CSE328 Fundamentals of Computer Graphics: Concepts, Theory, Algorithms, and Applications

Hong Qin
Department of Computer Science
Stony Brook University (SUNY at Stony Brook)
Stony Brook, New York 11794-4400
Tel: (631)632-8450; Fax: (631)632-8334
qin@cs.sunysb.edu
http://www.cs.sunysb.edu/~qin

Texture Mapping for Computer Graphics

The Limitations of Geometric Modeling

- Although graphics cards can render over 10 million polygons per second, that number is insufficient for many phenomena
  - Clouds
  - Grass
  - Terrain
  - Skin

The Problem with Geometric Models

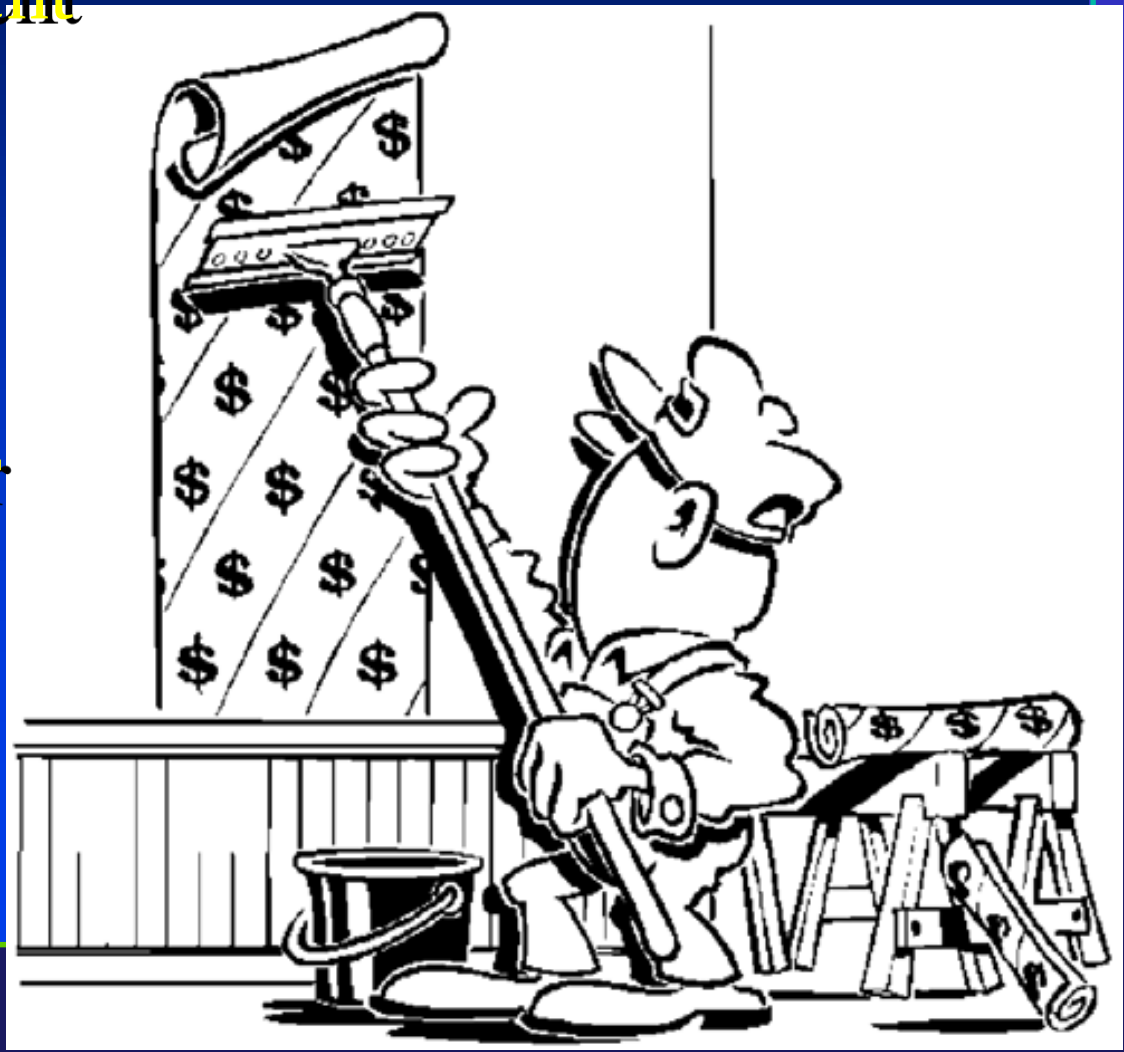
- We do not want to represent all of these details with geometry ONLY!!!

Objectives and Topics

- Introduction of mapping methods
  - Texture mapping
  - Environment mapping
  - Bump mapping
- Consider basic strategies
  - Forward vs. backward mapping
  - Point sampling vs. area averaging

Texture Mapping: Basic Concept

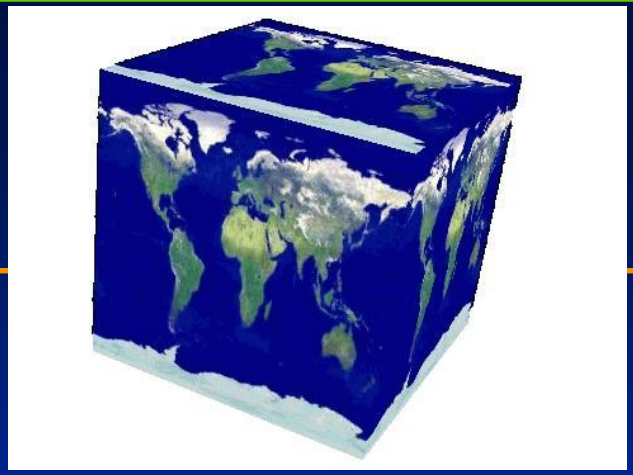
- Increase the apparent complexity of simple geometry
- Like wallpapering or gift-wrapping with stretchy paper
- Curved surfaces require extra stretching or even cutting



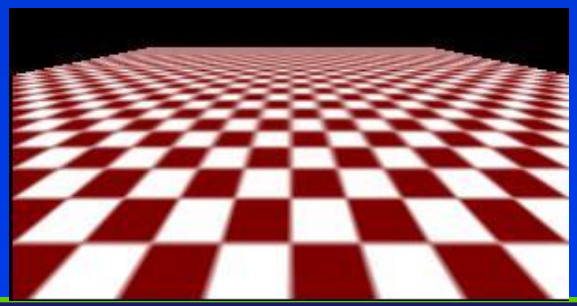
Modeling an Orange (A Classical Example)

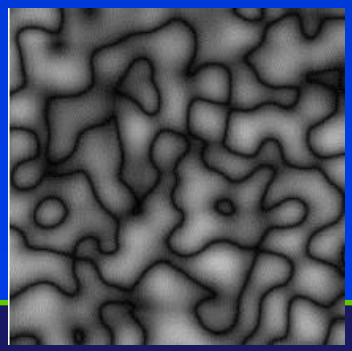
- Consider the problem of modeling an orange (the fruit)
- Start with an orange-colored sphere
  - Too simple
- Replace sphere with a more complex shape
  - Does not capture surface characteristics (small dimples)
  - Takes too many polygons to model all the dimples

Texture Mapping



- A clever way of adding surface details
- Two ways can achieve the goal:
  - ❖Surface detail polygons: create more and more polygons to model object details
    - ❖Add scene complexity and thus slow down the graphics rendering performance
    - ❖Some fine features are hard to model!
  - ✓Map a texture to the surface (a more popular approach)



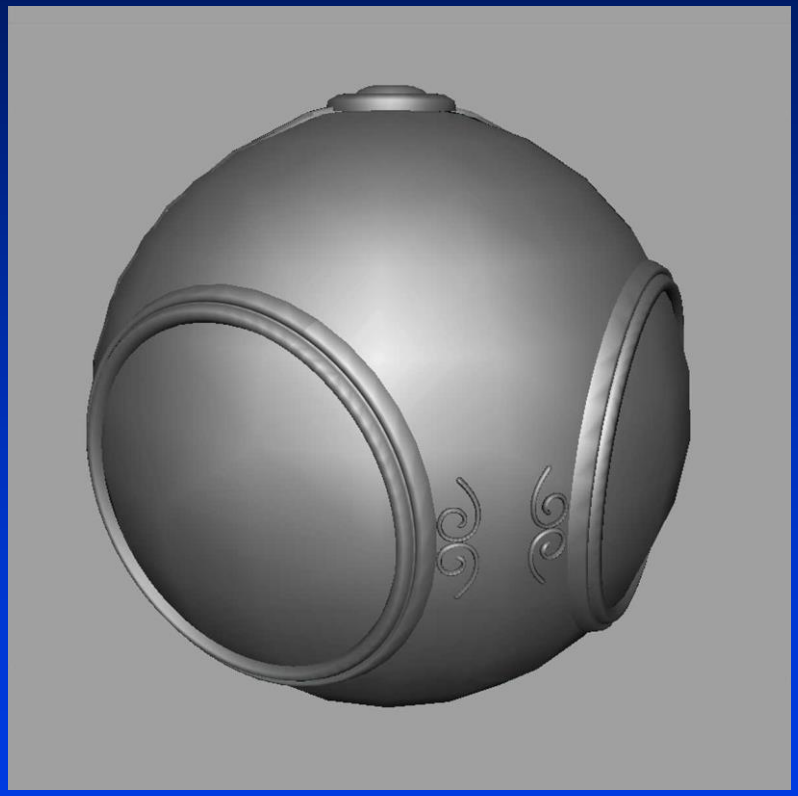


Complexity of images does
Not affect the complexity
Of geometry processing
(transformation, clipping…)

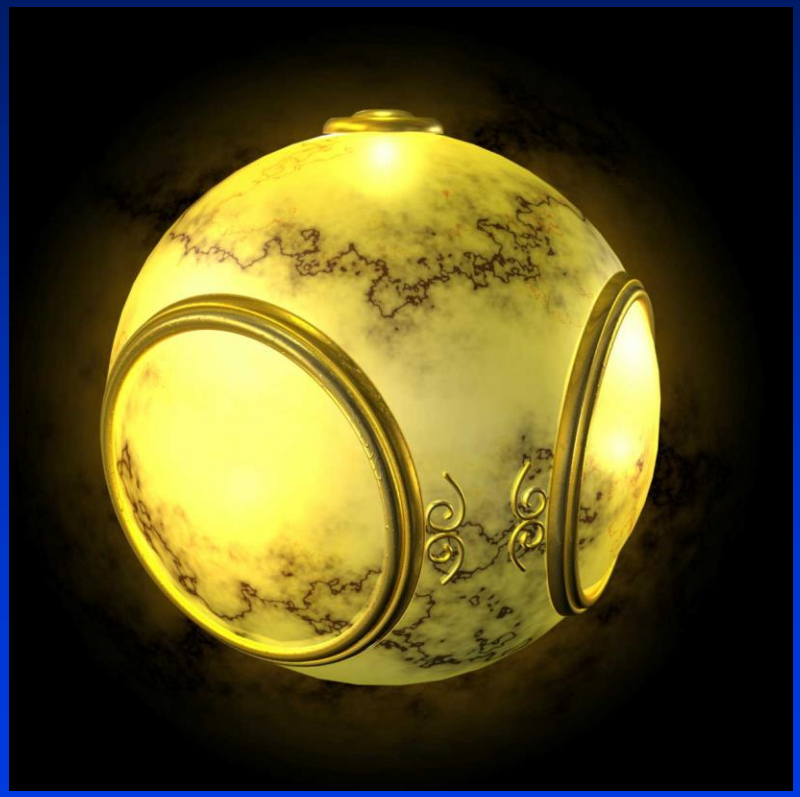
Modeling an Orange

- Take a picture of a real orange, scan it, and "paste" onto simple geometric model
  - This process is known as texture mapping
- Still might not be sufficient because resulting surface will be smooth
  - Need to change local shape
  - Bump mapping

Texture Mapping



geometric model



Texture-mapped model

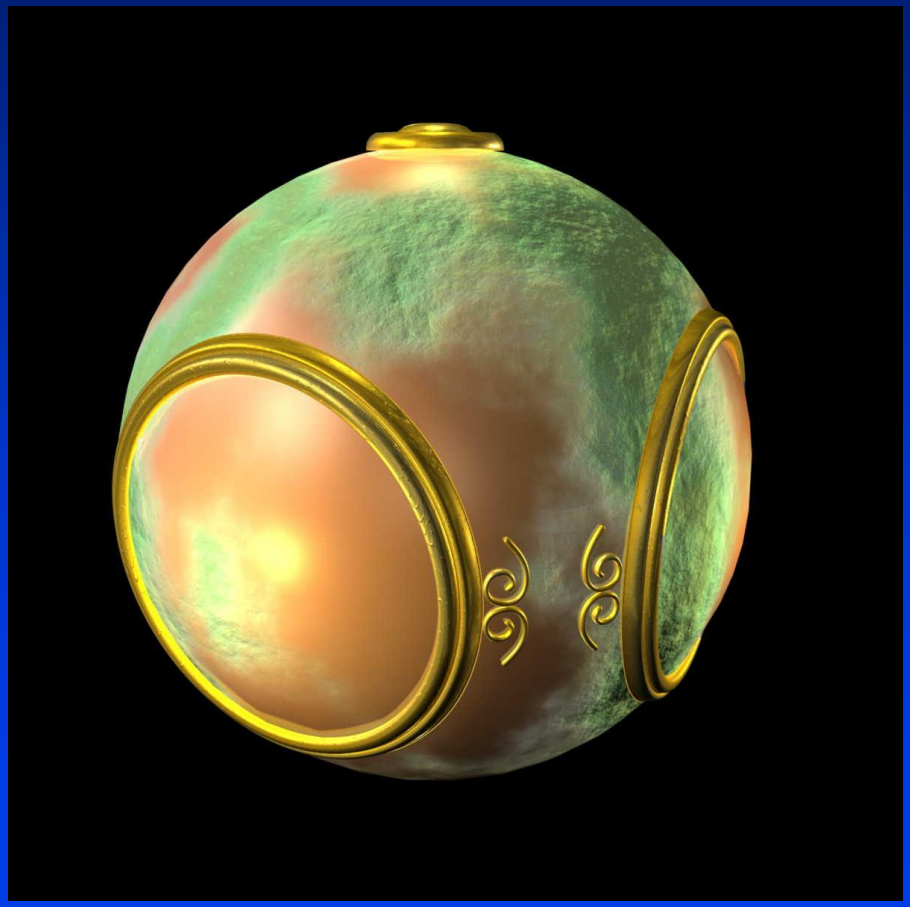
Three Types of Mapping

- Texture mapping
  - Uses images to fill inside of polygons
- Environment (reflection mapping)
  - Uses a picture of the environment for texture maps
  - Allows simulation of highly specular surfaces
- Bump mapping
  - Emulates altering normal vectors during the rendering process

Environment Mapping

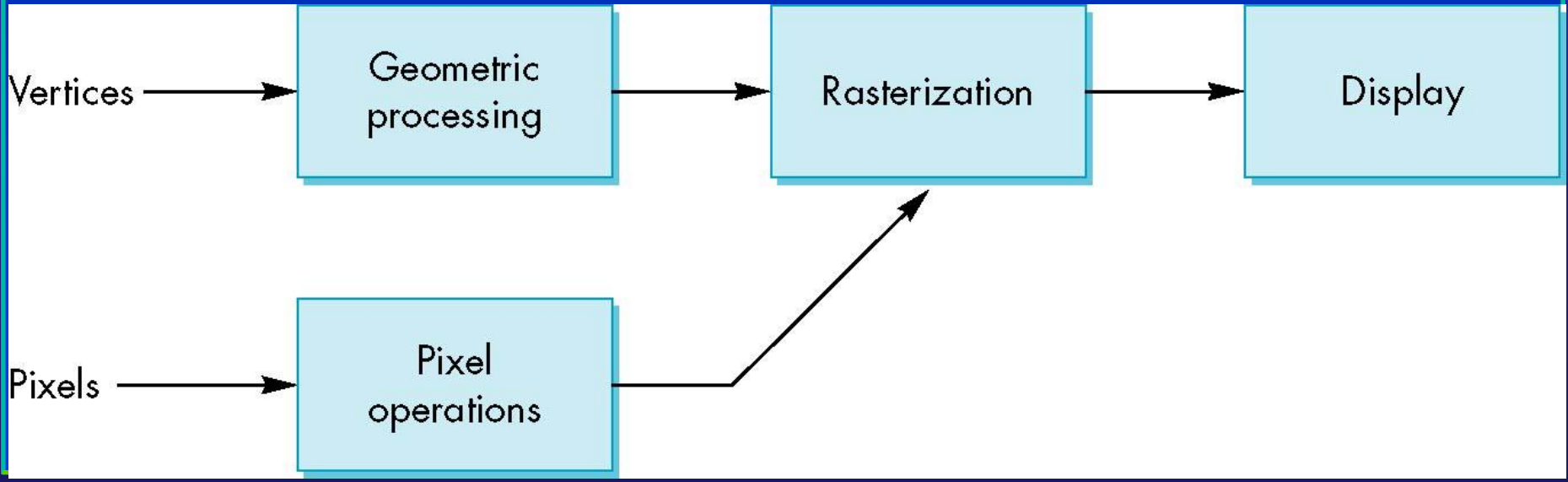
Environment Mapping Example

Bump Mapping



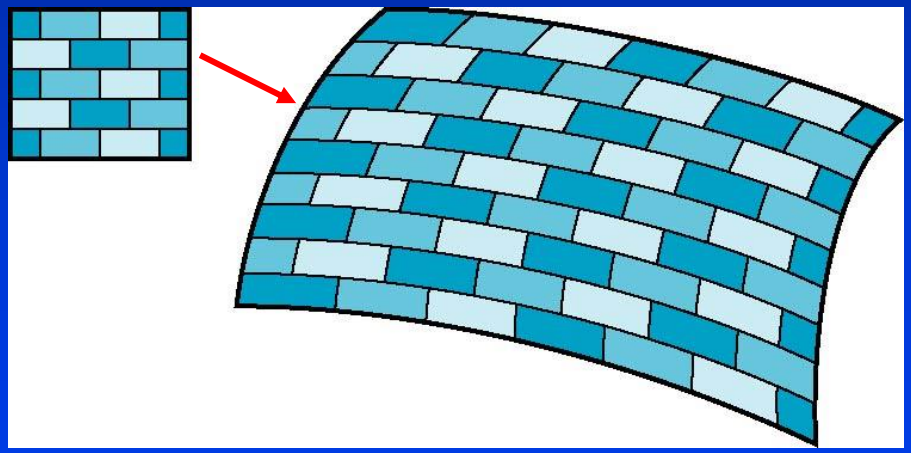
Where Does Mapping Take Place?

