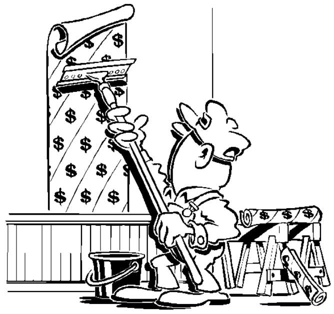
Texture Mapping & Other Fun Stuff

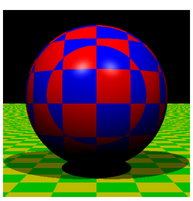


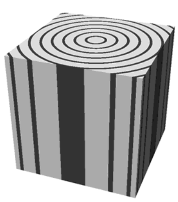
The Problem:

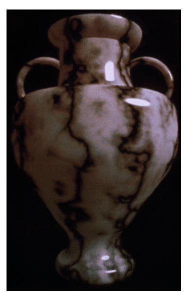
- Don't want to represent all this detail with geometry

Procedural Solid (3D) Textures

- Write a function: $f(x,y,z) \rightarrow$ color



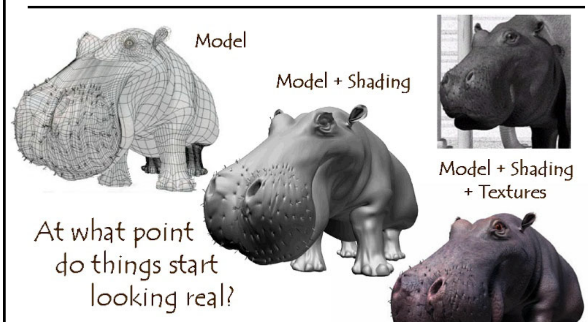




- non-intuitive
- difficult to match existing texture

Ken Perlin, SIGGRAPH '85.

The Quest for Visual Realism



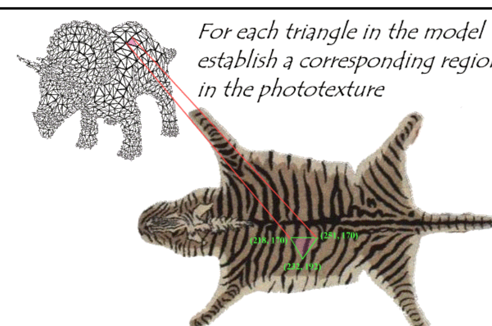
For more info on the computer artwork of Jeremy Birn see http://www.3drender.com/jbirn/productions.html

Today

- 2D Texture Mapping
  - Perspective Correct Interpolation
  - Illumination
  - Texture Mapping Difficulties
  - Projective Texturing
- Other Mapping Techniques

Photo-textures

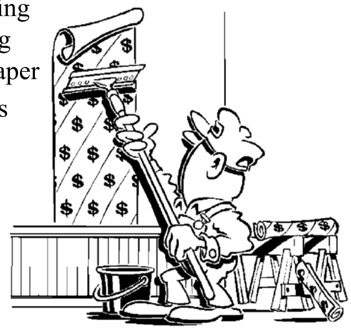
For each triangle in the model establish a corresponding region in the phototexture



During rasterization interpolate the coordinate indices into the texture map

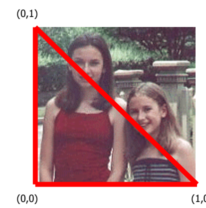
Texture Mapping

- Like wallpapering or gift-wrapping with stretchy paper
- Curved surfaces require extra stretching or cutting

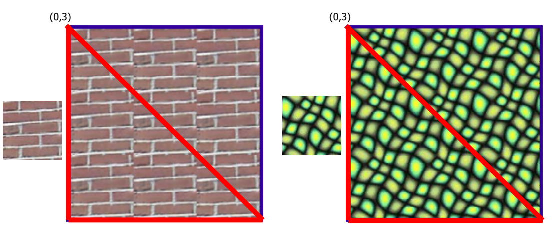


Texture Coordinates

- Specify a texture coordinate (u,v) at each vertex
- Canonical texture coordinates (0,0) → (1,1)
- Often the texture size is a power of 2 (but it doesn't have to be)
- How can we tile this texture?



