MANCHESTER 1824

COMP27112

Computer Graphics and Image Processing

9: Rendering (3)

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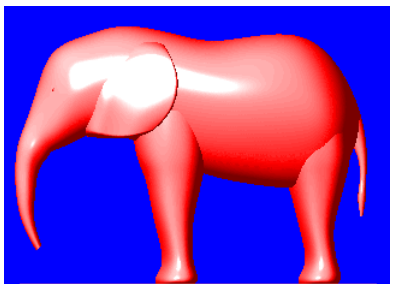
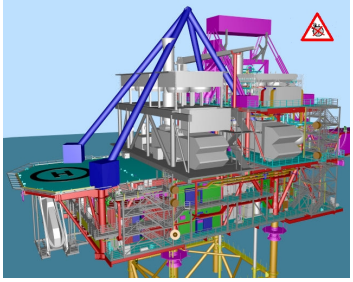
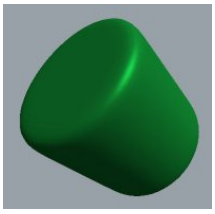
Examples of the simple local model



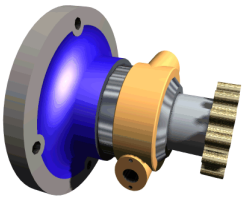
Lex Lennings



AIG



James Sinnott



Alan Watt

nVIDIA

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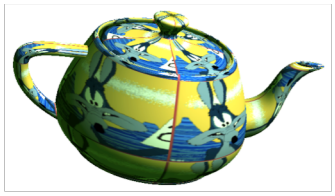
Surface detail

- We'll look at two methods for adding **surface detail** to rendered surfaces
  - texture mapping



  - bump mapping

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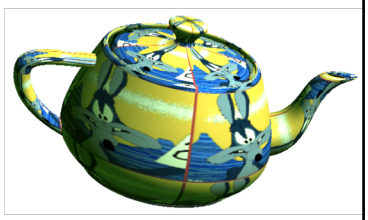
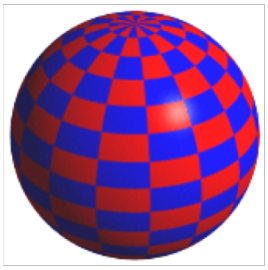
Types of texture mapping

- image-based
  - the texture is defined by an image which modifies pixel colours. This is the most common approach and we'll focus on this.



- procedural
  - a texture pattern is computed during rendering, based on algorithms/rules, which modifies pixel colour. Less common, and we won't look further at this.



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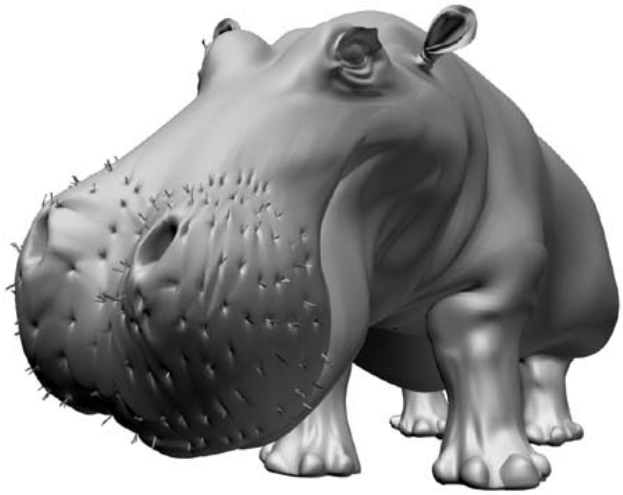
Texture mapping



Jeremy Birn

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Texture mapping

Jeremy Birn

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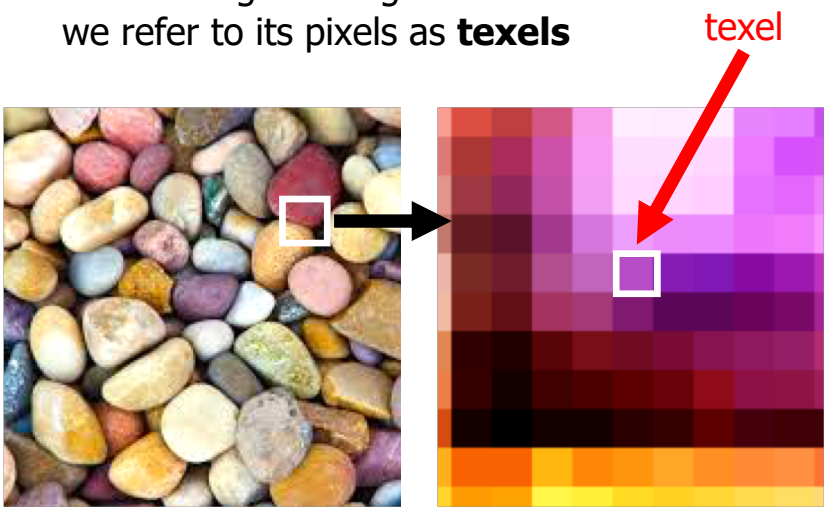
Defining a texture