- Mapping techniques are implemented at the end of the rendering pipeline
  - Very efficient because few polygons make it past the clipper



Is It Really Simple?

- Although the idea is simple - map an image to a surface - there are 3 or 4 coordinate systems involved



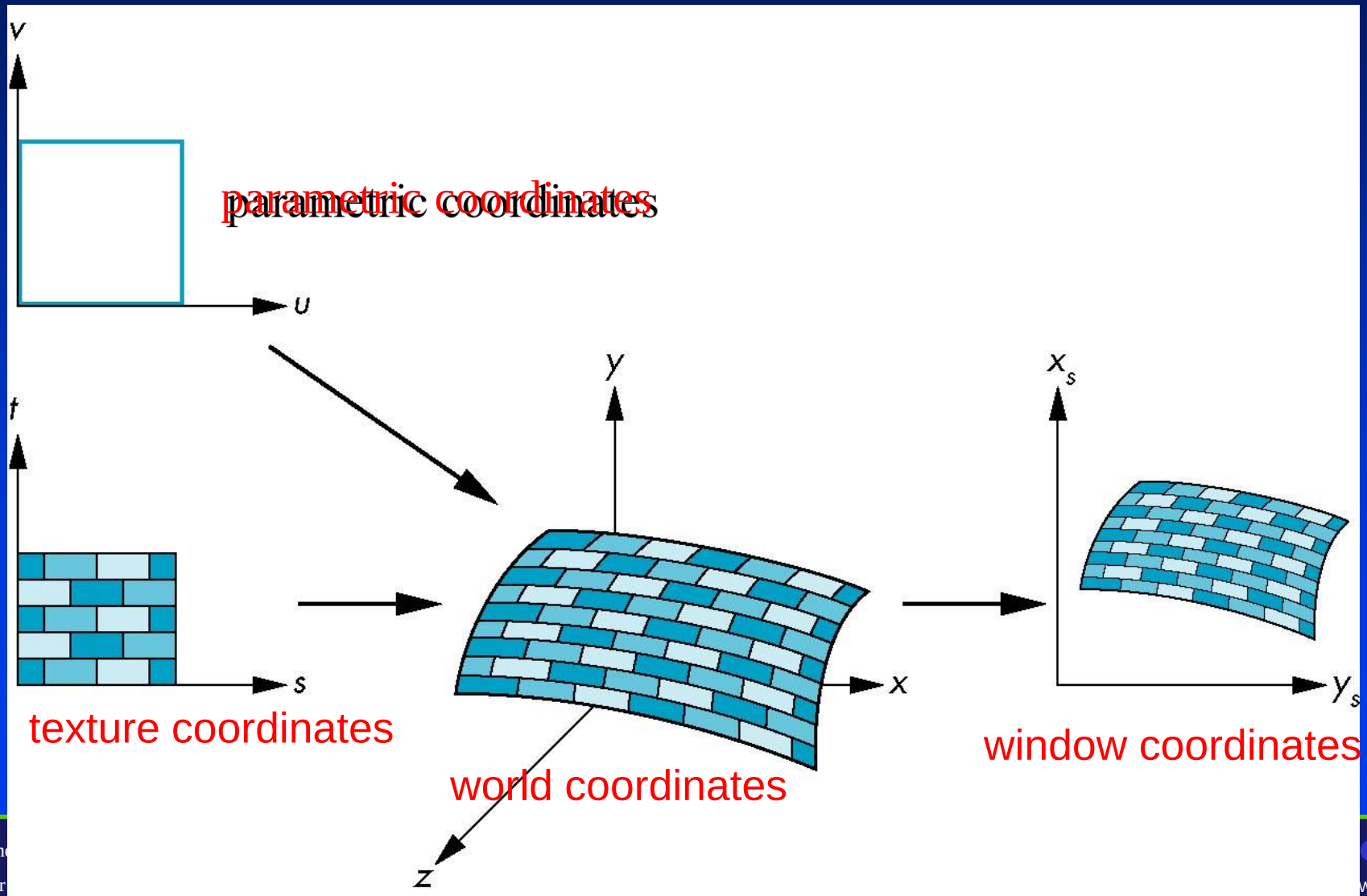
2D image

3D surface

Coordinate Systems

- Parametric coordinates
  - May be used to model curves and surfaces
- Texture coordinates
  - Used to identify points in the image to be mapped
- Object or World coordinates
  - Conceptually, where the mapping takes place
- Window coordinates
  - Where the final image is really produced

Texture Mapping

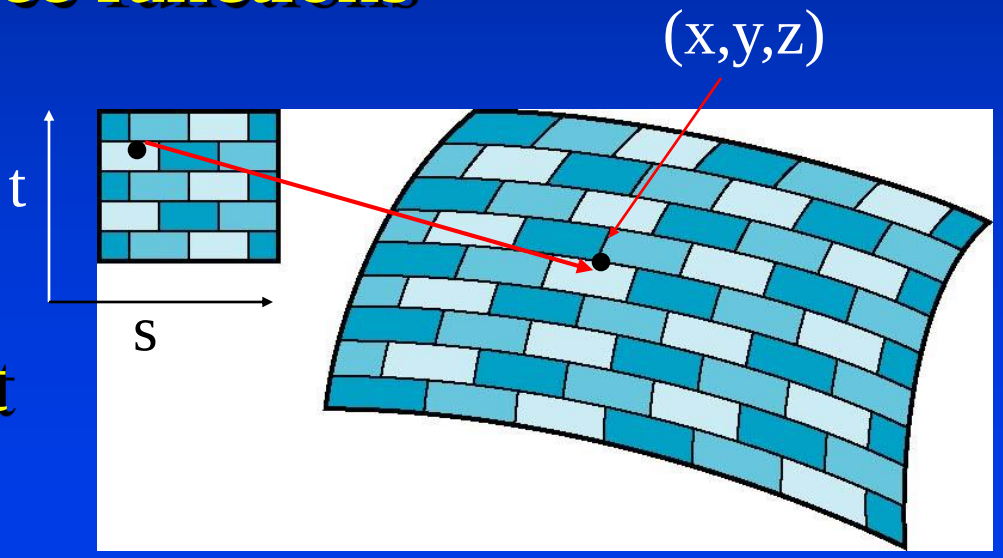


Mapping Functions

- Basic problem is how to find the maps
- Consider mapping from texture coordinates to a point of a surface
- Appear to need three functions

$$x = x(s,t)$$
$$y = y(s,t)$$
$$z = z(s,t)$$

- But we really want to go the other way



Backward Mapping

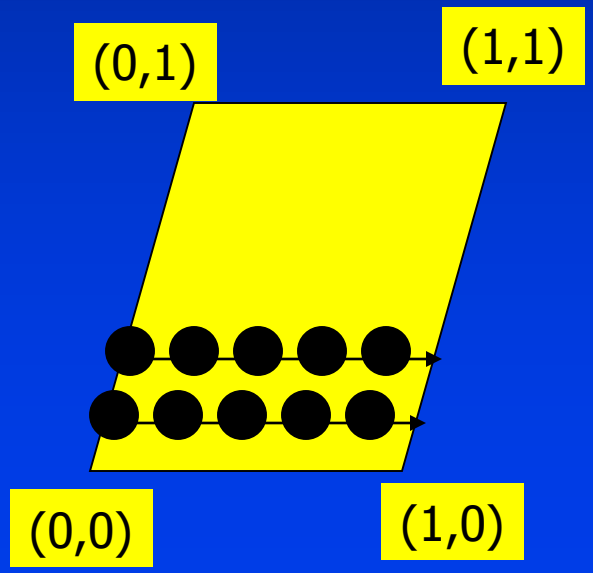
- We really want to go backwards
  - Given a pixel, we want to know to which point on an object it corresponds
  - Given a point on an object, we want to know to which point in the texture it corresponds
- Need a map of the form

  $s = s(x,y,z)$

  $t = t(x,y,z)$
- Such functions are difficult to find in general

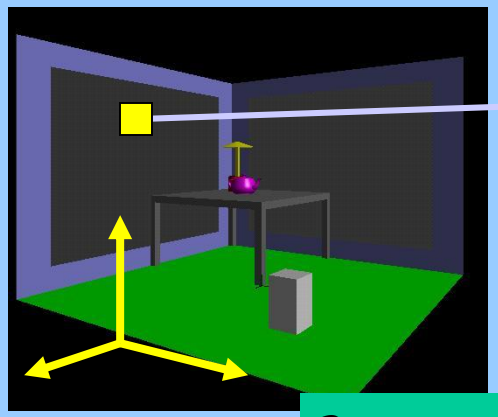
Map Textures to Surfaces

- Texture mapping is performed in rasterization (backward mapping)

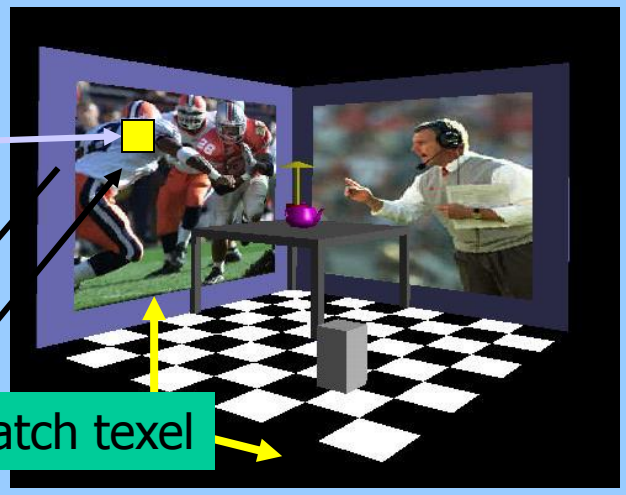


- For each pixel that is to be painted, its texture coordinates (s, t) are determined (interpolated) based on the corners' texture coordinates (why not just interpolate the color?)
- The interpolated texture coordinates are then used to perform texture lookup

Texture Mapping Pipeline



1. projection



3. patch texel

2. texture lookup

3D geometry

2D projection of 3D geometry

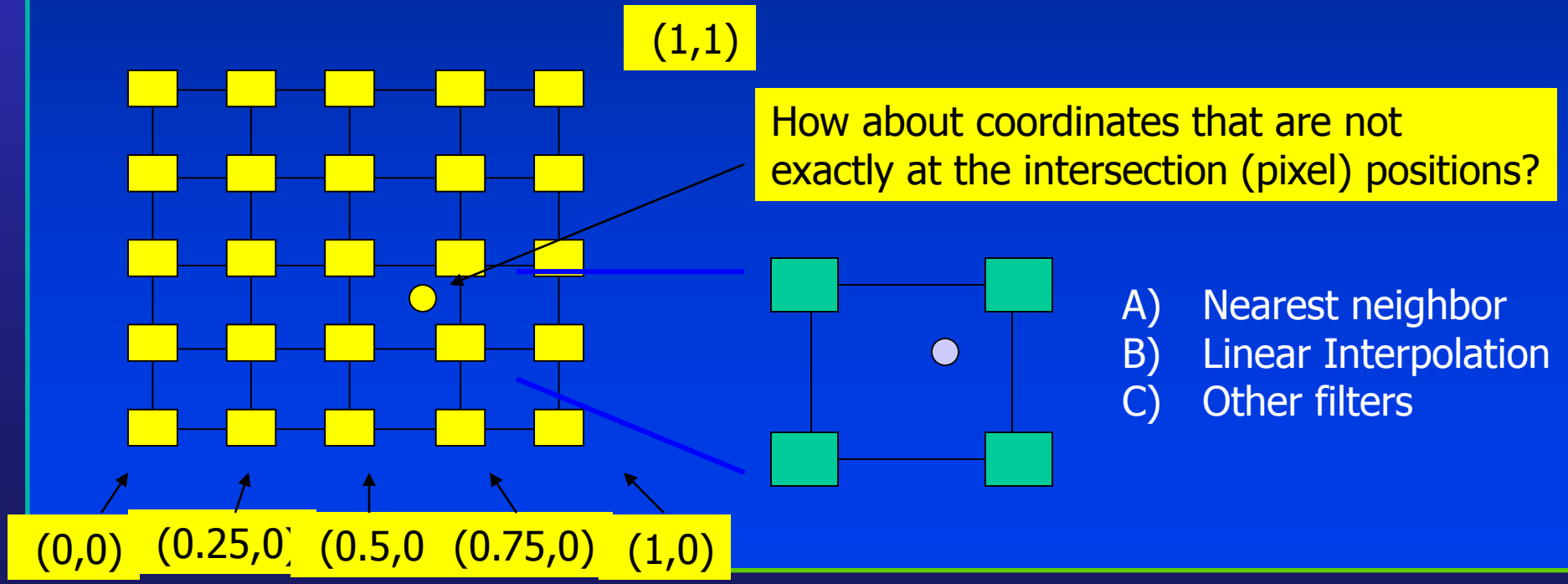
t

2D image

s

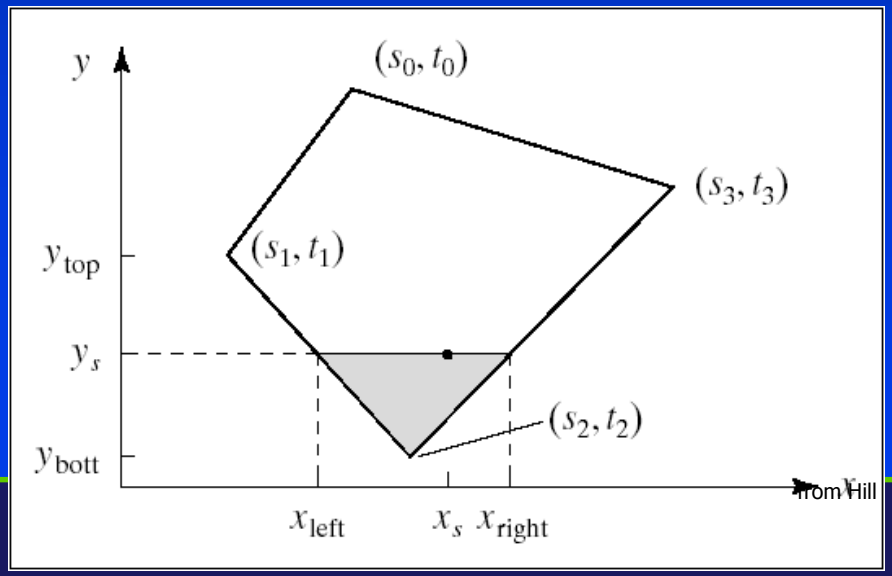
Texture Value Lookup

- For the given texture coordinates (s,t), we can find a unique image value from the texture map