Tiling Texture

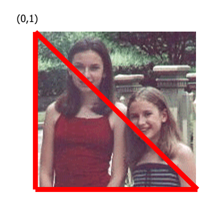


tiles with visible seams

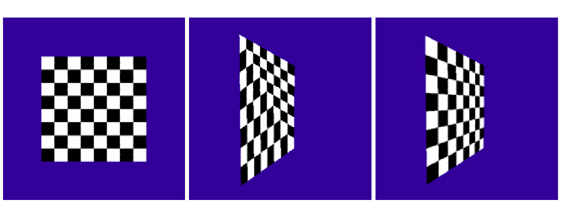
seamless tiling (repeating)

Texture Coordinates

- Specify a texture coordinate (s,t) at each vertex
- Canonical texture coordinates (0,0) → (1,1)
- Can we just linearly interpolate the values in screen space?



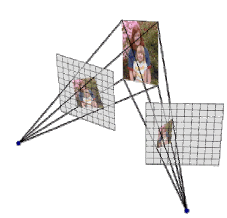
What Goes Wrong?

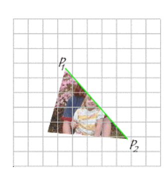


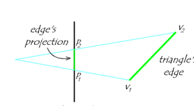
texture source | what we get | what we want

Looking at One Edge

- Consider one edge from a given triangle. This edge and its projection onto our viewport lie in a single common plane illustrated below:

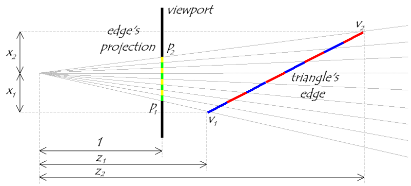






Visualizing the Problem

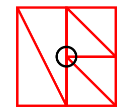
Let's assume that the viewport is located 1 unit away from the center of projection.



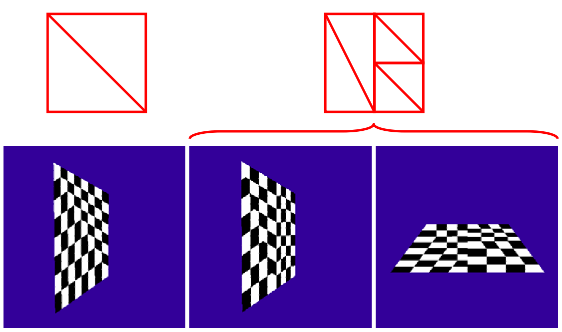
Notice that uniform steps on the image plane do not correspond to uniform steps along the edge.

How do we fix it?

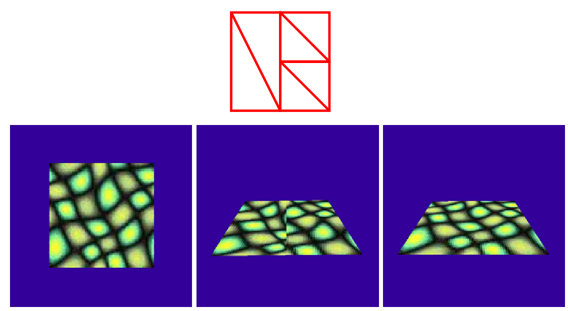
- We can reduce the perceived artifacts of non-perspective correct interpolation by subdividing the model into smaller triangles. Why?
- However, sometimes the errors become obvious
  - At "T" joints
  - When switching between levels-of-detail representations (mipmapping... next time)