- When using an image as a texture we refer to its pixels as **texels**



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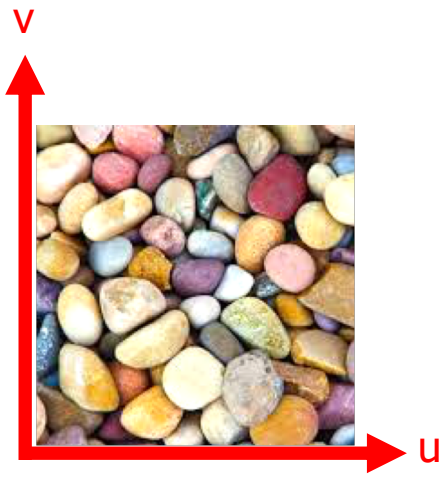
Texture coordinates

- for convenience, a texture is defined in its own coordinate system
- this is conventionally referred to as (u,v) or (s,t)



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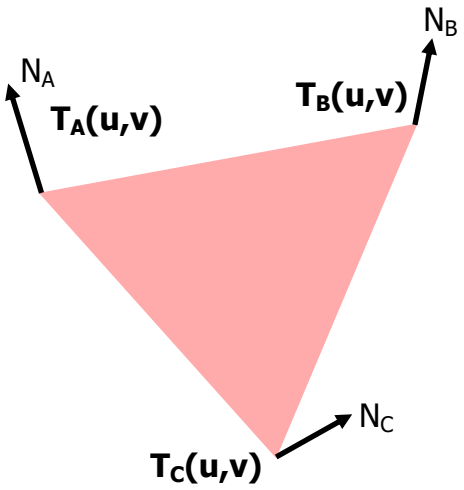
Mapping texture per-polygon

- We associate (u,v) texture coordinates with each (x,y,z) vertex of a polygon
- And interpolate the texture coordinates during scan-conversion
- Then we **blend** the pixel colour with the texture colour



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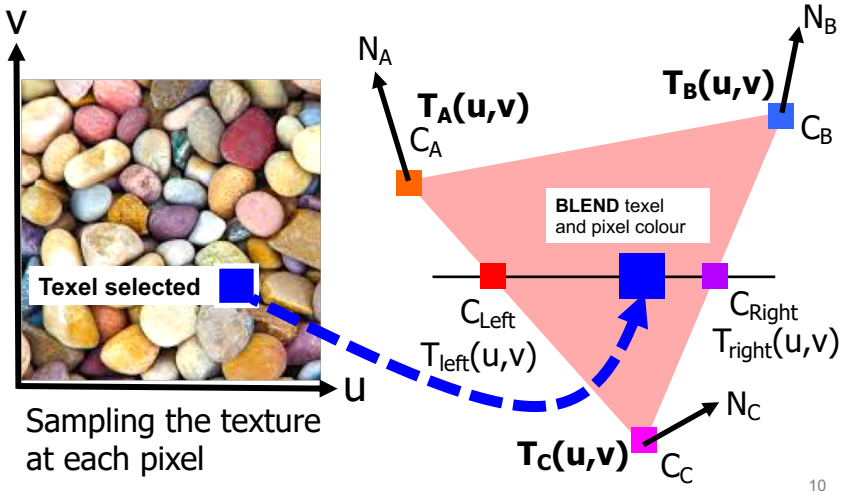
Performing texture mapping

- We do texture mapping as part of rasterisation



Sampling the texture at each pixel

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Blending texture and pixel colours

- Programmer has fine control of blending
- Examples: ADD, MODULATE, DECAL, BLEND, REPLACE, COMBINE
- See Coursework 3
- See ex11.c in OpenGL manual
- Details are not examinable
- https://www.khronos.org/registry/OpenGL-Refpages/gl2.1/xhtml/glTexEnv.xml

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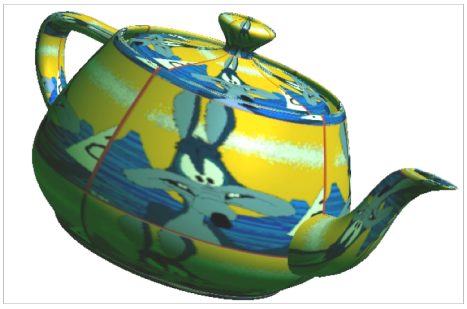
Meshes and seams

- In order to realistically texture a mesh, we often have to use multiple textures in different places, which can give rise to ugly "seams"



- One solution is to use textures that are **seamless**, so the edge of one exactly matches the edge of another
- Creating textures is an art!

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Resolution mismatches

Texture image

rendered triangle

In this particular example, **texture resolution** happens to match **pixel resolution** (this is lucky, and very unusual)

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Resolution mismatches

Texture image

But now the camera has changed...

...so texture resolution no longer matches pixel resolution – this is almost always the situation we have to deal with

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Resolution mismatches

- There are two cases:
  - pixel resolution **>** texture resolution (i.e. pixels are smaller than texels).
  - pixel resolution **<** texture resolution (i.e. pixels are bigger than texels)
- In each case we need to filter, aka sample
- Each case requires a different approach

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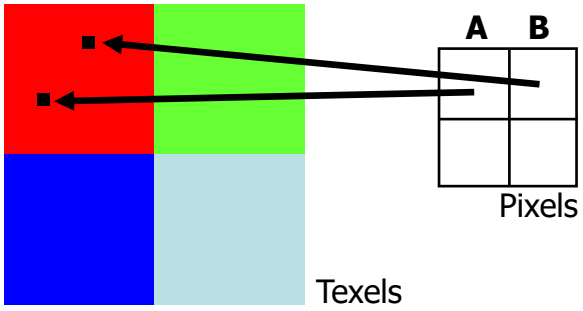
pixel resolution > texel resolution

- Pixels **A** and **B** happen to map to the same texel, because pixel resolution > texel resolution



