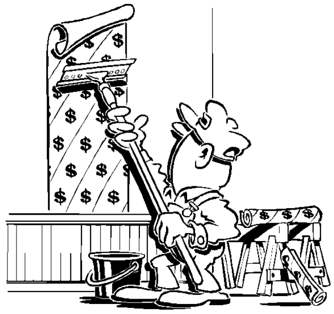
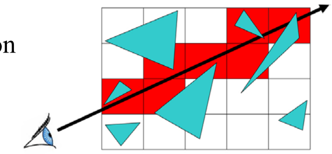
Texture Mapping & Other Fun Stuff



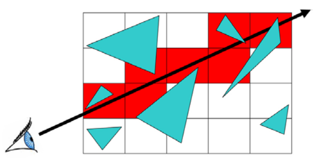
Last Time?

- Distribution Ray Tracing
- Bounding Boxes
- Spatial Acceleration Data Structures
  - Regular Grid
  - Adaptive Grids
  - Hierarchical Bounding Volumes
- Flattening the Transformation Hierarchy



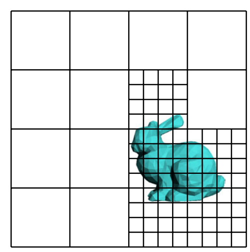
Regular Grid Discussion

- Advantages?
  - easy to construct
  - easy to traverse
- Disadvantages?
  - may be only sparsely filled
  - geometry may still be clumped

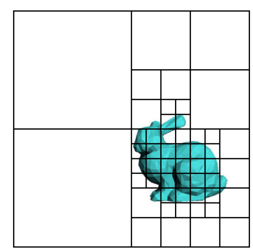


Adaptive Grids

- Subdivide until each cell contains no more than *n* elements, or maximum depth *d* is reached



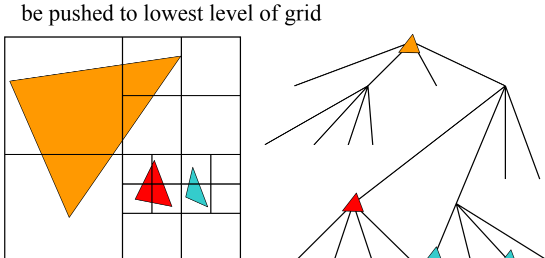
Nested Grids



Octree/(Quadtree)

Primitives in an Adaptive Grid

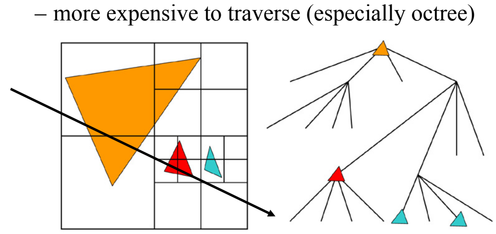
- Can live at intermediate levels, or be pushed to lowest level of grid



Octree/(Quadtree)

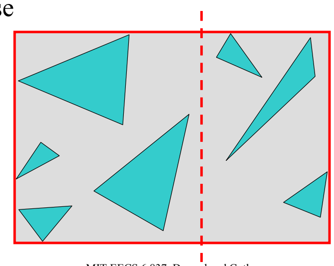
Adaptive Grid Discussion

- Advantages?
  - grid complexity matches geometric density
- Disadvantages?
  - more expensive to traverse (especially octree)