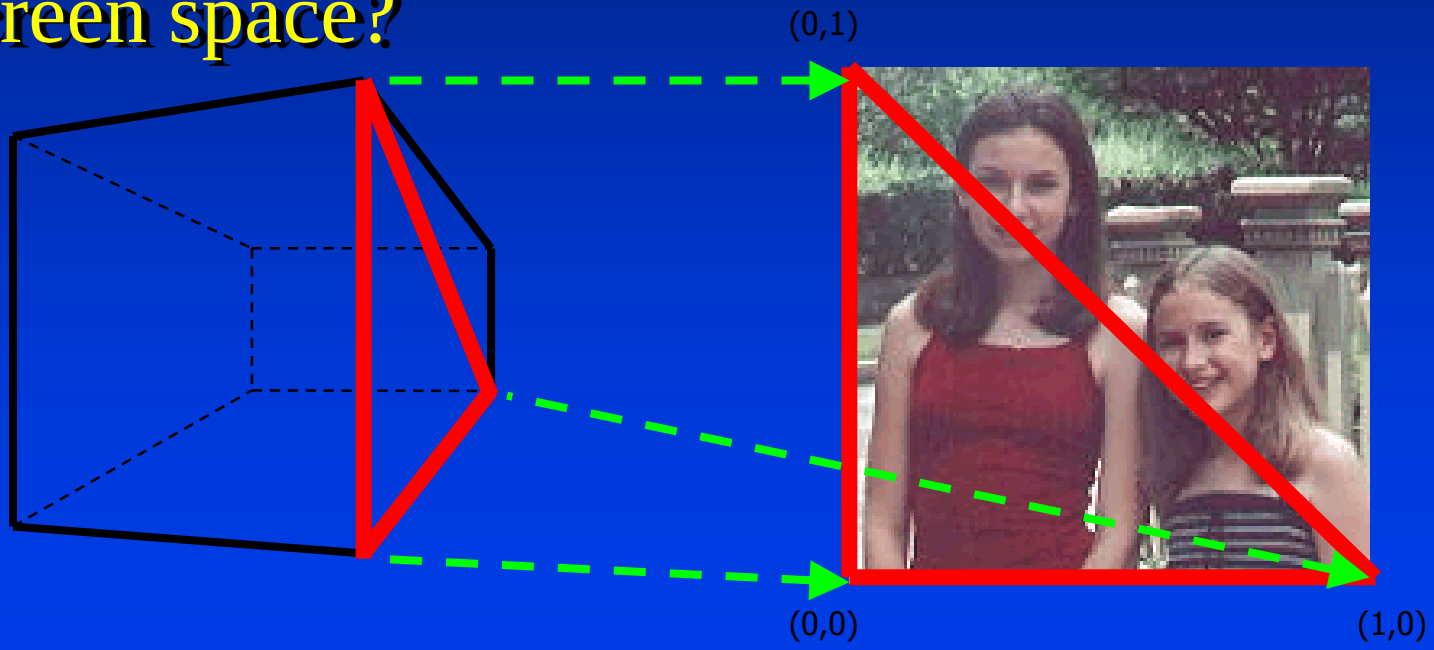
Texture Rasterization

- Texture coordinates are interpolated from polygon vertices just like … remember line drawing …
  - ➢ Color : Gouraud shading
  - ➢ Depth: Z-buffer
  - – First along polygon edges between vertices
  - – Then along scanlines between left and right sides



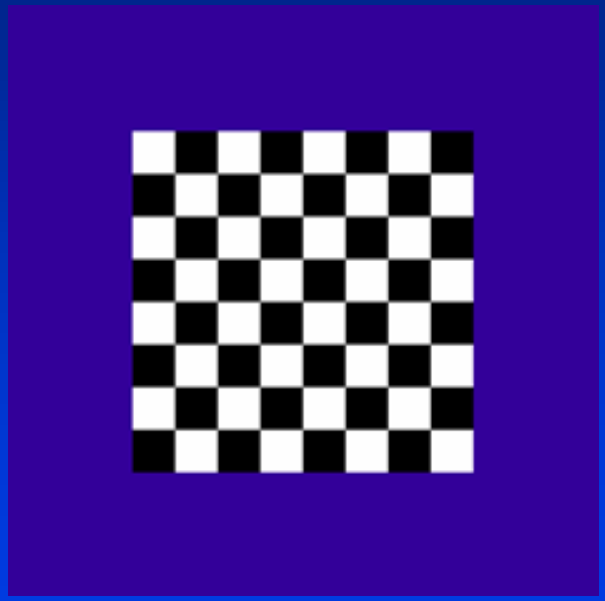
Texture Interpolation

- 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:**



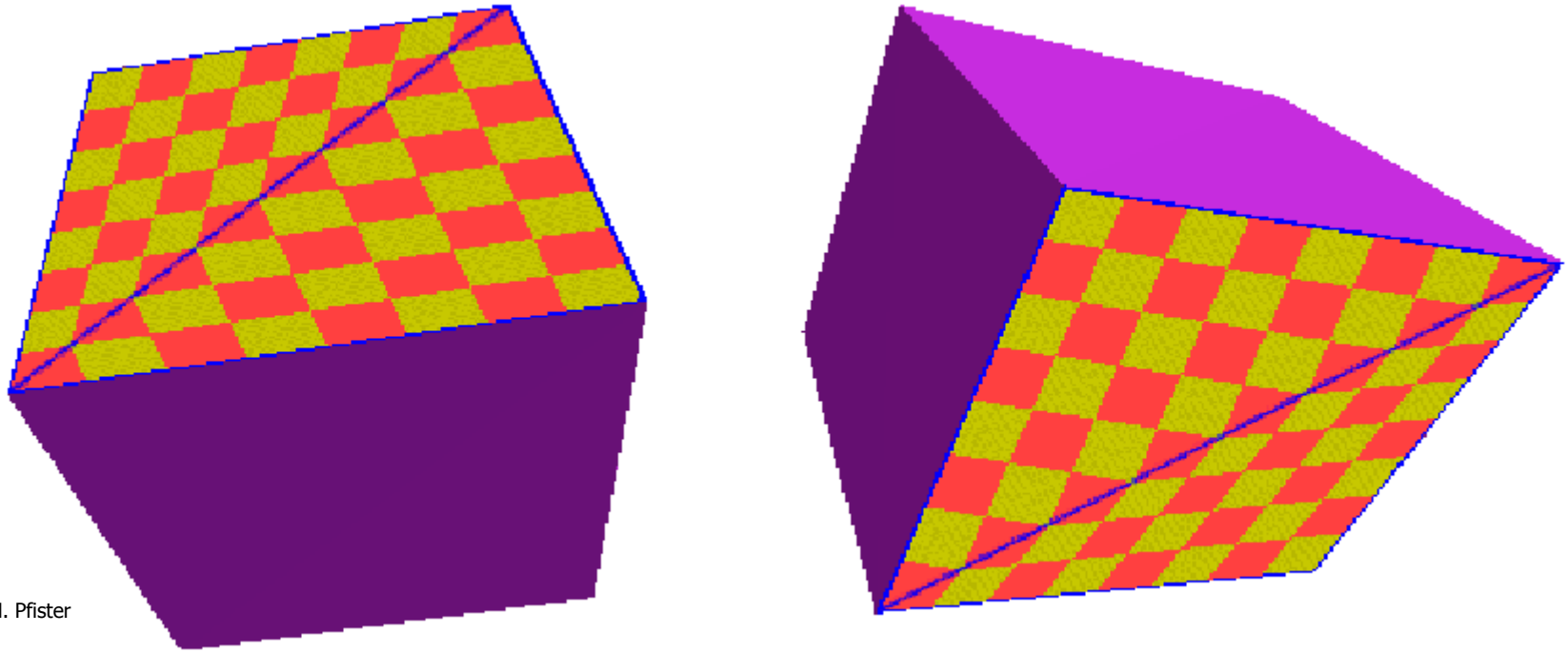
texture source image

what we get

what we want

Linear Texture Coordinate Interpolation

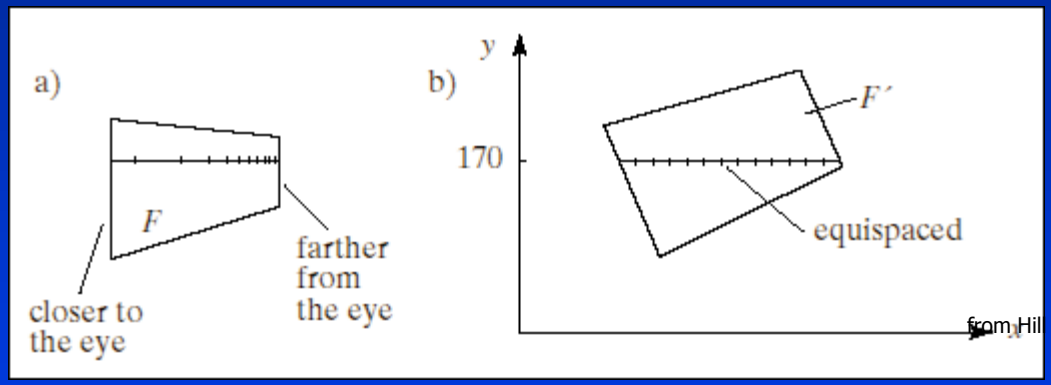
- This doesn't work in perspective projection!
- The textures look warped along the diagonal
- Noticeable during an animation

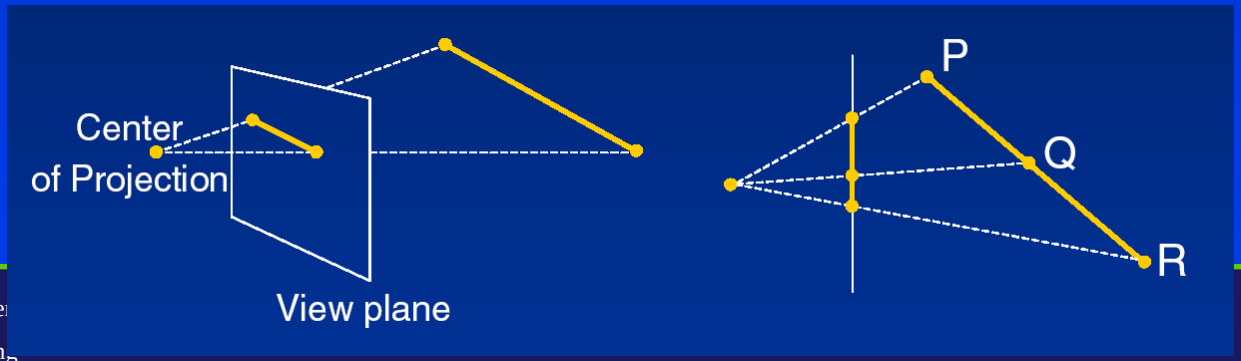


courtesy of H. Pfister

Why?

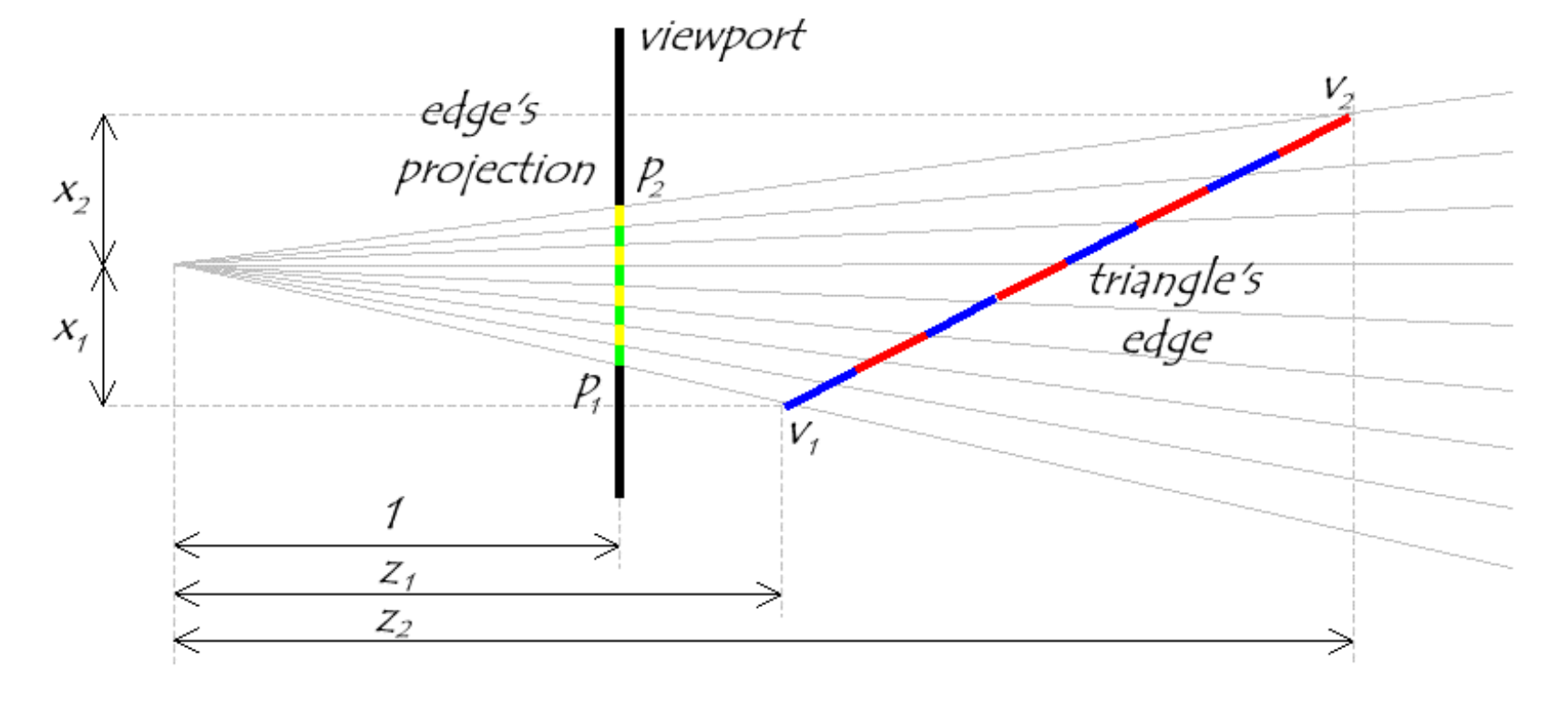
- Equal spacing in screen (pixel) space is **not** the same as in texture space in perspective projection
  - **Perspective foreshortening**





courtesy of H. Pfister

Visualizing the Problem



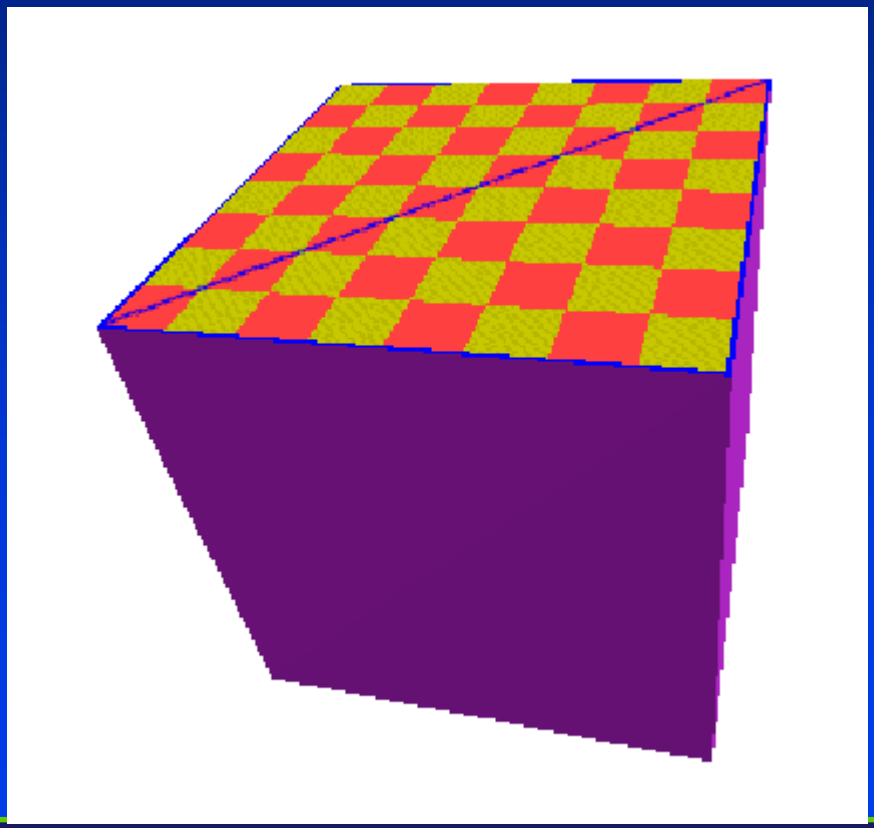
- Notice that uniform steps on the image plane do not correspond to uniform steps along the edge.