- We' ll look at two approaches (there are more)
  1. no filter
  2. bilinear interpolation filter

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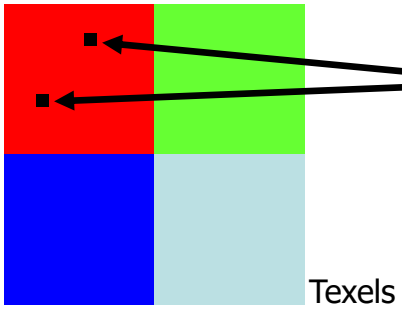
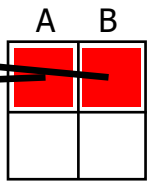
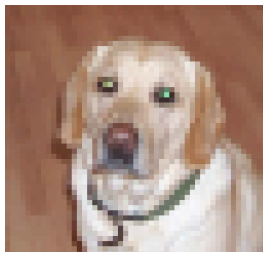
1. No filter

- We simply select the texel to which the pixel maps





Texels



- The resulting rendering looks blocky

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Pixel resolution == Texel resolution

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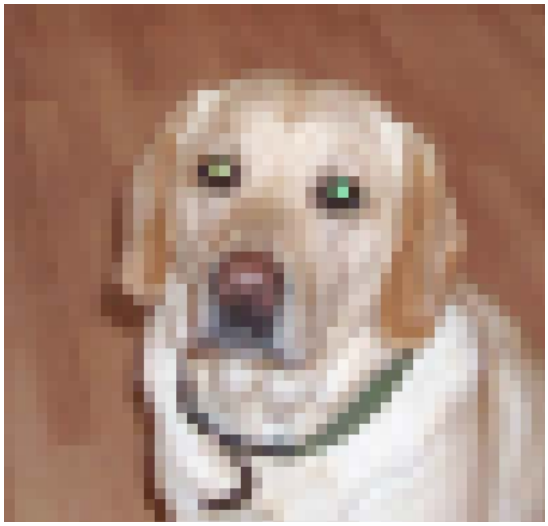
Pixel resolution > Texel resolution: no filter



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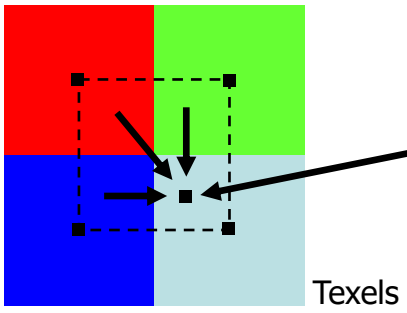
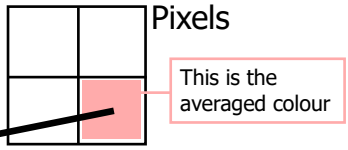
2. Bilinear interpolation filter

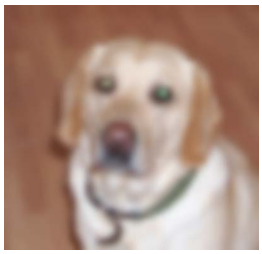
- We compute a texel colour from adjacent texels, **averaging** horizontally and vertically





Texels

- The resulting pixel image looks smoother



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Pixel resolution == Texel resolution

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Pixel resolution > Texel resolution: bilinear filter

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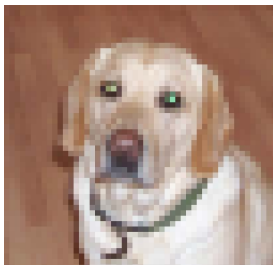
Texture filtering: comparison

Unfiltered texture (1 to 1 pixel correspondence)



No filter

Bilinear interpolation filter

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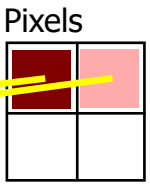
pixel resolution < texel resolution

- If pixel resolution **<** texel resolution, **adjacent** pixels may map to texels **far apart** in the texture, leading to missing detail, aka aliasing
- In animated sequences especially, we see unpleasant aliasing effects, as pixels "pop" on and off, or change colour unexpectedly in each frame



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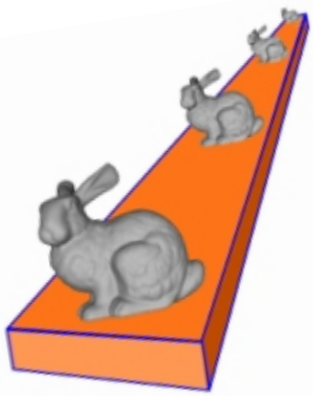
Mipmap filtering

- One technique to minimise this effect is **mipmapping**
- **mip** = *multum in parvo* (Latin), meaning "many things in a small place"
- The idea is simple: the further away from the viewpoint, the less detail we need
- So, we use a **set** of texture maps, and **select** which map to use, according to the **distance** of a pixel from the viewer



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Creating a mipmap

t0

256 x 256

t0 is the original full-resolution texture

t1

128 x 128

t1 is ½ res

t2

64 x 64

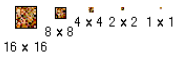
t2 is ¼ res

t3

32 x 32

t3 is 1/8 res (etc)

t4 (etc)



16 x 16 8 x 8 4 x 4 2 x 2 1 x 1

Starting from the original texture **t0**, we repeatedly create smaller versions of it (**t1**, **t2** etc), **downsampling** (i.e., averaging) by ½ each time, until we reach a 1x1 texture. This is a **pre-processing** procedure, and we store each texture in memory.