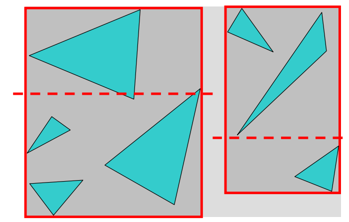
Bounding Volume Hierarchy

- Find bounding box of objects
- Split objects into two groups
- Recurse



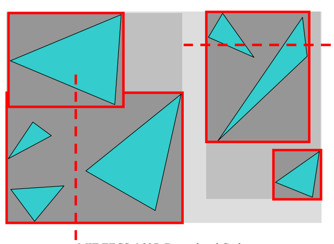
Bounding Volume Hierarchy

- Find bounding box of objects
- Split objects into two groups
- Recurse



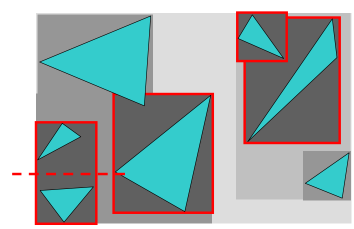
Bounding Volume Hierarchy

- Find bounding box of objects
- Split objects into two groups
- Recurse



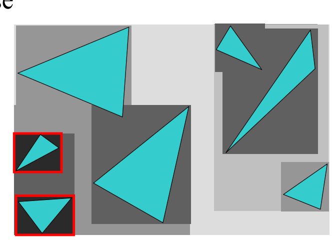
Bounding Volume Hierarchy

- Find bounding box of objects
- Split objects into two groups
- Recurse



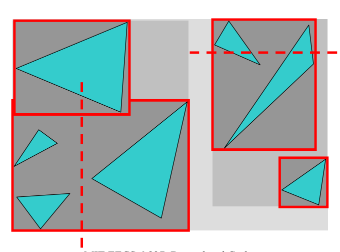
Bounding Volume Hierarchy

- Find bounding box of objects
- Split objects into two groups
- Recurse



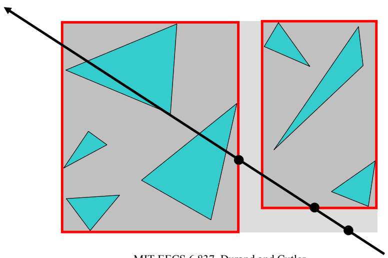
Where to split objects?

- At midpoint *OR*
- Sort, and put half of the objects on each side *OR*
- Use modeling hierarchy



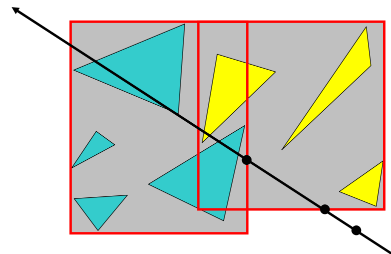
Intersection with BVH

- Check sub-volume with closer intersection first



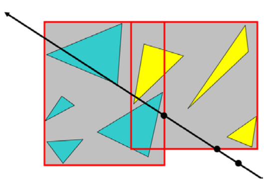
Intersection with BVH

- Don't return intersection immediately if the other subvolume may have a closer intersection



Bounding Volume Hierarchy Discussion

- Advantages
  - easy to construct
  - easy to traverse
  - binary



- Disadvantages
  - may be difficult to choose a good split for a node
  - poor split may result in minimal spatial pruning

Questions?

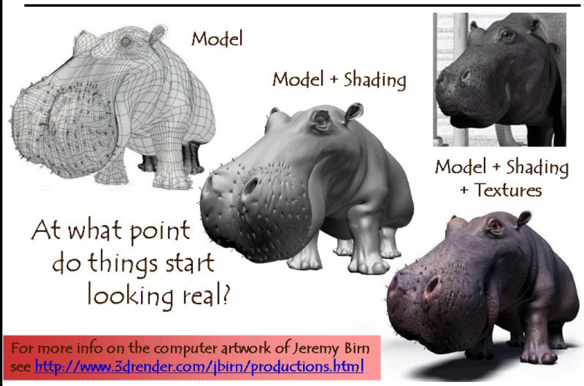
Today

- 2D Texture Mapping
  - Perspective Correct Interpolation
  - Specifying Texture Coordinates
  - Illumination & Reflectance
- Procedural Solid Textures
- Other Mapping Techniques
- Texture Aliasing

The Problem:

- We don't want to represent all this detail with geometry

The Quest for Visual Realism



Texture Mapping

- Increase the apparent complexity of simple geometry
- Like wallpapering or gift wrapping with stretchy paper
- Curved surfaces require extra stretching or even cutting

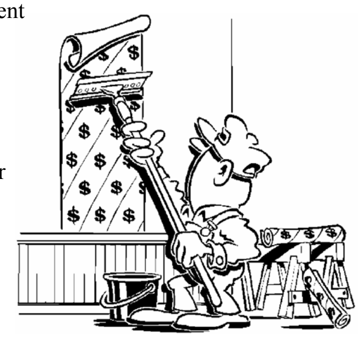
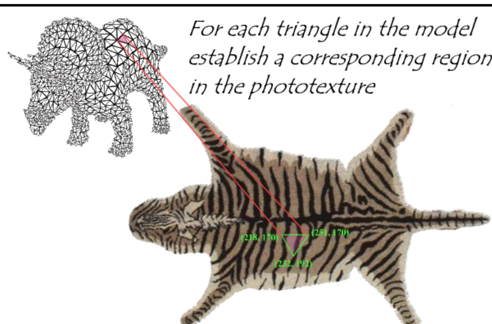