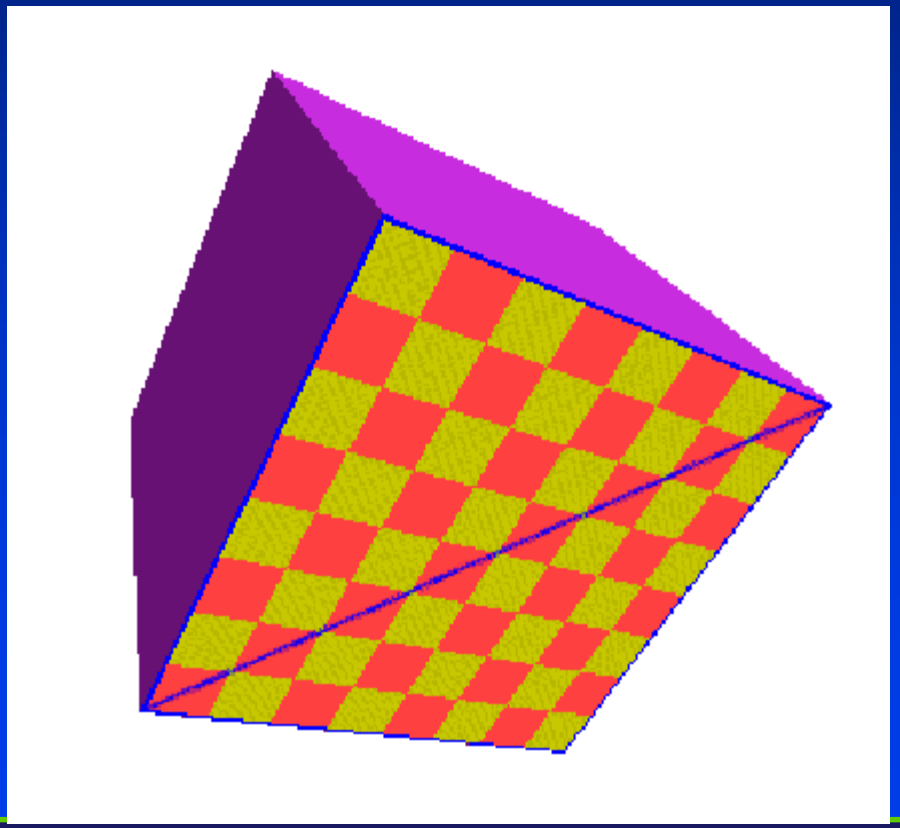
Perspective-Aware Texture Coordinate Interpolation

- Interpolate (tex_coord/*w*) over the polygon, then do perspective division after interpolation
- Compute at each vertex after perspective transformation
  - "Numerators" *s*/*w*, *t*/*w*
  - "Denominator" 1/*w*
- Linearly interpolate 1/*w*, *s*/*w*, and *t*/*w* across the polygon
- At each pixel
  - Perform perspective division of interpolated texture coordinates (*s*/*w*, *t*/*w*) by interpolated 1/*w* (i.e., numerator over denominator) to get (*s*, *t*)

Perspective-Correct Interpolation

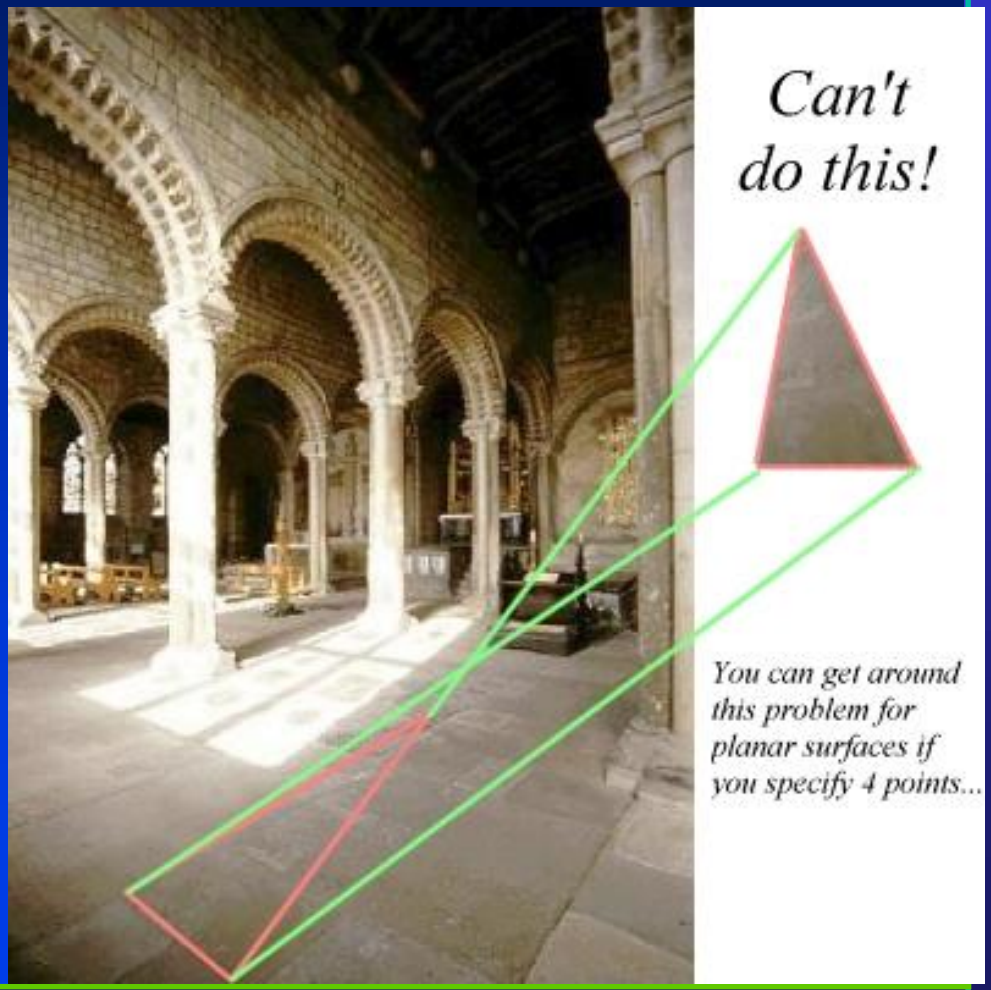
- That fixed it!





Texture Mapping Difficulties

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



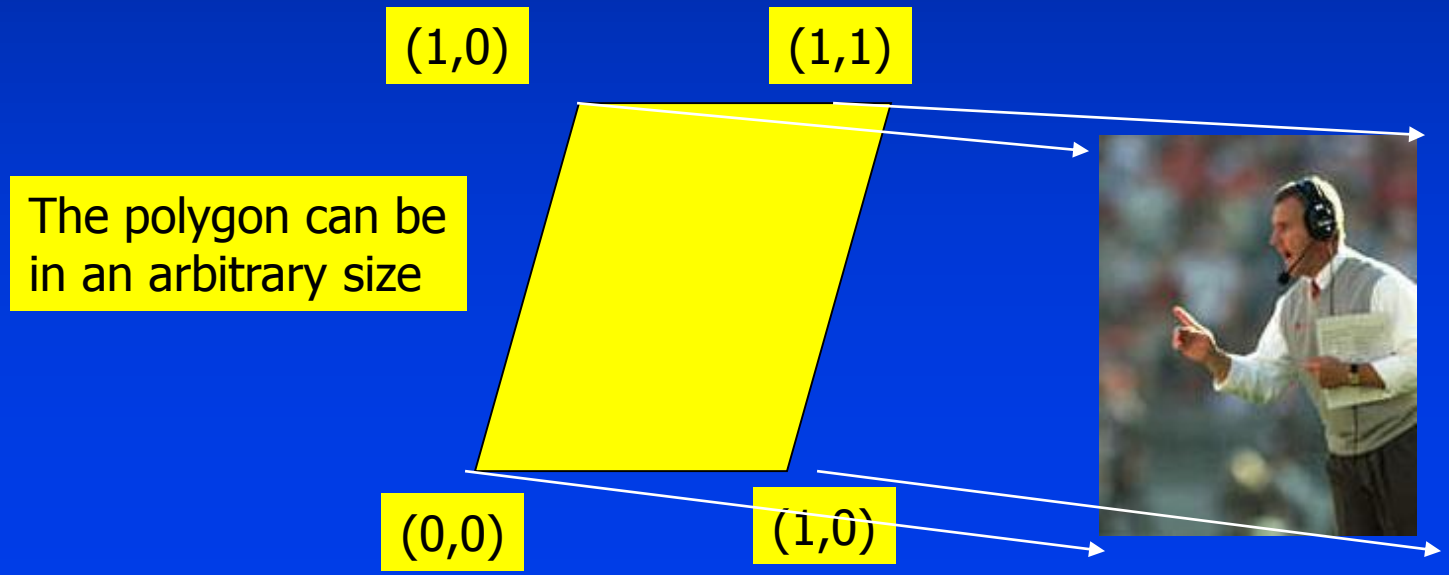
Common Texture Coordinate Mappings

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

Map Textures to Surfaces

- The key question: Establish mapping from texture to surfaces (polygons):

  - Application program needs to specify texture coordinates for each corner of the polygon

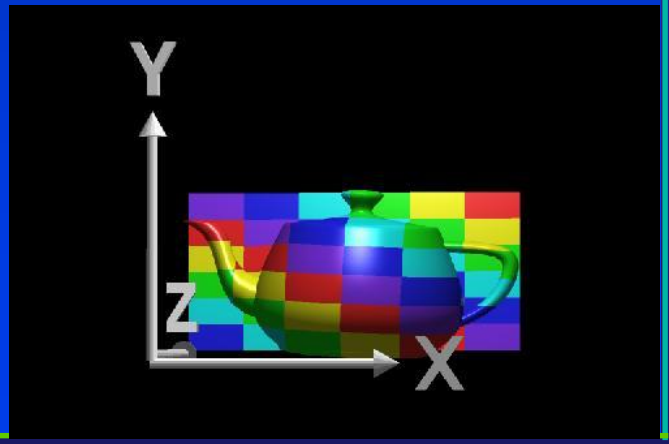


Projector Functions

- How do we map the texture onto a arbitrary (complex) object?
  - Construct a mapping between the 3-D point to an intermediate surface
- Idea: Project each object point to the intermediate surface with a parallel or perspective projection
  - The focal point is usually placed inside the object

  - Plane
  - Cylinder
  - Sphere
  - Cube

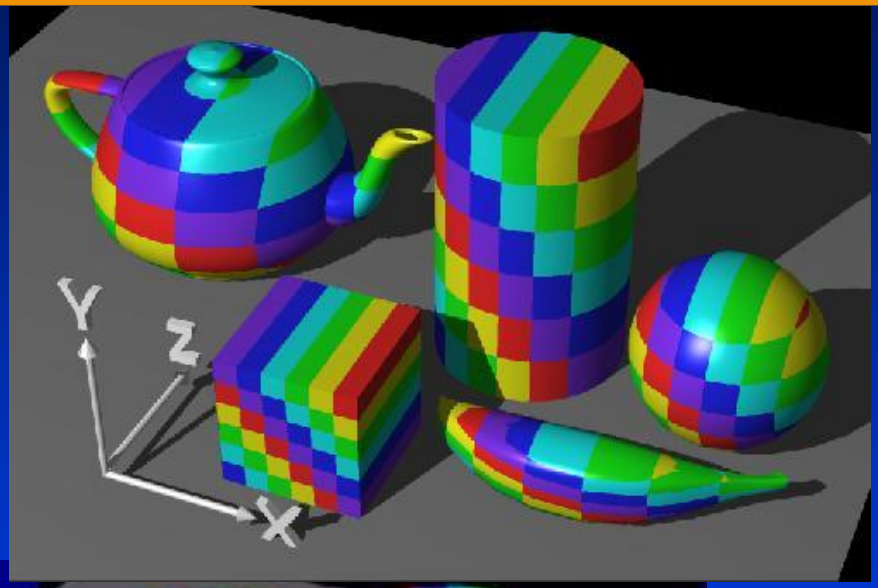
Planar projector



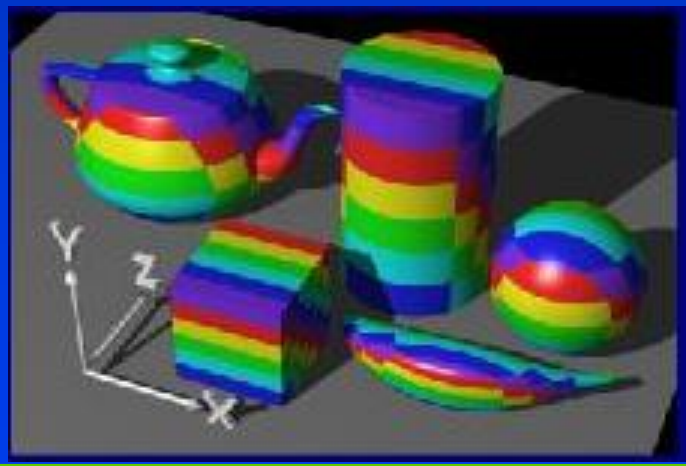
Planar Projector

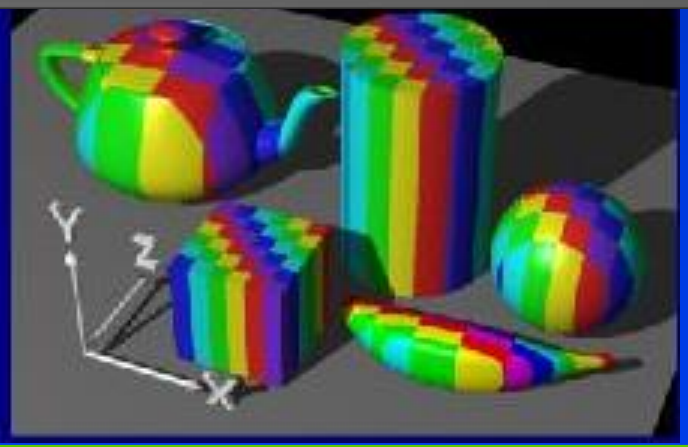
Orthographic projection onto XY plane:

$u = x, \quad v = y$



...onto YZ plane



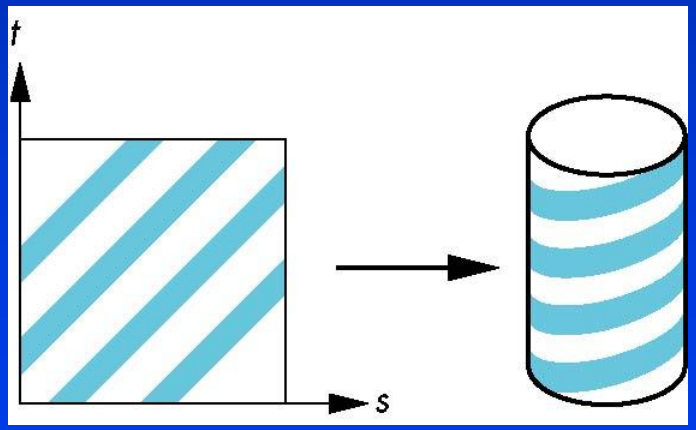


...onto XZ plane

courtesy of R. Wolfe

Two-part Mapping

- One solution to the mapping problem is to first map the texture to a simple intermediate surface
- Example: map to cylinder



Cylindrical Projector

- Convert rectangular coordinates (x, y, z) to cylindrical (r, μ, h), use only (h, μ) to index texture image

Cylindrical Mapping

parametric cylinder

$$x = r \cos 2\pi u$$
$$y = r \sin 2\pi u$$
$$z = v/h$$

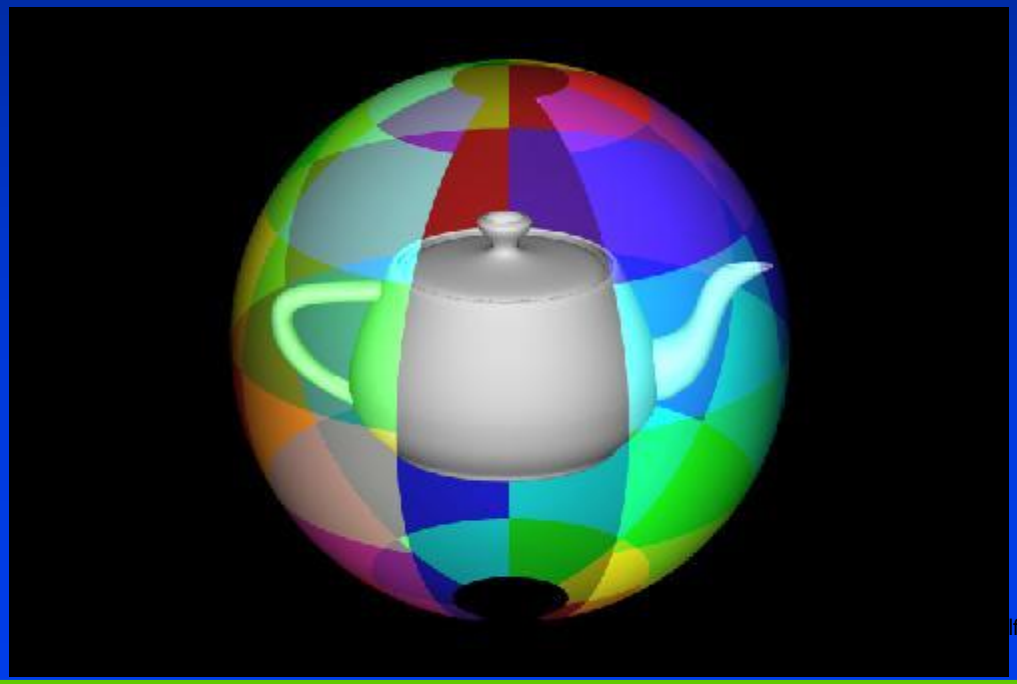
maps rectangle in u,v space to cylinder
of radius r and height h in world coordinates

$$s = u$$
$$t = v$$

maps from texture space

Spherical Projector

- Convert rectangular coordinates (x, y, z) to spherical (θ, ϕ)