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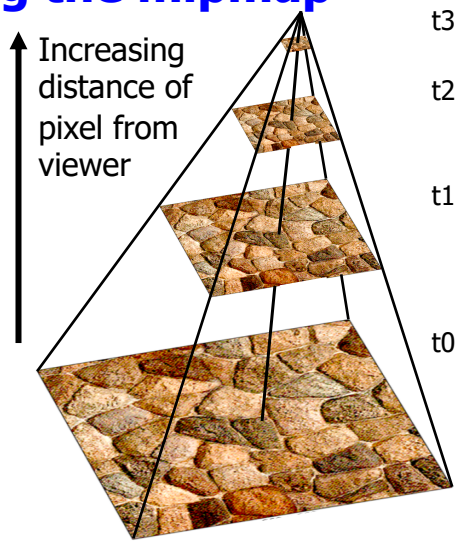
Rendering using the mipmap

- When rendering, we select one of the textures according to the **distance** of the pixel from the viewpoint
- Or, we can also choose the **two closest** textures, and do bilinear interpolation – for extra smoothness



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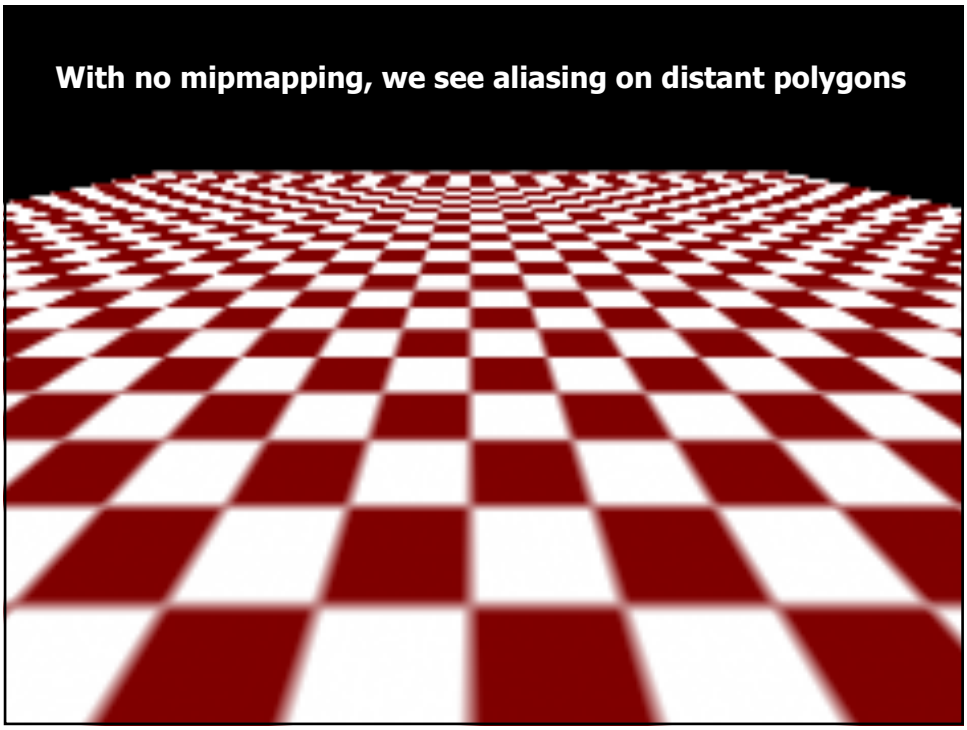
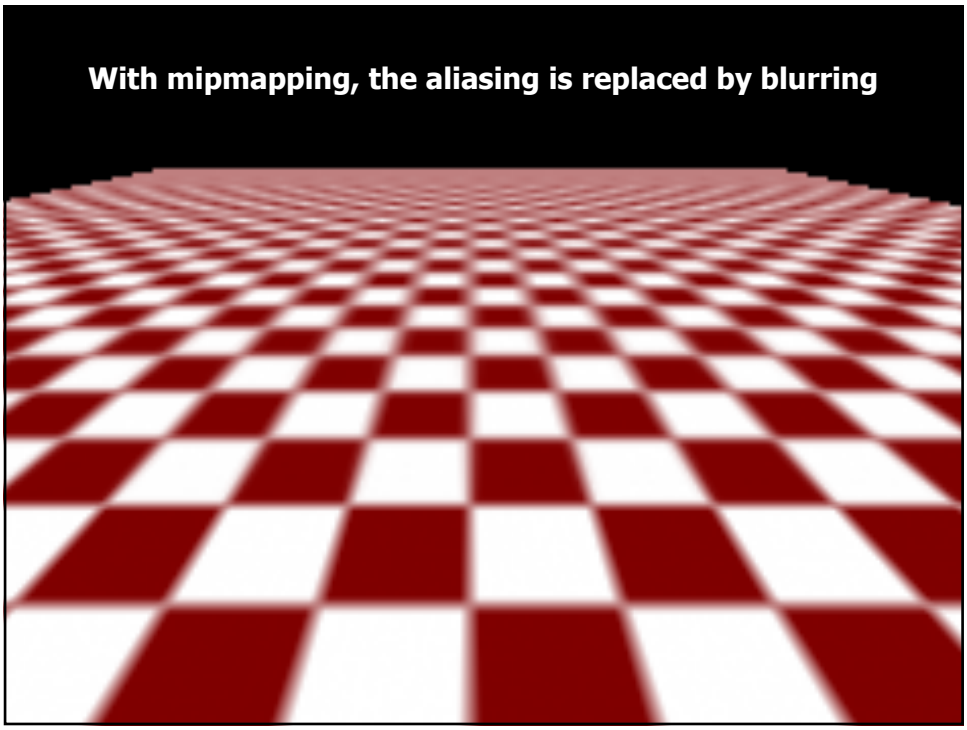
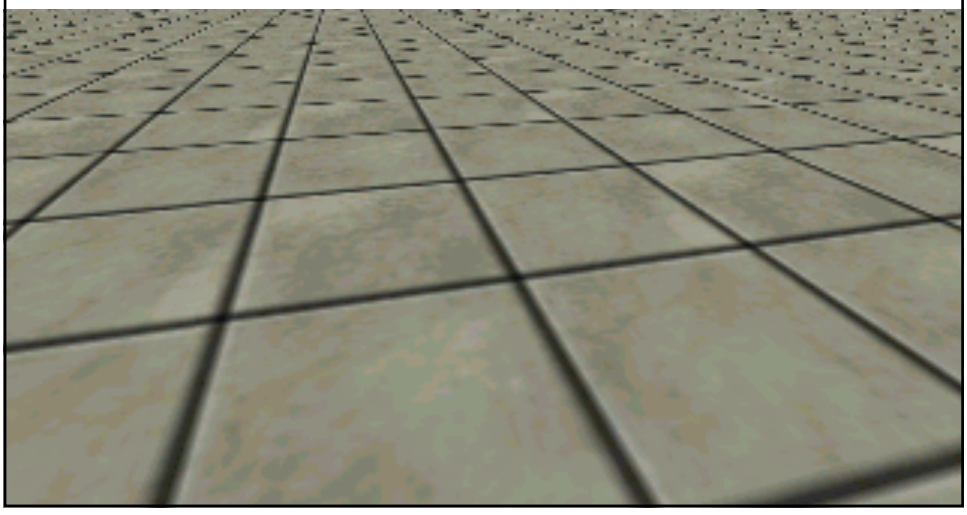
With no mipmapping, we see aliasing on distant polygons