Photo-textures

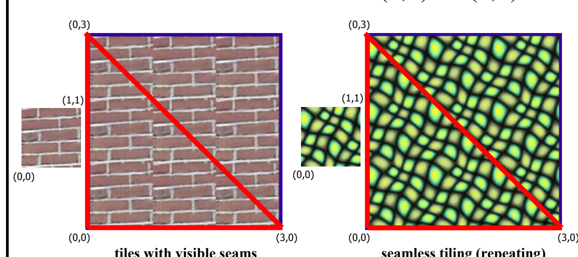
For each triangle in the model establish a corresponding region in the phototexture



During rasterization interpolate the coordinate indices into the texture map

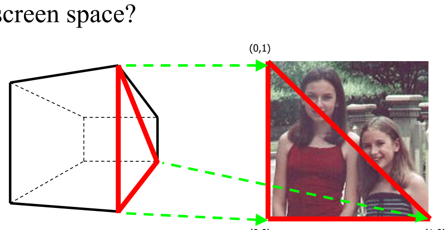
Texture Tiling

- Specify a texture coordinate (u,v) at each vertex
- Canonical texture coordinates (0,0) → (1,1)



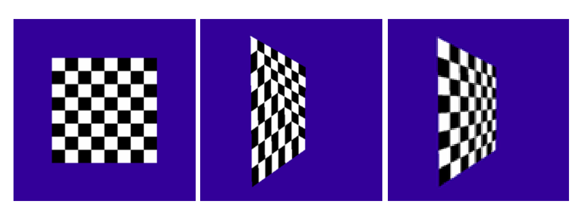
Texture Interpolation

- Specify a texture coordinate (u,v) at each vertex
- Can we just linearly interpolate the values in screen space?



Interpolation - What Goes Wrong?

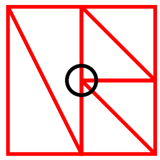
- Linear interpolation in screen space:



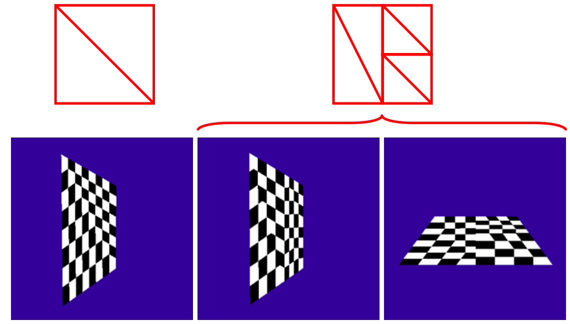
texture source — what we get — what we want

Specify More Coordinates?

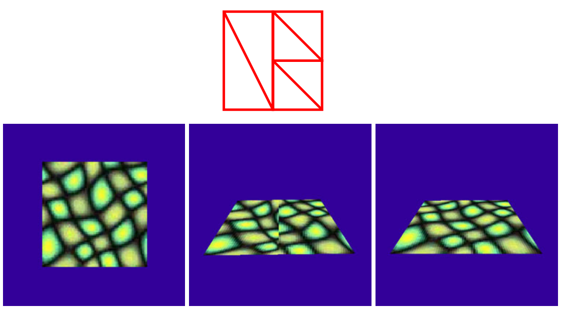
- We can reduce the perceived artifacts by subdividing the model into smaller triangles.
- However, sometimes the errors become obvious
  - At "T" joints
  - Between levels of detail (mipmapping... in a few weeks)



Subdivision

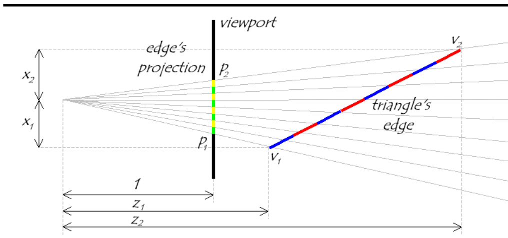


Subdivision



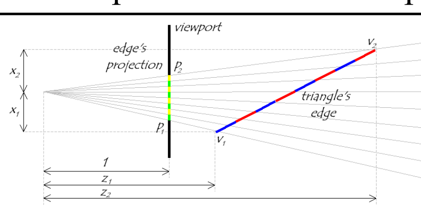
texture source | what we get | what we want