Spherical Map

We can use a parametric sphere

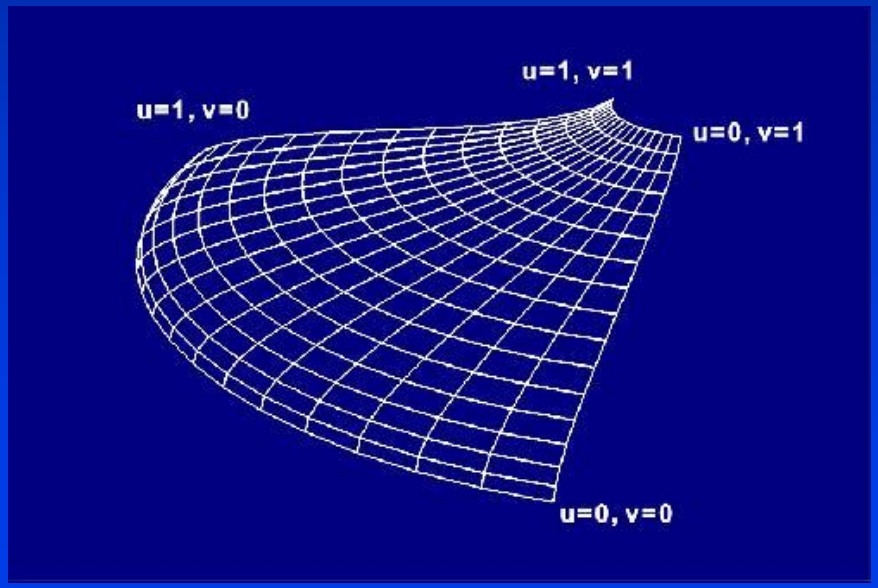
$$x = r \cos 2\pi u$$
$$y = r \sin 2\pi u \cos 2\pi v$$
$$z = r \sin 2\pi u \sin 2\pi v$$

in a similar manner to the cylinder
but have to decide where to put
the distortion

Spheres are used in environmental maps

Parametric Surfaces

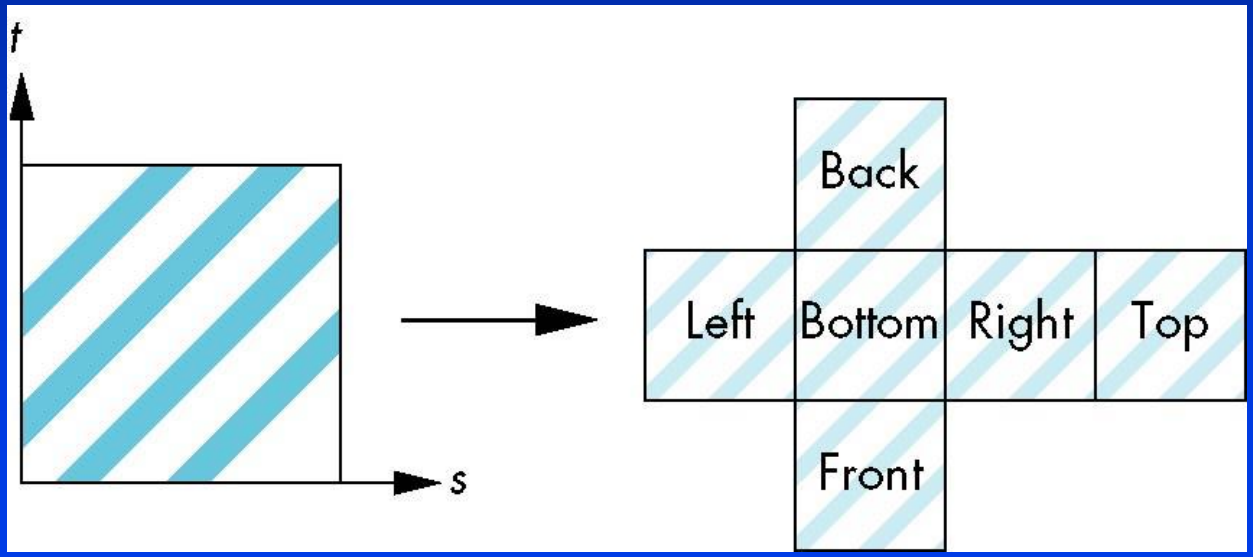
- A parameterized surface patch
  - $x = f(u, v), y = g(u, v), z = h(u, v)$
  - You will get the mapping via parameterization



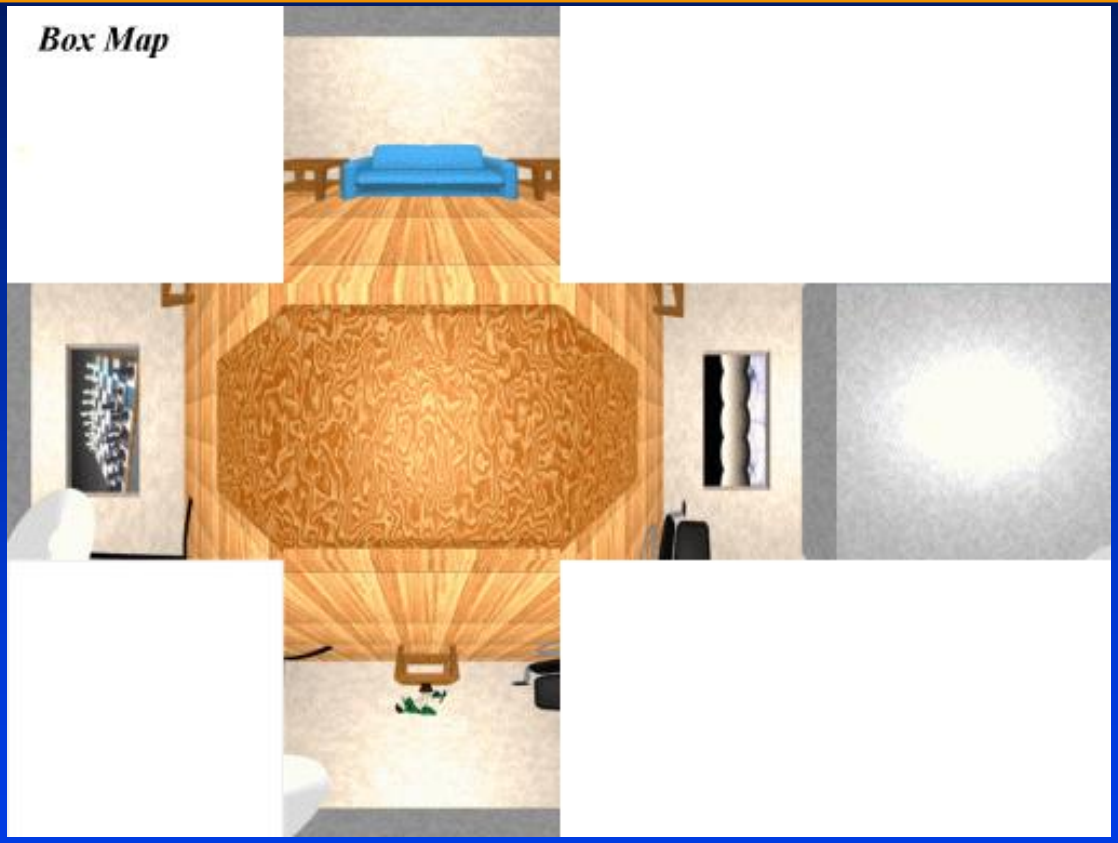
courtesy of R. Wolfe

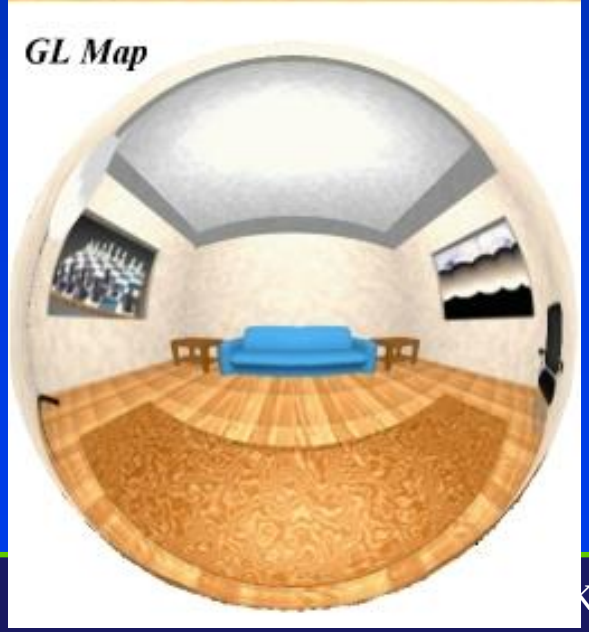
Box Mapping

- Easy to use with simple orthographic projection
- Also used in environment maps



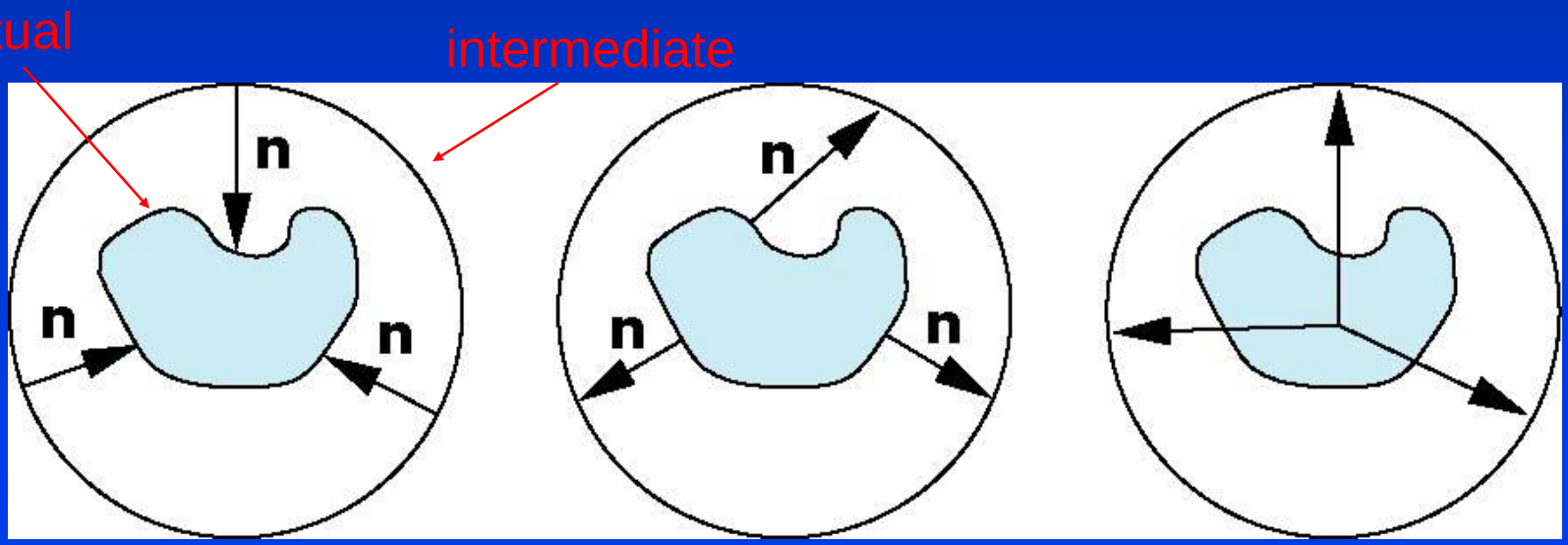
What's the Best Chart?





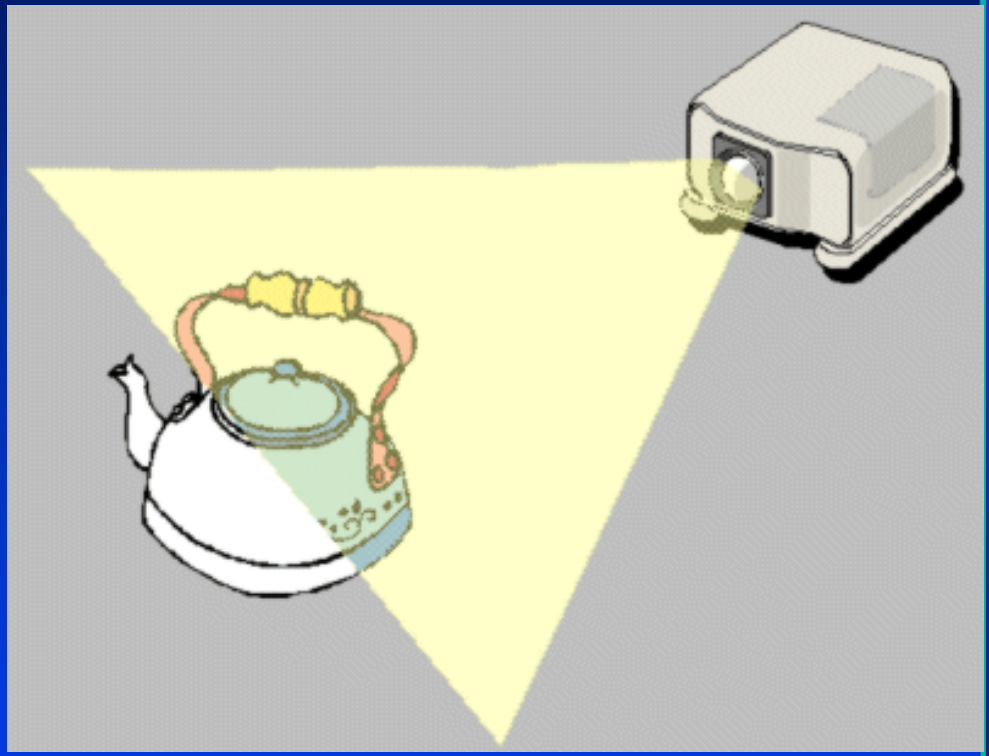
Second Mapping

- Map from intermediate object to actual object
  - Normals from intermediate to actual
  - Normals from actual to intermediate
  - Vectors from center of intermediate



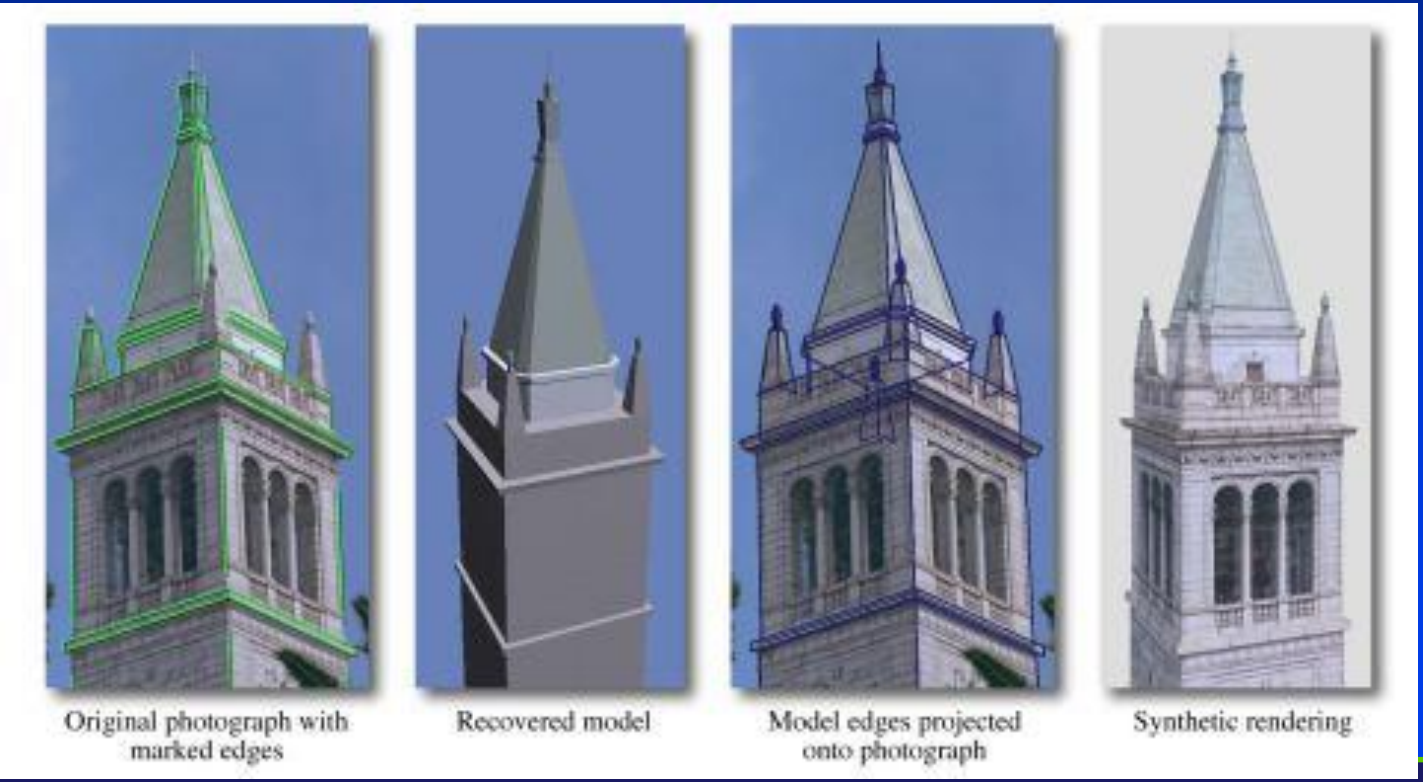
Projective Textures

- 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)