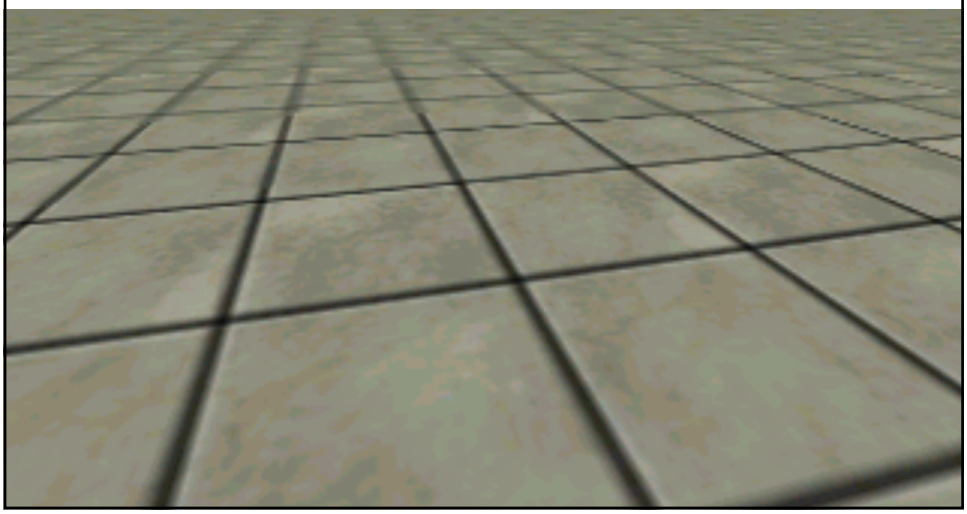




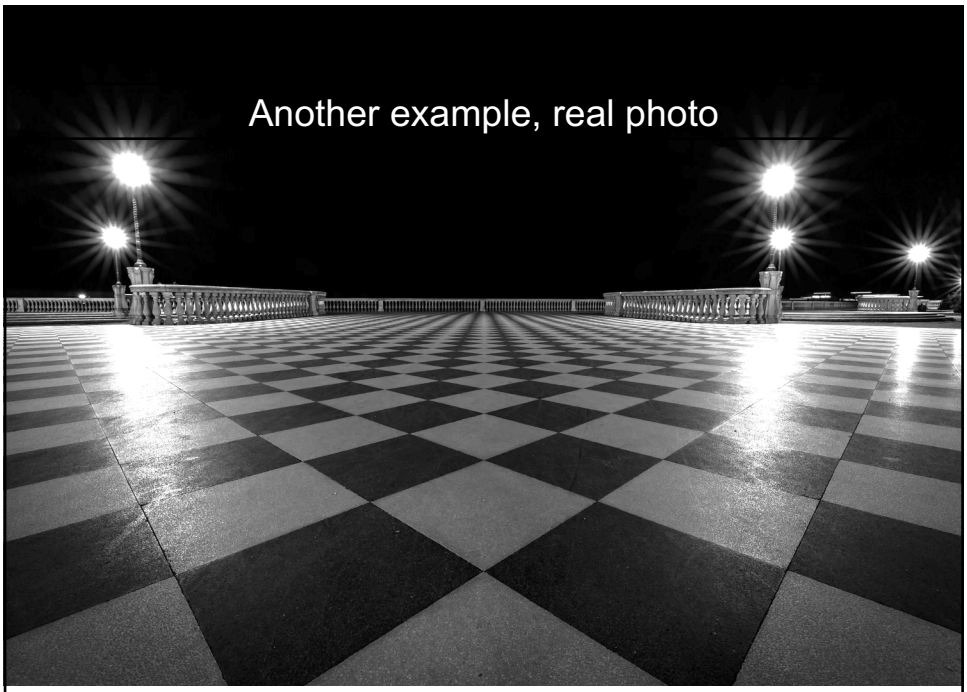
Another example, without mip-mapping



Another example, with mip-mapping



Another example, real photo



Nico Angeli (https://www.flickr.com/photos/135915437@N08/)