Subdivision

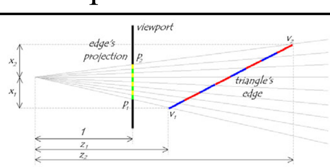


Subdivision



texture source | what we get | what we want

Linear Interpolation in Screen Space



Compare linear interpolation in screen space

$$p(t) = p_1 + t(p_2 - p_1) = \tfrac{x_1}{z_1} + t\left(\tfrac{x_2}{z_2} - \tfrac{x_1}{z_1}\right)$$

to interpolation in 3-space

$$\begin{bmatrix} x \\ z \end{bmatrix} = \begin{bmatrix} x_1 \\ z_1 \end{bmatrix} + s\left(\begin{bmatrix} x_2 \\ z_2 \end{bmatrix} - \begin{bmatrix} x_1 \\ z_1 \end{bmatrix}\right) \qquad P\left(\begin{bmatrix} x \\ z \end{bmatrix}\right) = \frac{x_1 + s(x_2 - x_1)}{z_1 + s(z_2 - z_1)}$$

Perspective Correct Interpolation

We need a mapping from t values to s values:

$$\tfrac{x_1}{z_1} + t\left(\tfrac{x_2}{z_2} - \tfrac{x_1}{z_1}\right) = \frac{x_1 + s(x_2 - x_1)}{z_1 + s(z_2 - z_1)}$$

Solve for s in terms of t:

$$s = \frac{t\, z_1}{z_2 + t\,(z_1 - z_2)}$$

Unfortunately, at this point in the pipeline (after projection) we no longer have z. However, we do have $w_1 = 1/z_1$ and $w_2 = 1/z_2$, so:

$$s = \frac{t\, \frac{1}{w_1}}{\frac{1}{w_2} + t\,\left(\frac{1}{w_1} - \frac{1}{w_2}\right)} = \frac{t\, w_2}{w_1 + t\,(w_2 - w_1)}$$

Questions?

Today

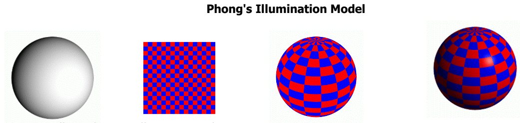
- 2D Texture Mapping
  - Perspective Correct Interpolation
  - Illumination
  - Texture Mapping Difficulties
  - Projective Texturing
- Other Mapping Techniques

Texture Mapping & Illumination

- Texture mapping can be used to alter some or all of the constants in the illumination equation: as the final color for the pixel, or as the diffuse color, or to alter the normal, ... the possibilities are endless! (e.g. GL_DECAL, GL_MODULATE, GL_BLEND, ...)

$$I_{total} = k_a I_{ambient} + \sum_{i=1}^{lights} I_i \left(k_d \left(\hat{N} \cdot \hat{L} \right) + k_s \left(\hat{V} \cdot \hat{R} \right)^{n_{shiny}} \right)$$

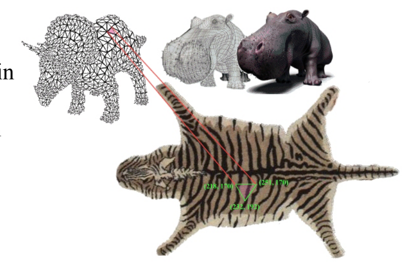
Phong's Illumination Model



Constant Diffuse Color — Diffuse Texture Color — Texture used as Label — Texture used as Diffuse Color

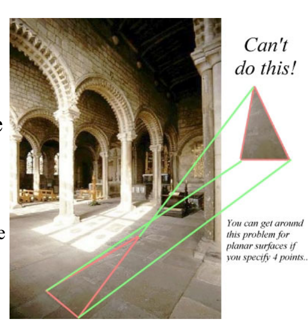
2D Texture Mapping

- Increases the apparent complexity of simple geometry
- Requires perspective projection correction
- Specifies variations in shading within a primitive:
  - Illumination
  - Surface Reflectance