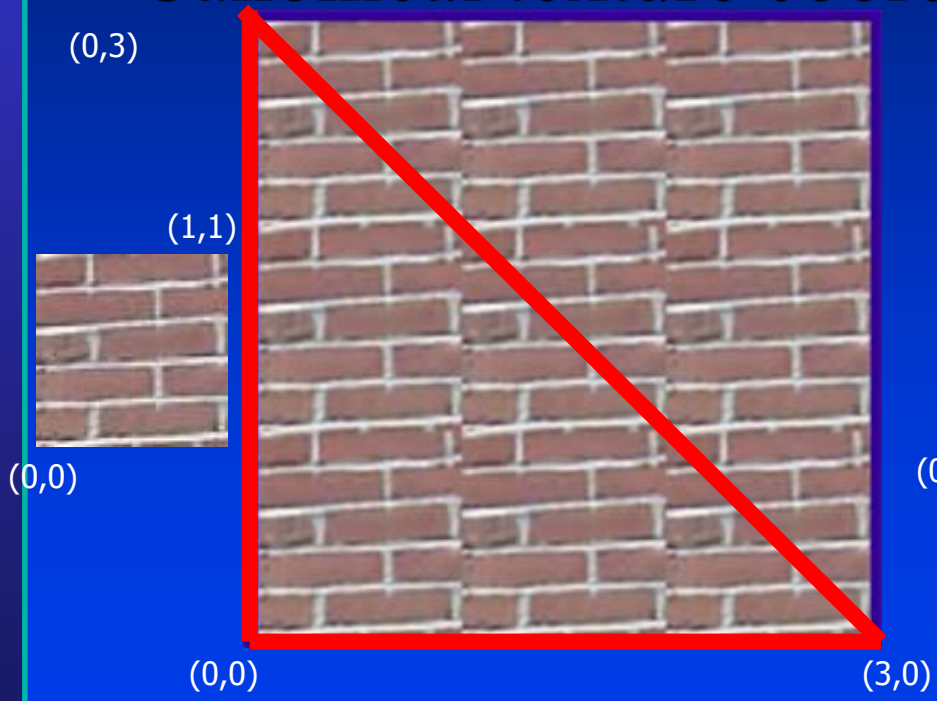
Projective Texture Example

- Modeling from photographs
- Using input photos as textures

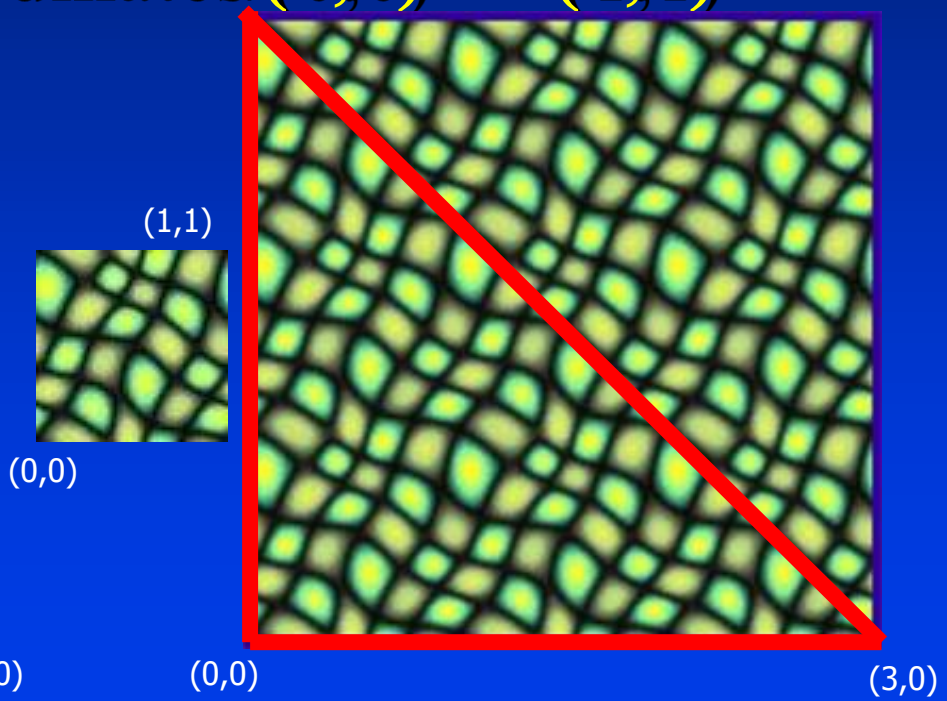


Texture Tiling

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



tiles with visible seams

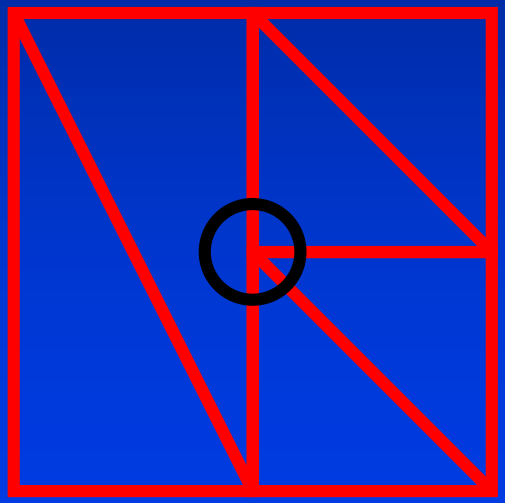


seamless tiling (repeating)

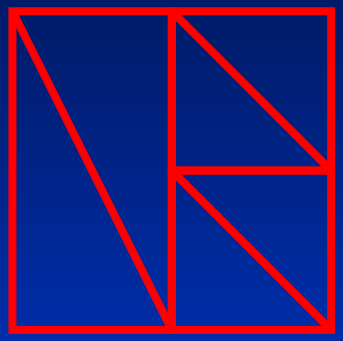
Specify More Coordinates?

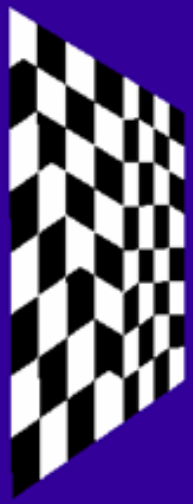
- We can reduce the perceived artifacts by subdividing the model into smaller triangles.

- However, sometimes the errors become obvious
  - At "T" joints
  - Between levels-of-details

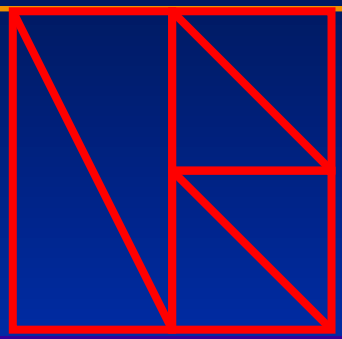


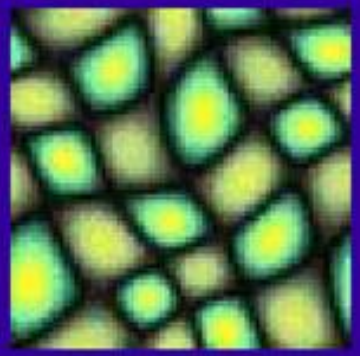
Subdivision

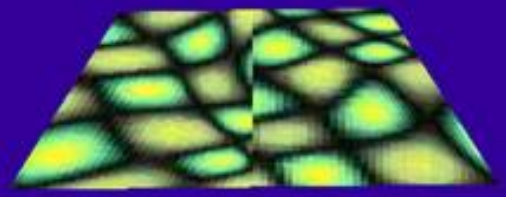


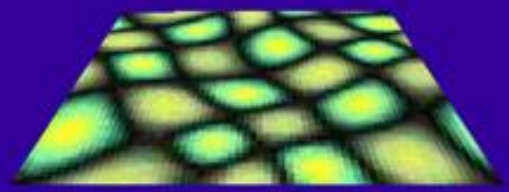


Subdivision









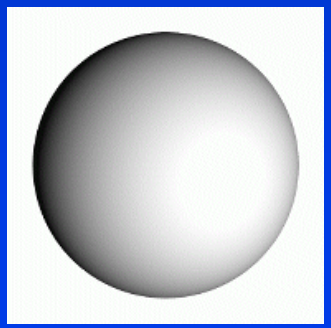
texture source | what we get | what we want

Texture Mapping & Illumination

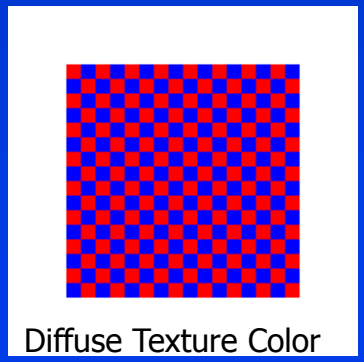
- Texture mapping can be used to alter some or all of the constants in the illumination equation:
  - pixel color, diffuse color, alter the normal, ….