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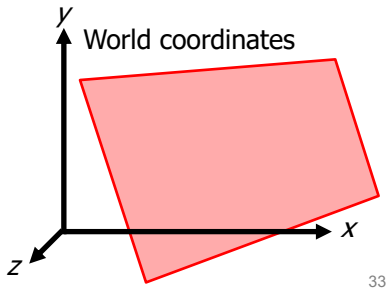
Textures in OpenGL

```
glBegin(GL_QUADS);
 glVertex3f(x0, y0, z0);
 glVertex3f(x1, y1, z1);
 glVertex3f(x2, y2, z2);
 glVertex3f(x3, y3, z3);
glEnd();
```



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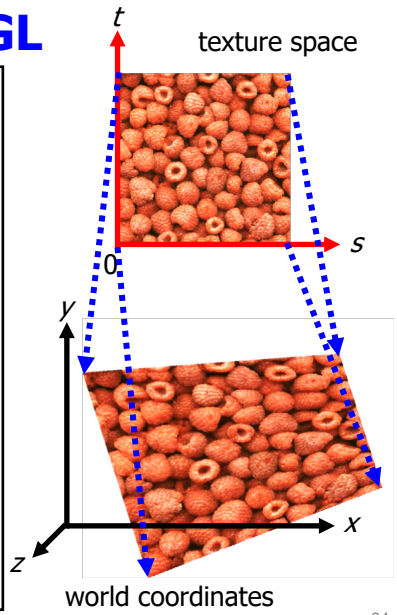
Textures in OpenGL

```
/* First call functions to
   read texture from
   image file, and to set
   its properties – how
   it BLENDS with pixels
*/

glBegin(GL_QUADS);
 glTexCoord(0.0, 0.0);
   glVertex3f(x0, y0, z0);
 glTexCoord(1.0, 0.0);
   glVertex3f(x1, y1, z1);
 glTexCoord(1.0, 1.0);
   glVertex3f(x2, y2, z2);
 glTexCoord(0.0, 1.0);
   glVertex3f(x3, y3, z3);
glEnd();
```



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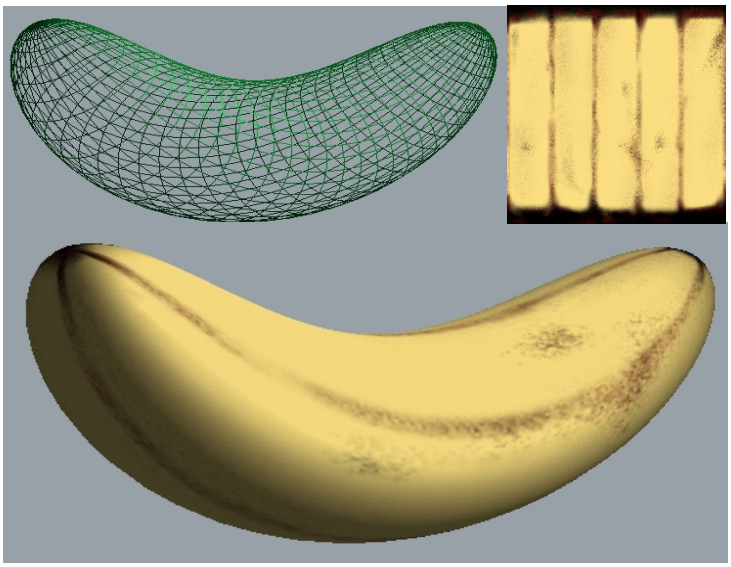
Texture example



James Sinnott

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Textures as illumination

- Textures can be used to add accurate illumination to a real-time scene
- Off-line, pre-compute accurate diffuse illumination of the scene, using a global model (e.g., radiosity)
- Save rendered surfaces as textures – called **lightmaps**
- In real-time, apply lightmap textures, and also actual surface textures.

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Lightmaps only

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Lightmaps blended with other textures

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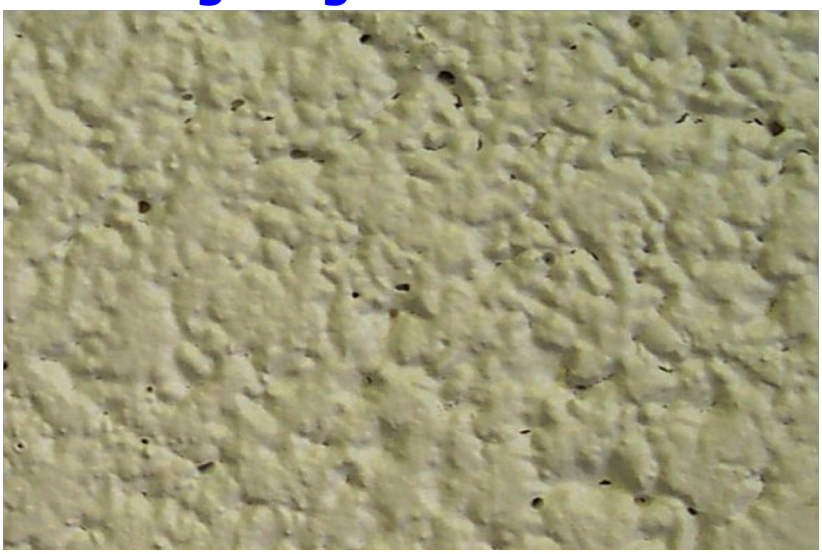
Modelling rough surfaces