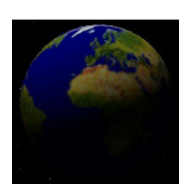
Texture Mapping Difficulties

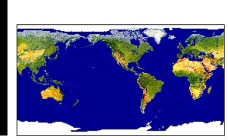
- Tedious to specify texture coordinates for every triangle
- Easier to model variations in reflectance than illumination
- Acquiring textures is surprisingly difficult
  - Texture image can't have projective distortions
  - Seamless tiling
  - Non-repeating textures



Common Texture Coordinate Mappings

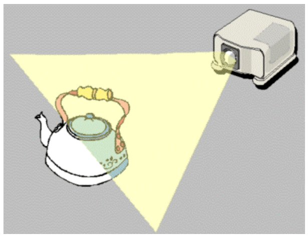
- Orthogonal
- Cylindrical
- Spherical
- Perspective Projection
- Texture Chart





Projective Textures

- Treat the texture as a light source (a slide projector)
- No need to specify texture coordinates explicitly
- A good model for shading variations due to illumination
- A fair model for reflectance (can use pictures)



Projective Texture Example

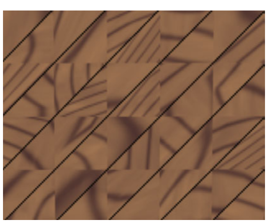
- Modeling from photograph
- Using input photos as textures

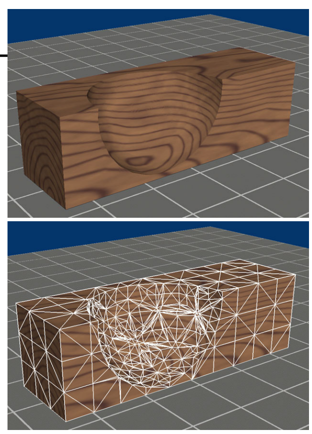
Original photograph with marked edges | Recovered model | Model edges projected onto photograph | Synthetic rendering

Figure from Debevec, Taylor & Malik
http://www.debevec.org/Research

Texture Chart

- Pack triangles into a single image





Questions?

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- 2D Texture Mapping
- Other Mapping Techniques:
  - Projective Shadows and Shadow Maps
  - Bump Mapping
  - Displacement Mapping
  - Environment Mapping (for Reflections)

Projective Shadows

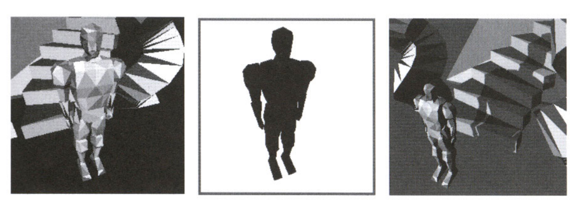


Image from light source | BW image of obstacle | Final image

Figure from Moller & Haines "Real Time Rendering"

Shadow Maps

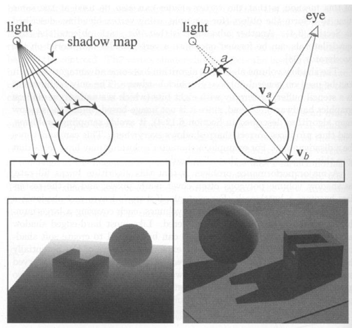
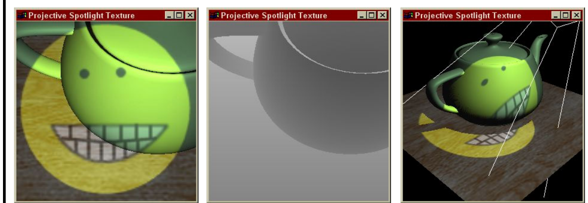


Figure from Foley et al. “Computer Graphics Principles and Practice”

Projective Texturing + Shadow Map



Light’s View | Depth/Shadow Map | Eye’s View

Images from Cass Everitt et al., “Hardware Shadow Mapping” NVIDIA SDK White Paper