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

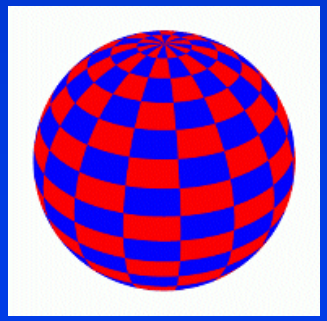
Phong's Illumination Model



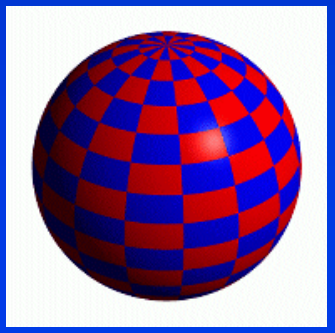
Constant Diffuse Color



Diffuse Texture Color



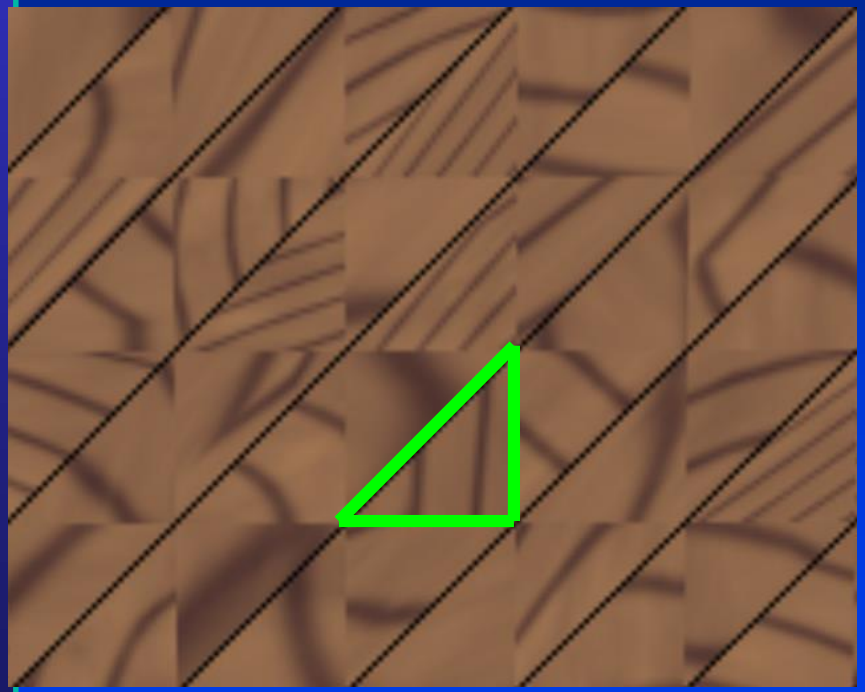
Texture used as Label

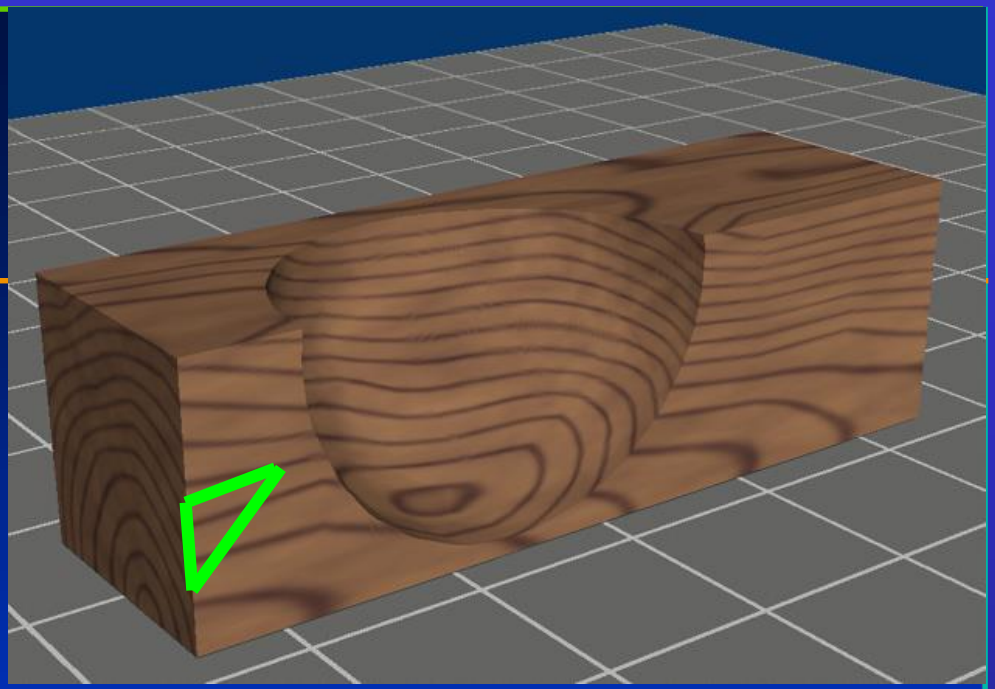


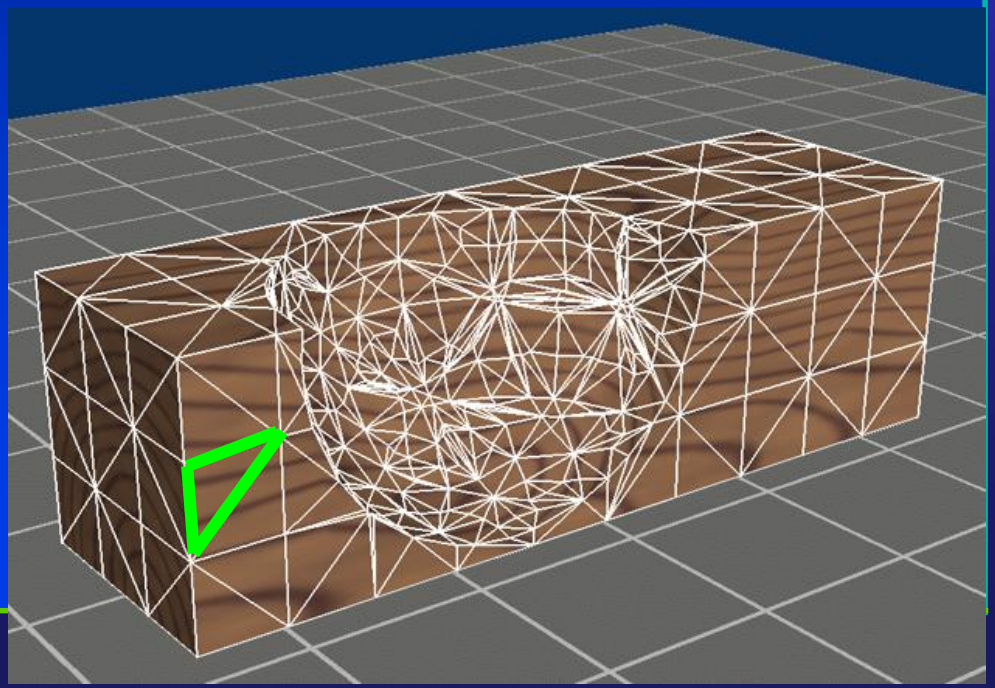
Texture used as Diffuse Color

Texture Chart

- Pack triangles into a single image



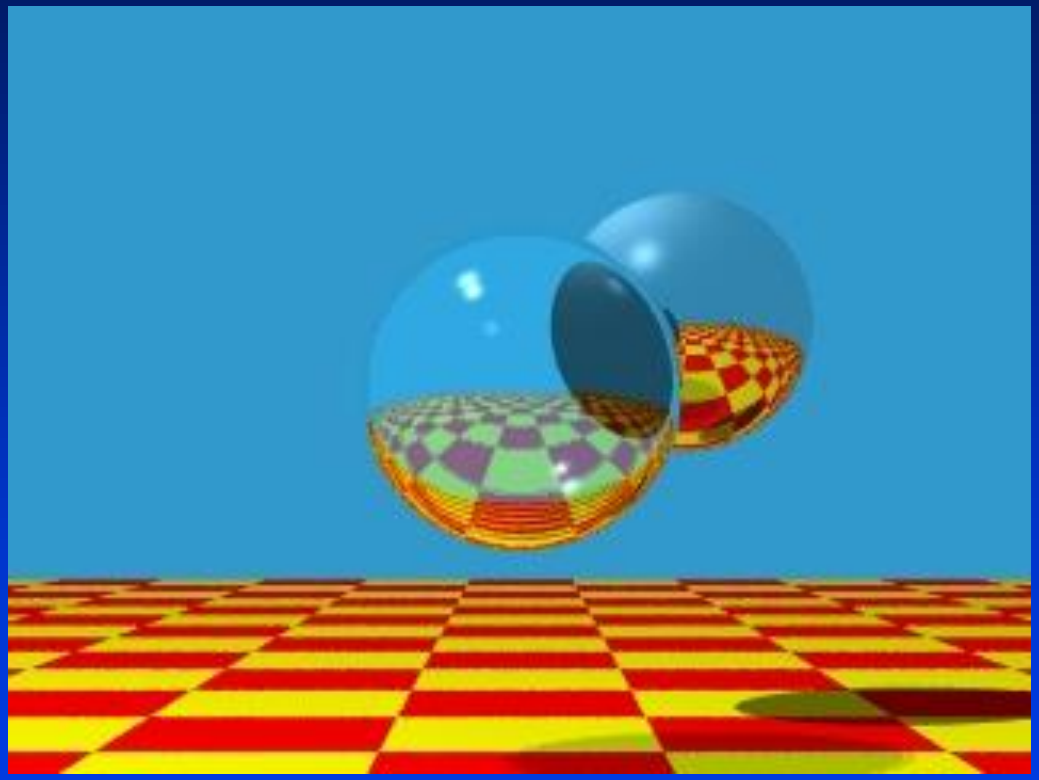




Procedural and Solid Textures

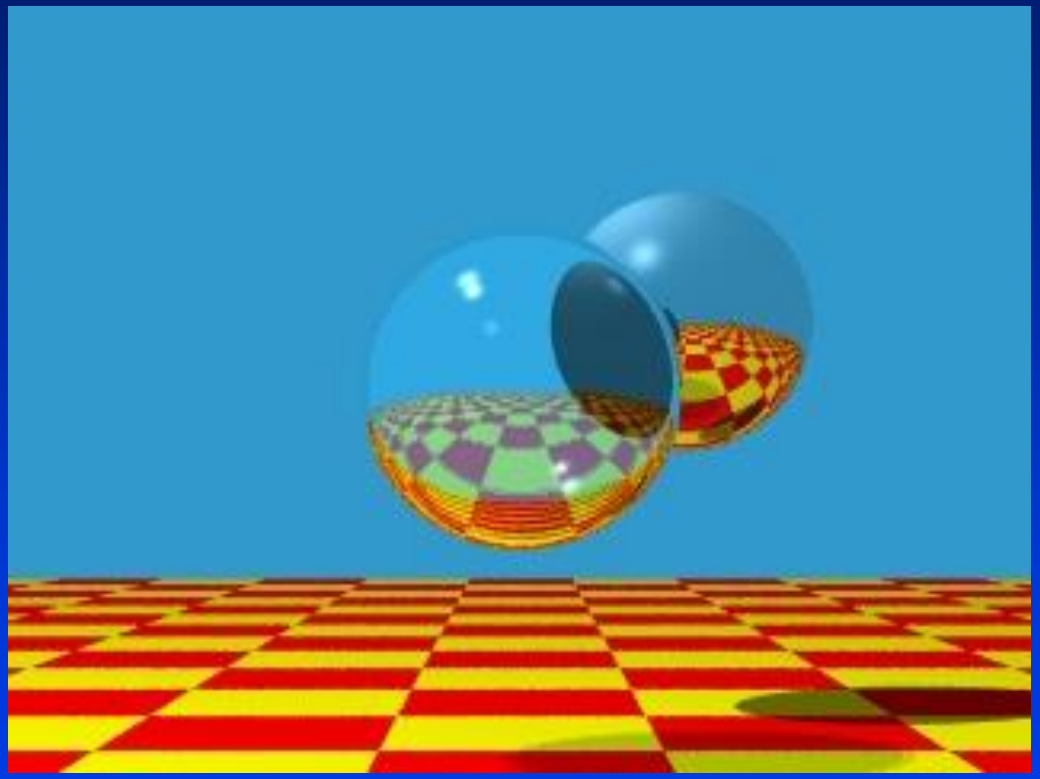
Procedural Textures

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



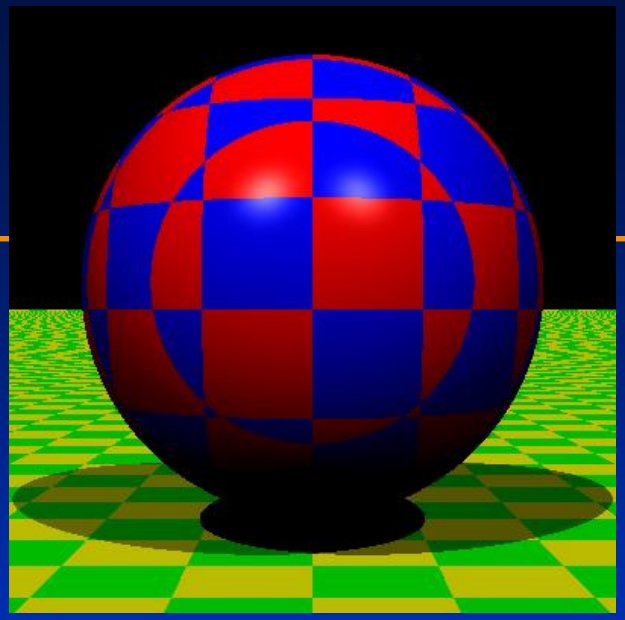
Procedural Textures

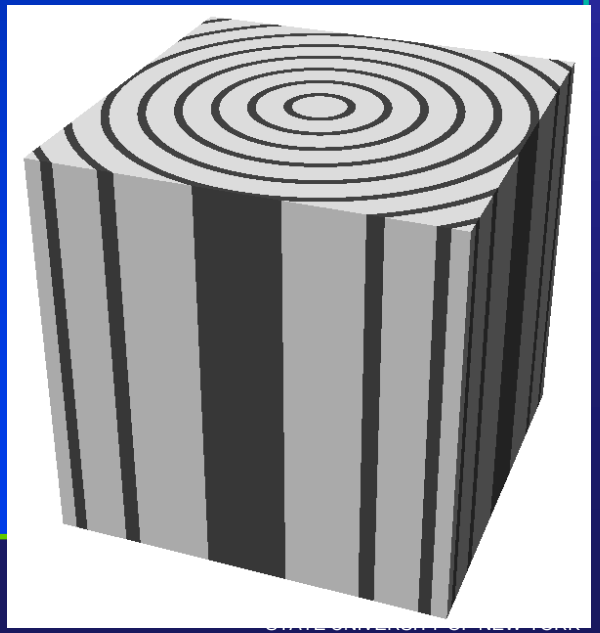
$f(x,y,z) \rightarrow \text{color}$



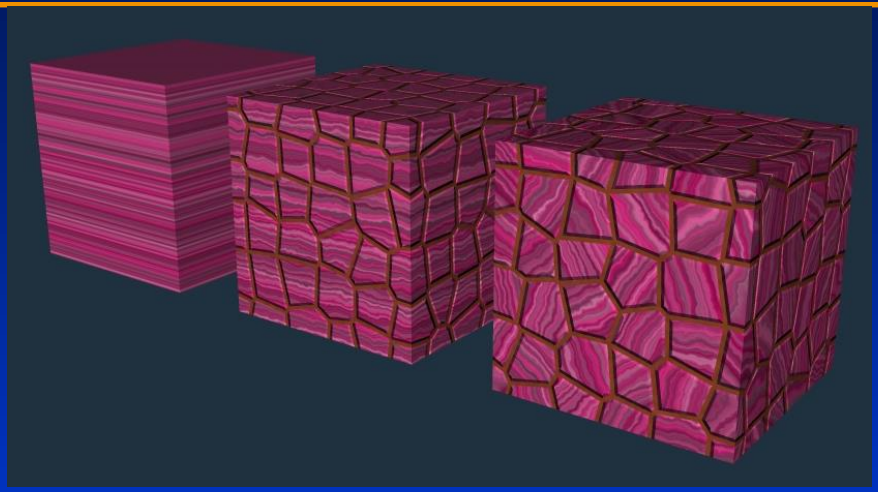
Procedural Textures

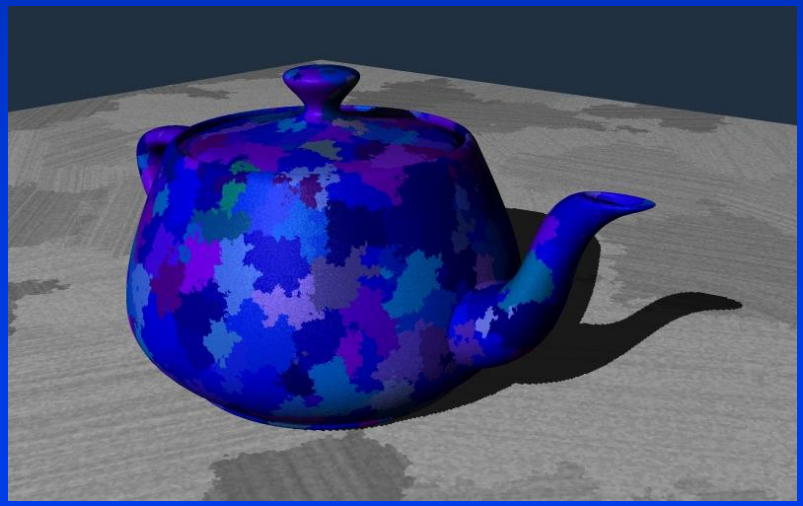
- Advantages:
  - easy to implement in ray tracer
  - more compact than texture maps
  - especially for solid textures
  - infinite resolution
- Disadvantages
  - non-intuitive
  - difficult to match existing texture





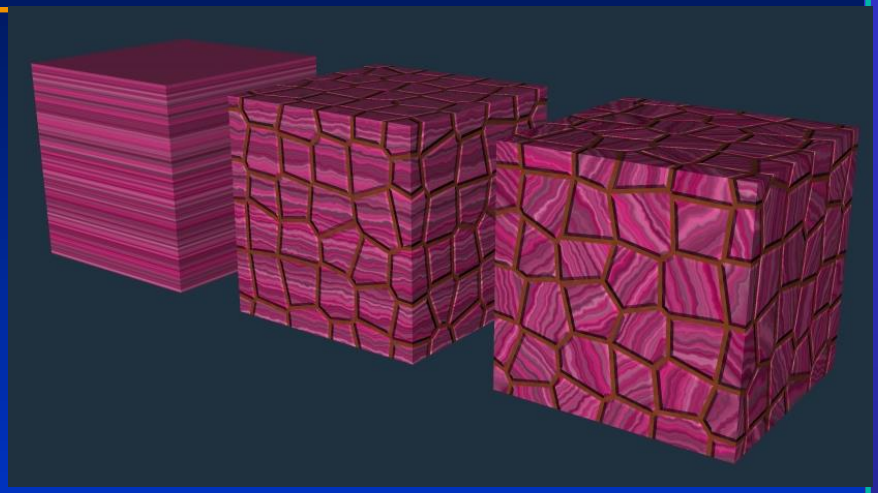
Solid Texture Examples

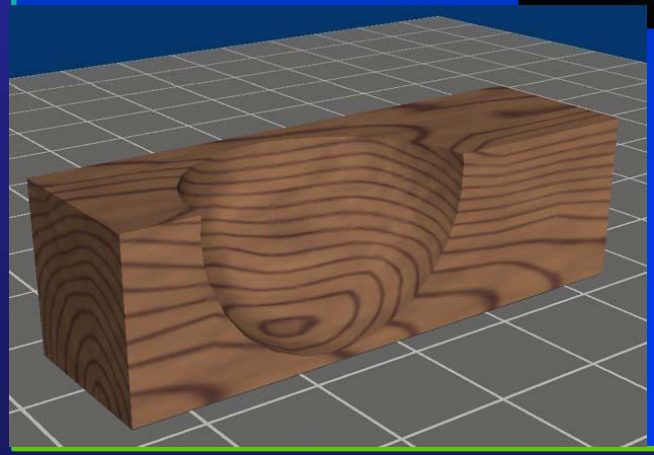


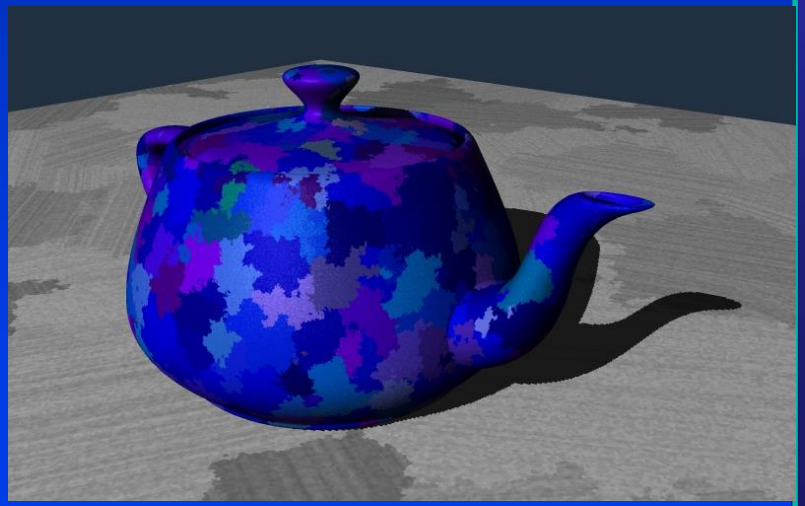


Procedural Solid Textures

- Noise
- Turbulence



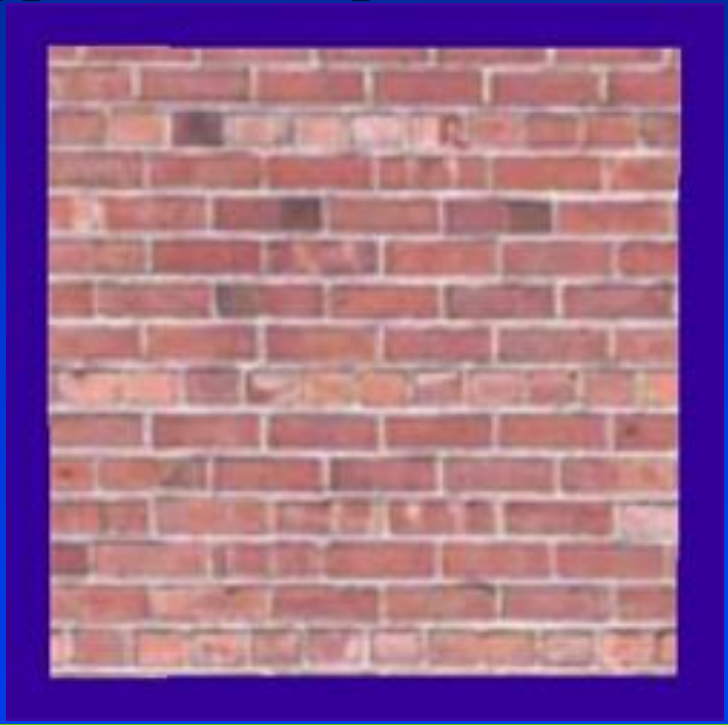


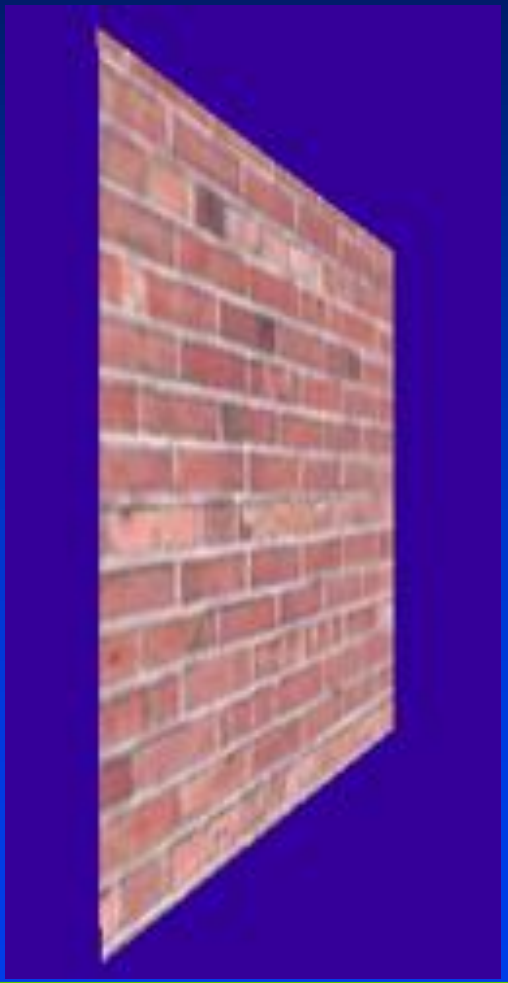


What's Missing?