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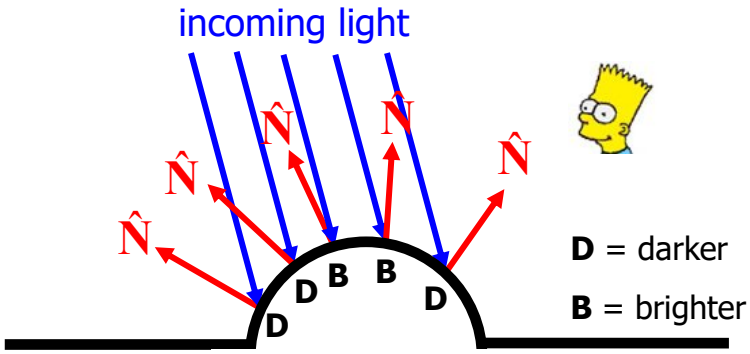
Bump mapping



- Why do rough surfaces look rough?
- The **surface normals** change across the bumps, so the top of the bumps appear brighter than the sides

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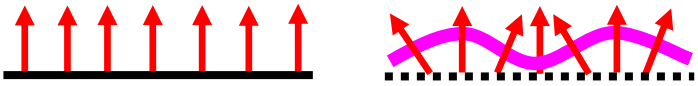
Bump mapping

- Rather than alter the surface **colour**, as in texturing, we can alter the **surface normal**
- this has the same effect on the illumination model as if the surface were really geometrically different (but it isn't)



original normals altered normals

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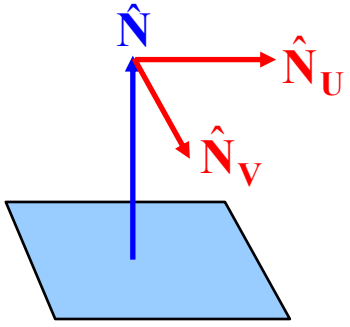
Altering a surface normal



- Step 1: Introduce two **unit** vectors $\hat{N}_U$ and $\hat{N}_V$ each orthogonal to the surface normal

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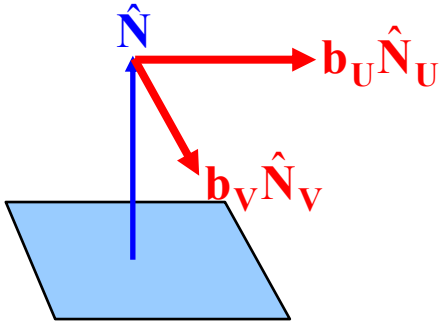
Altering a surface normal



- Step 2: Scale $\hat{\mathbf{N}}_U$ and $\hat{\mathbf{N}}_V$ by $\mathbf{b}_U$ and $\mathbf{b}_V$
- To give the "bump vectors"

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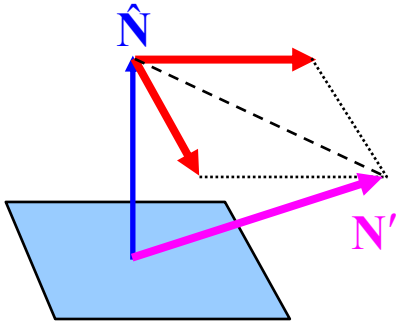
Altering a surface normal



- Step 3: Add the bump vectors to the original surface normal to get an altered surface normal
- $\mathbf{N}' = \hat{\mathbf{N}} + (\mathbf{b}_U\hat{\mathbf{N}}_U + \mathbf{b}_V\hat{\mathbf{N}}_V)$

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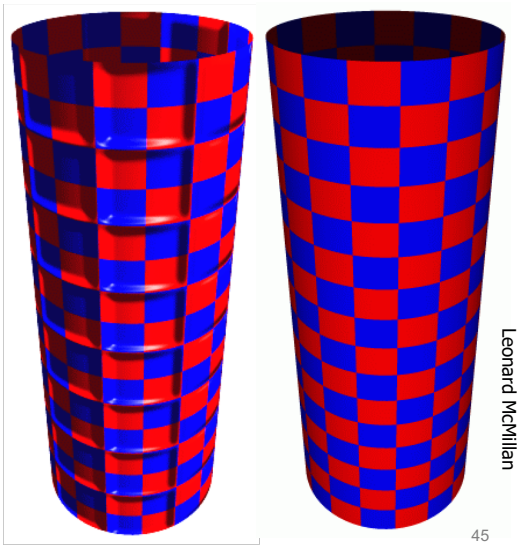
Bump mapping example

- The altered surface normals make the mesh look bumpy
- But only the normals are changing during rendering
- The definition of the mesh does not change



Leonard McMillan

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Where do we get b_U and b_V ?