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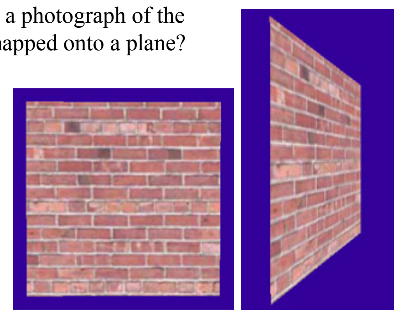
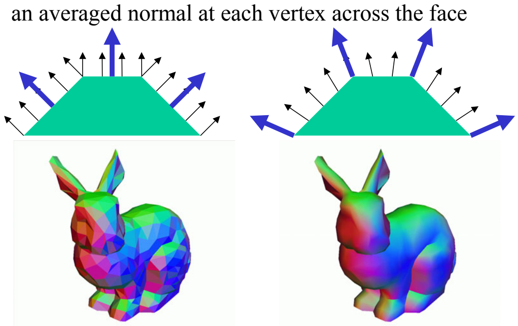
What's Missing?

- What's the difference between a real brick wall and a photograph of the wall texture-mapped onto a plane?
- What happens if we change the lighting or the camera position?



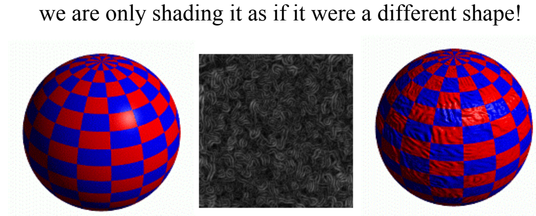
Remember Phong Normal Interpolation?

- Instead of using the normal of the triangle, interpolate an averaged normal at each vertex across the face



Bump Mapping

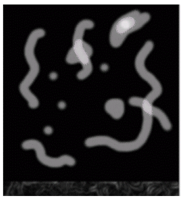
- Textures can be used to alter the surface normal of an object.
- This does not change the actual shape of the surface -- we are only shading it as if it were a different shape!

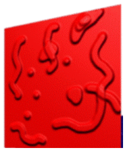


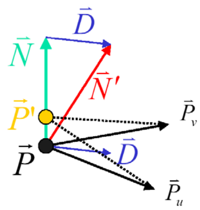
Sphere w/Diffuse Texture | Swirly Bump Map | Sphere w/Diffuse Texture & Bump Map

Bump Mapping

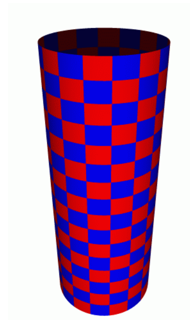
- The texture map is treated as a single-valued height function.
- The partial derivatives of the texture tell us how to alter the true surface normal at each point to make the object appear as if it were deformed by the height function.



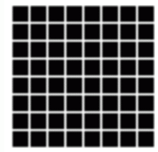




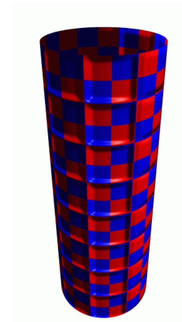
Another Bump Map Example



Cylinder w/Diffuse Texture Map

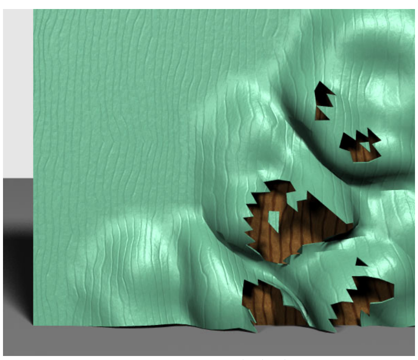


Bump Map



Cylinder w/Texture Map & Bump Map

Another Bump Map Example



Questions?

