MIPMAP_LINEAR:
level 0, combination of
texels (0,0), (1,0), (1,1), (0,1)

LINEAR_MIPMAP_LINEAR
:
Combination of level 0
and level 1, 4 texels
from each level, using 8
texels in all

Other Texture Stuff

- Texture must be in fast memory - it is accessed for every pixel drawn
  - If you exceed it, performance will degrade horribly
  - Skilled artists can pack textures for different objects into one image
- Texture memory is typically limited, so a range of functions are available to manage it
- Sometimes you want to apply multiple textures to the same point: *Multitexturing* is now in most new hardware

Next Time

- Mesh and Modelling