Visualizing the Problem



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

Linear Interpolation in Screen Space



linear interpolation in screen space

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

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:

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

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:

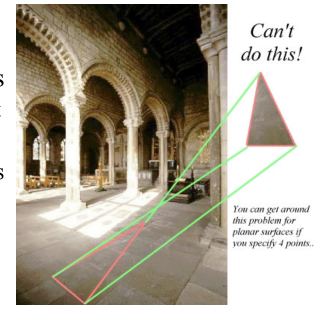
$$s = \frac{t\,\frac{1}{w_1}}{\frac{1}{w_2} + t\,\left(\frac{1}{w_1} - \frac{1}{w_2}\right)} = \frac{t\, w_2}{w_1 + t\,(w_2 - w_1)}$$

Today

- 2D Texture Mapping
  - Perspective Correct Interpolation
  - Specifying Texture Coordinates
  - Illumination & Reflectance
- Procedural Solid Textures
- Other Mapping Techniques
- Texture Aliasing

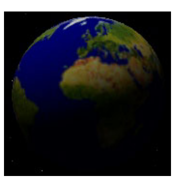
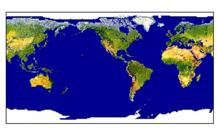
Texture Mapping Difficulties

- Tedious to specify texture coordinates
- Acquiring textures is surprisingly difficult
  - Photographs have projective distortions
  - Variations in reflectance and illumination
  - Tiling problems



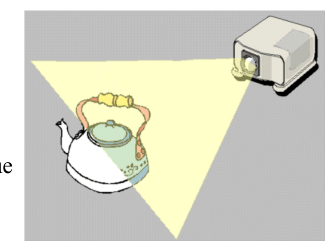
Common Texture Coordinate Mappings

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

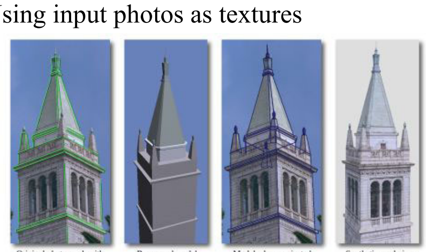
Projective Textures

- Use the texture like 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 photographs
- Using input photos as textures



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

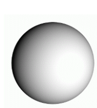
Figure from Debevec, Taylor & Malik
http://www.debevec.org/Research

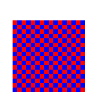
Texture Mapping & Illumination

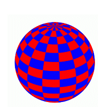
- Texture mapping can be used to alter some or all of the constants in the illumination equation:
  - pixel color, diffuse color, alter the normal, ….

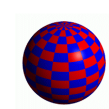
$$I_{total} = k_a I_{ambient} + \sum_{i=1}^{lights} I_i \left(k_d \left(\hat{N} \cdot \hat{L} \right) + k_s \left(\hat{V} \cdot \hat{R} \right)^{n_{shiny}} \right)$$

Phong's Illumination Model


Constant Diffuse Color

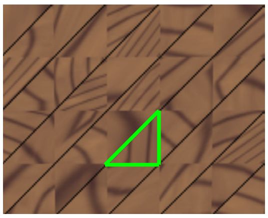

Diffuse Texture Color

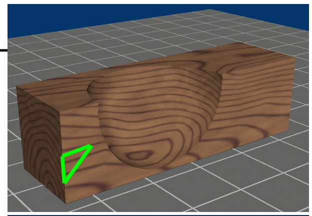

Texture used as Label

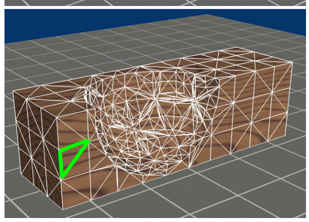

Texture used as Diffuse Color

Texture Chart

- Pack triangles into a single image







Questions?