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  - Displacement Mapping
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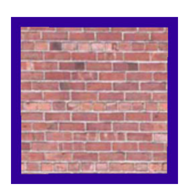
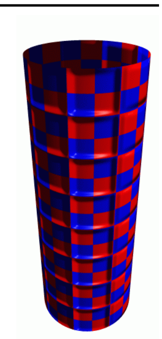
What's Missing?

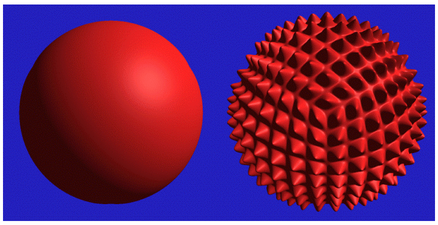
- What does a texture- & bump-mapped brick wall look like as you move the viewpoint?
- What does the silhouette of a bump-mapped sphere look like?





Displacement Mapping

- Use the texture map to actually move the surface point. How is this different than bump mapping?
- The geometry must be displaced before visibility is determined. Is this easily done in the graphics pipeline? In a ray-tracer?



Displacement Mapping

Image from:

Geometry Caching for Ray-Tracing Displacement Maps

by Matt Pharr and Pat Hanrahan.

note the detailed shadows cast by the stones

Displacement Mapping

Ken Musgrave

Questions?

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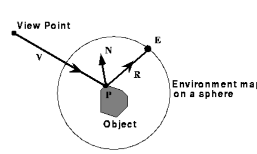
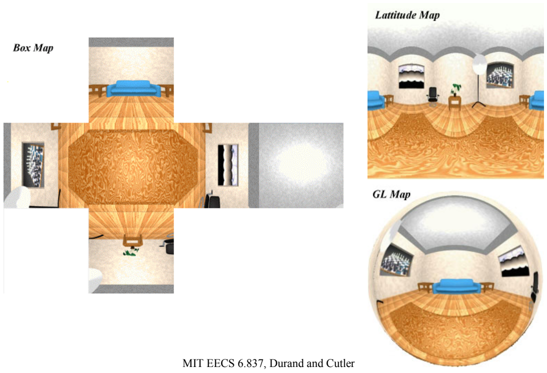
Environment Maps

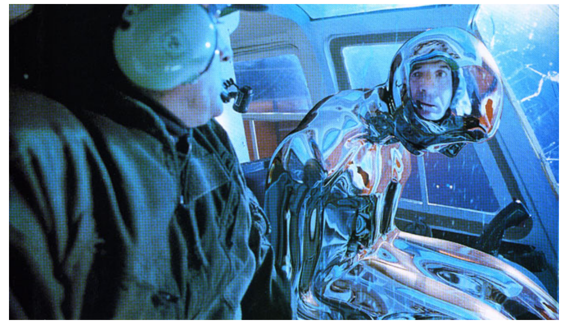
- We can simulate reflections by using the direction of the reflected ray to index a spherical texture map at "infinity".
- Assumes that all reflected rays begin from the same point.



What's the Best Chart?



Environment Mapping Example



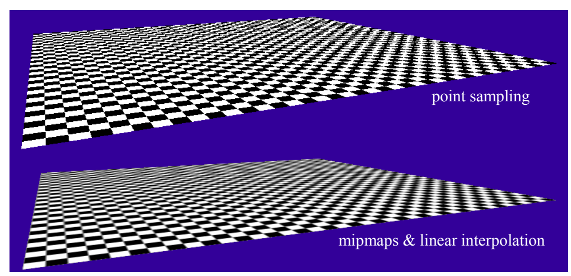
Terminator II

Questions?

Image by Henrik Wann Jensen
Environment map by Paul Debevec

Textures can Alias

- *Aliasing* is the under-sampling of a signal, and it's especially noticeable during animation



Next Time:

Aliasing, Anti-Aliasing
&
Mipmaps for Texturing