- One way is to use a texture as a **bump map** to derive b_U and b_V
- We use the texel colours to encode bumpiness

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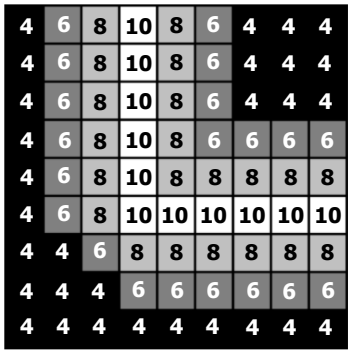
Format of a bump map

- We treat the value of each texel as a "height" which will control the bumpiness of the surface
- We can say that brighter texels are "higher" than darker texels



Hugo Elias

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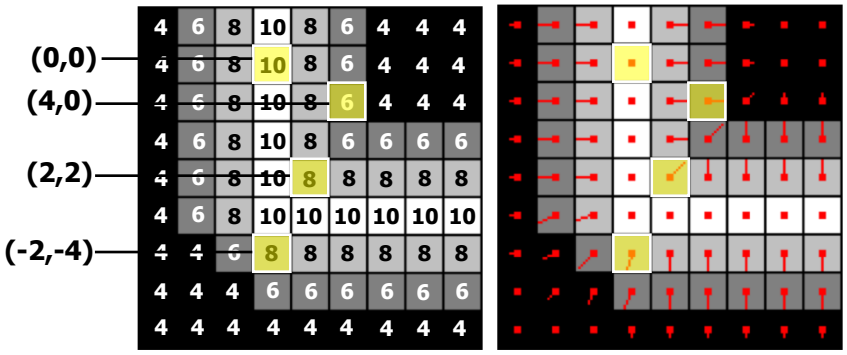
Deriving b_U and b_V

- For each texel T, we compute its x and y brightness **gradients** and use them as b_U and b_V:
  - $b_U = T(x-1, y) - T(x+1, y)$
  - $b_V = T(x, y-1) - T(x, y+1)$



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Bump mapping example

NVIDIA

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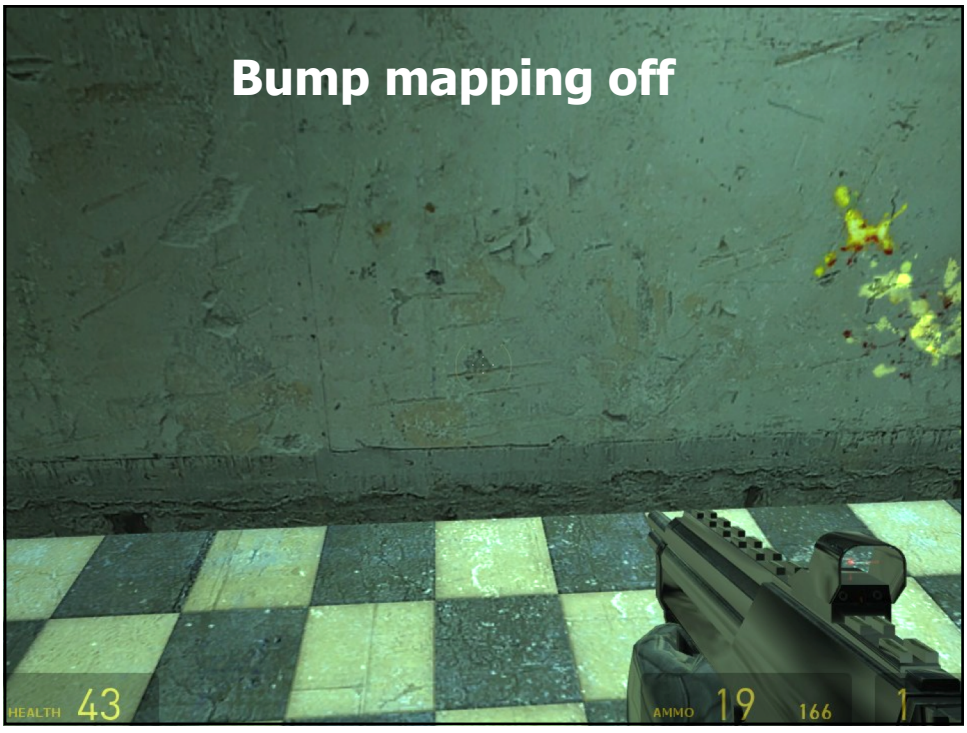

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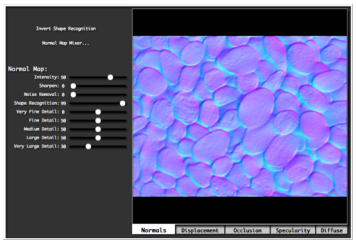
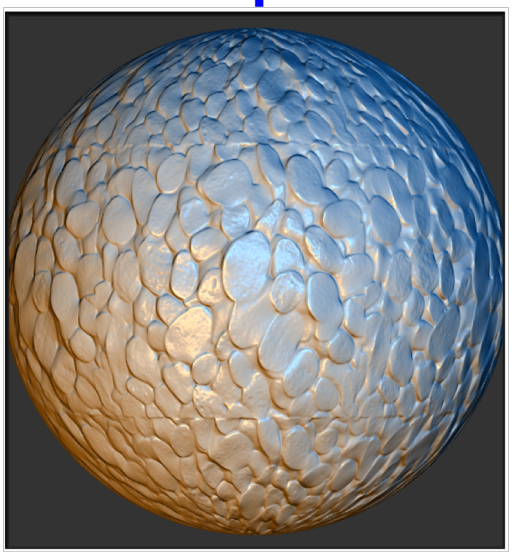
Crazybump – do some experiments





www.crazybump.com (mac/win)

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What we've covered in Part 1 of the course