Today

- 2D Texture Mapping
- Procedural Solid Textures
- Other Mapping Techniques
- Texture Aliasing

Procedural Textures

$f(x,y,z) \rightarrow$ color

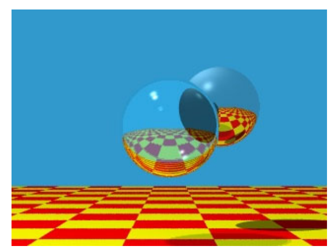
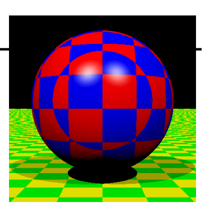


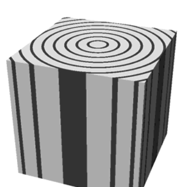
Image by Turner Whitted

Procedural Textures

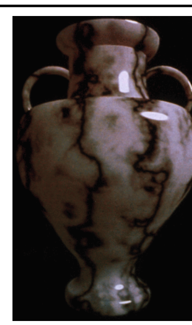
- Advantages:
  - easy to implement in ray tracer
  - more compact than texture maps (especially for solid textures)
  - infinite resolution



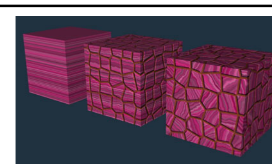
- Disadvantages
  - non-intuitive
  - difficult to match existing texture



Questions?



Ken Perlin



Justin Legakis

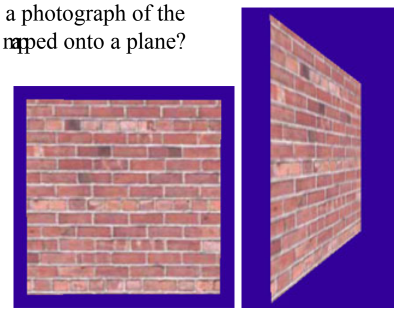
Justin Legakis

Today

- 2D Texture Mapping
- Procedural Solid Textures
- Other Mapping Techniques:
  - Bump Mapping
  - Displacement Mapping
  - Environment Mapping (for Reflections)
  - Light Maps (for Illumination)
- Texture Aliasing

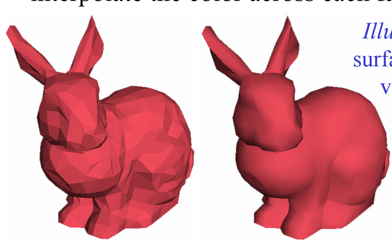
What's Missing?

- 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 Gouraud Shading?

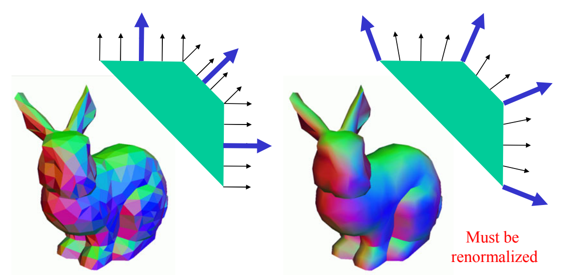
- Instead of shading with the normal of the triangle, shade the vertices with the *average normal* and interpolate the color across each face



Illusion of a smooth surface with smoothly varying normals

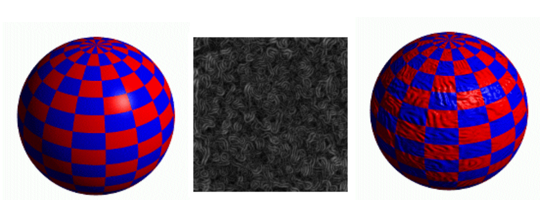
Phong Normal Interpolation (Not Phong *Shading*)

- Interpolate the average vertex normals across the face and compute *per-pixel shading*



Bump Mapping

- Use textures to alter the surface normal
  - Does not change the actual shape of the surface
  - Just shaded as if it were a different shape

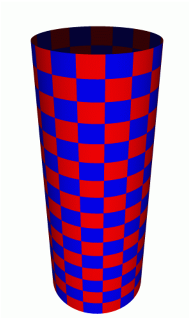


Sphere w/Diffuse Texture — Swirly Bump Map — Sphere w/Diffuse Texture & Bump Map

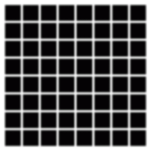
Bump Mapping

- Treat the texture as a single-valued height function
- Compute the normal from the partial derivatives in the texture

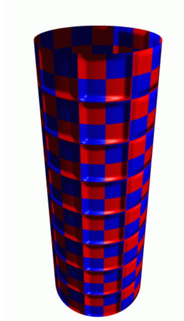
Another Bump Map Example



Cylinder w/Diffuse Texture Map



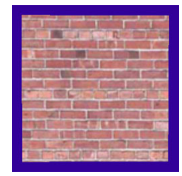
Bump Map

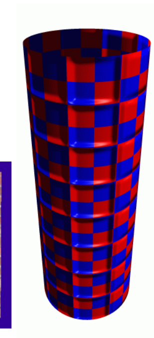


Cylinder w/Texture Map & Bump Map

What's Missing?

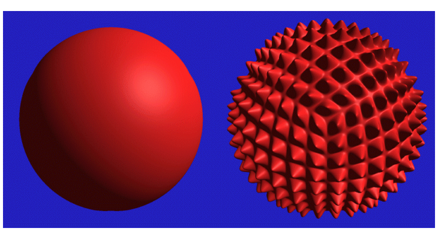
- There are no bumps on the silhouette of a bump-mapped object
- Bump maps don't allow self-occlusion or self-shadowing





Displacement Mapping

- Use the texture map to actually move the surface point
- The geometry must be displaced before visibility is determined



Displacement Mapping

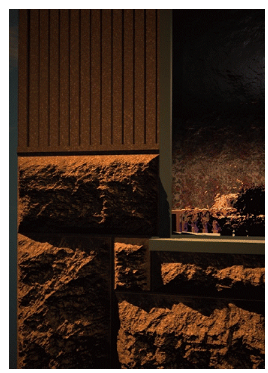


Image from:

Geometry Caching for Ray-Tracing Displacement Maps

by Matt Pharr and Pat Hanrahan.

note the detailed shadows cast by the stones

Displacement Mapping

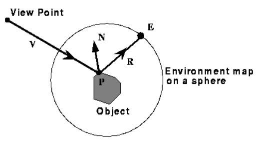
Ken Musgrave

Today

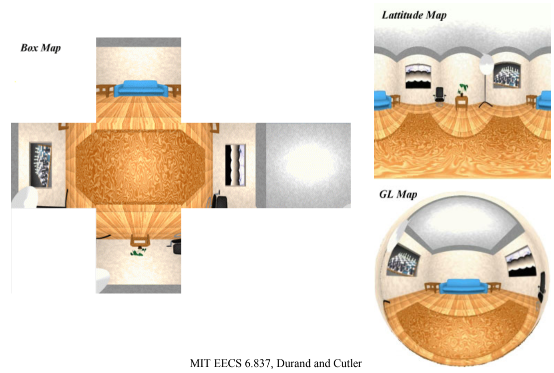
- 2D Texture Mapping
- Procedural Solid Textures
- Other Mapping Techniques:
  - Projective Shadows and Shadow Maps
  - Bump Mapping
  - Displacement Mapping
  - Environment Mapping (for Reflections)
  - Light Maps (for Illumination)
- Texture Aliasing

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?

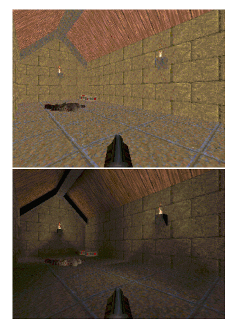


Environment Mapping Example

Terminator II

Texture Maps for Illumination

- Also called "Light Maps"



Quake

Questions?

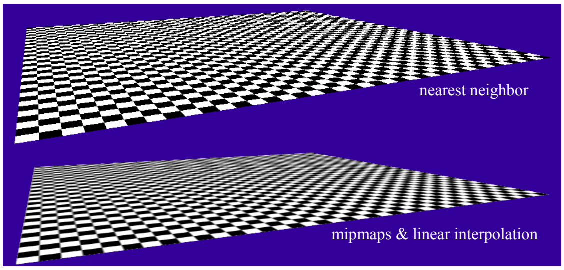
Image by Henrik Wann Jensen
Environment map by Paul Debevec

Today

- 2D Texture Mapping
- Procedural Solid Textures
- Other Mapping Techniques:
- Texture Aliasing

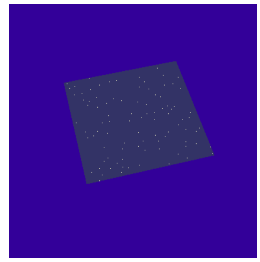
Textures can Alias

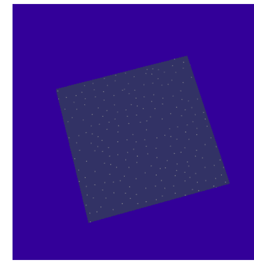
- *Aliasing* is the under-sampling of a signal, and it's especially noticeable during animation



Textures can Alias

- Small details may "pop" in and out of view


nearest neighbor


mipmaps & linear interpolation

Next Time:

Real-Time
Shadows