- 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?



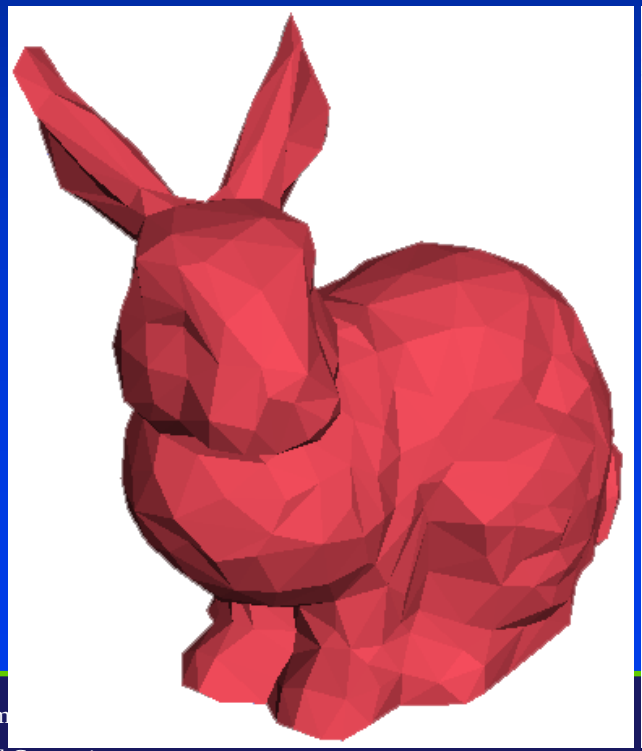


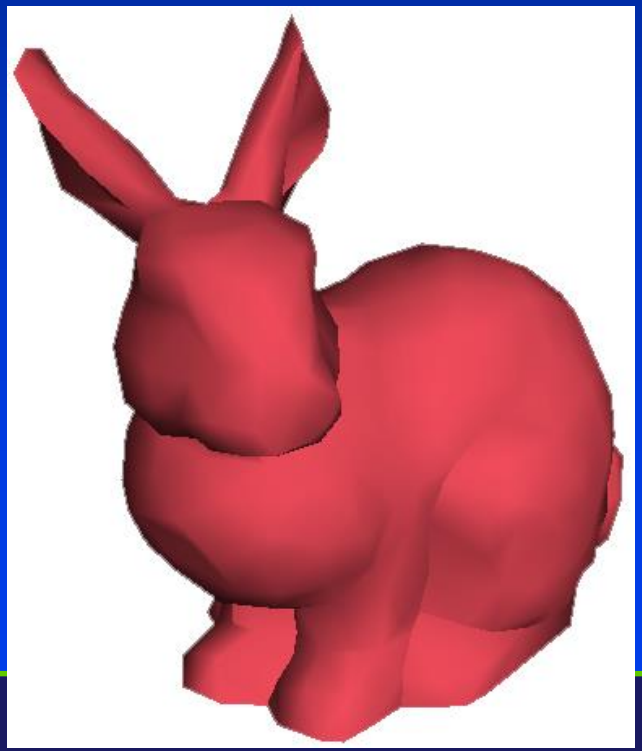
Bump Mapping

- Other Mapping Techniques:
  - Bump Mapping
  - Displacement Mapping

Remember Gouraud Shading?

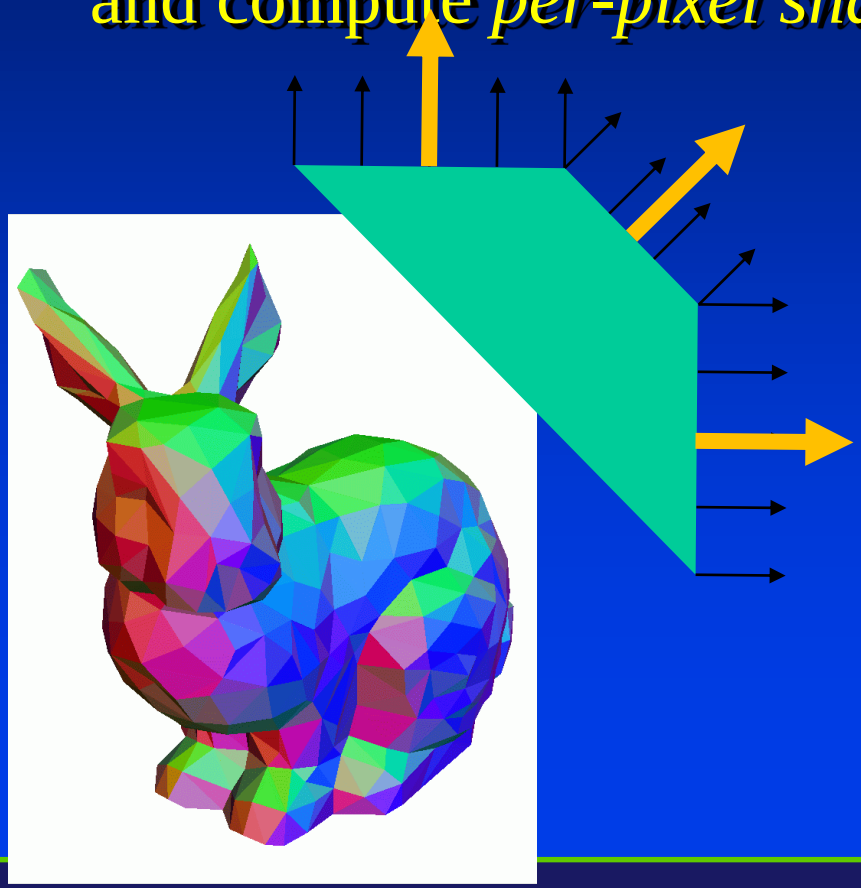
- Instead of shading with the normal of the triangle, shade the vertices with the *average normal* and interpolate the color across each face

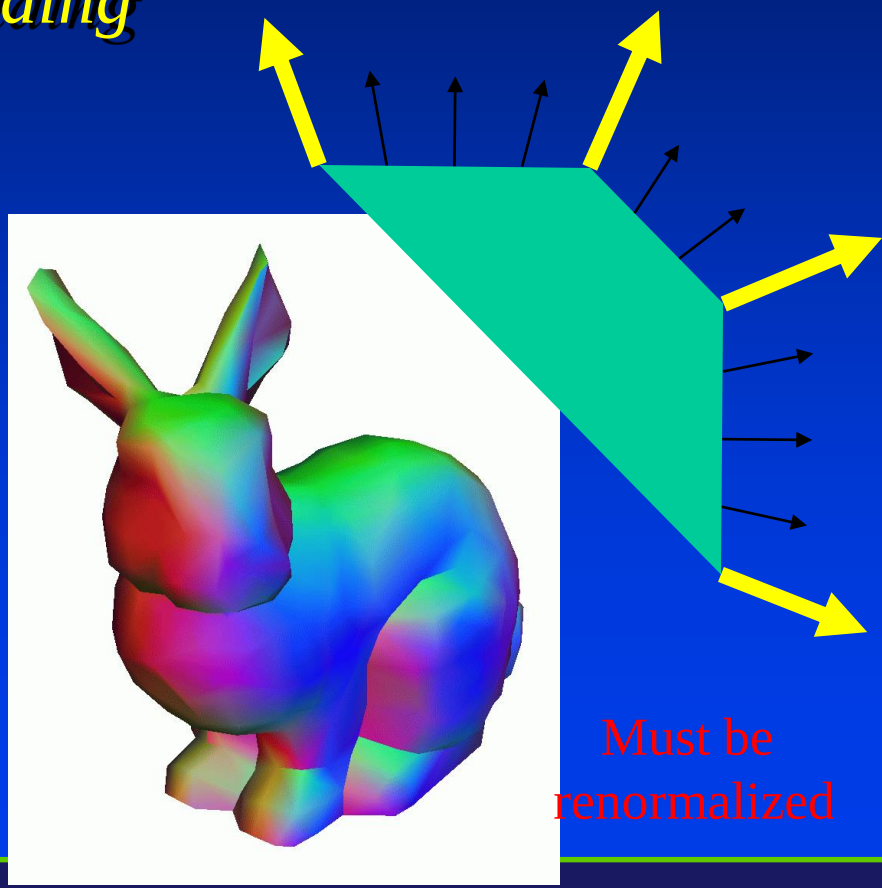




Phong Normal Interpolation

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

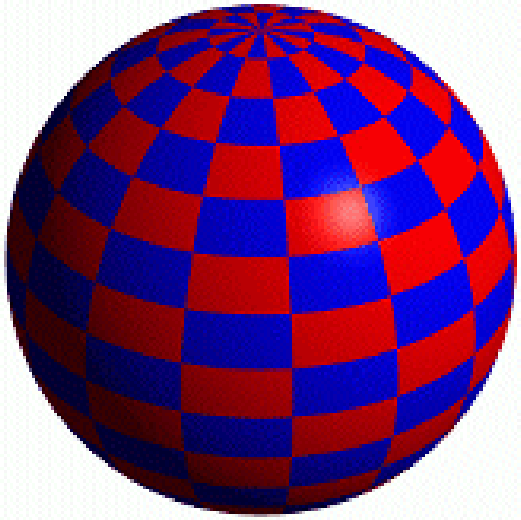




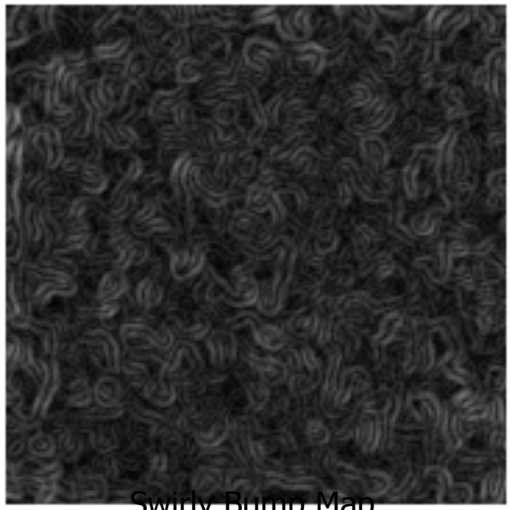
Must be renormalized

Bump Mapping

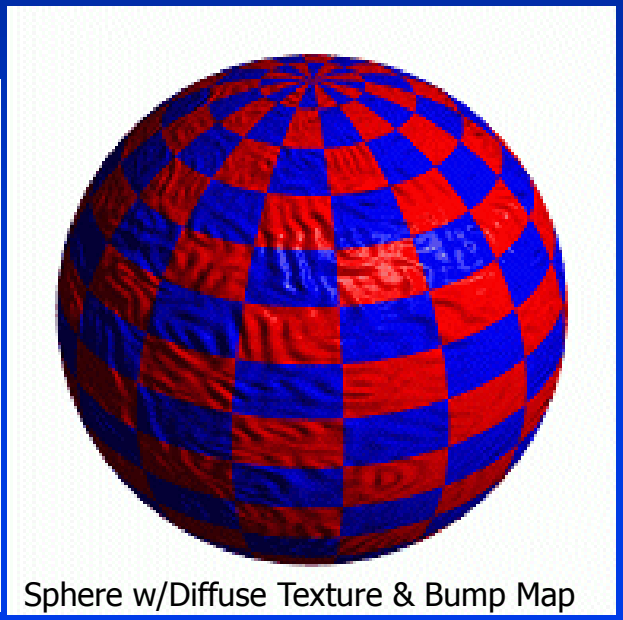
- Use textures to alter the surface normal
  - Does not change the actual shape of the surface
  - Just shade as if it were a different shape



Sphere w/Diffuse Texture



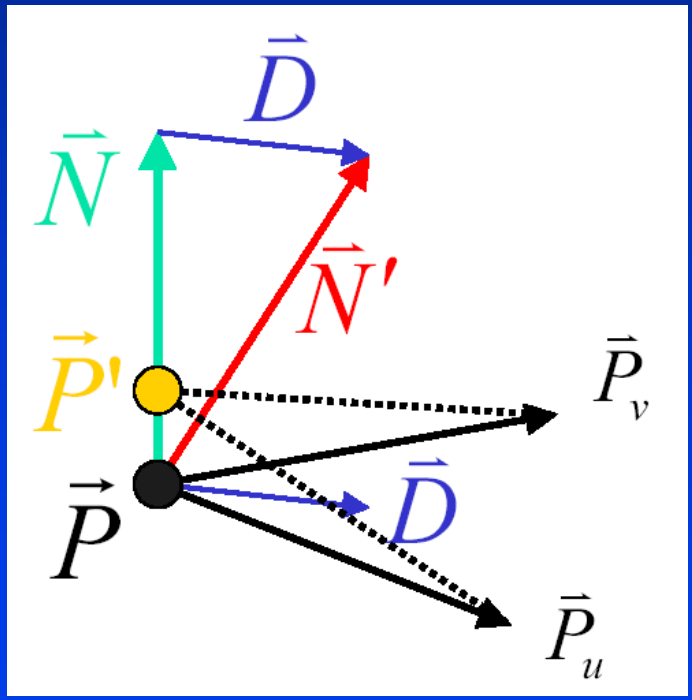
Swirly Bump Map



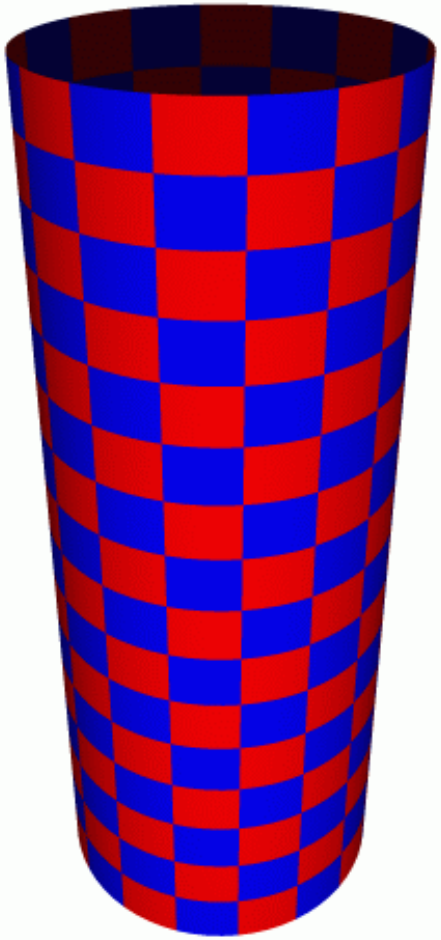
Sphere w/Diffuse Texture & Bump Map

Bump Mapping

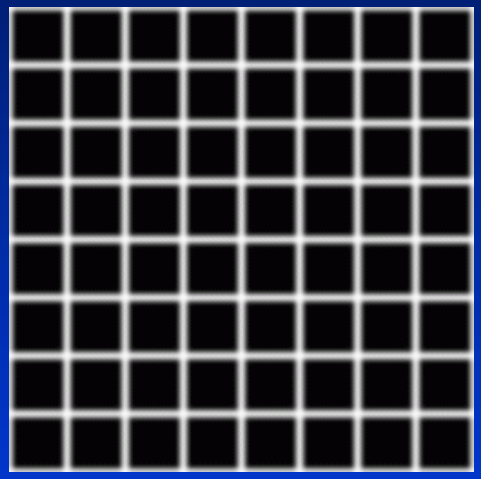
- Treat the texture as a single-valued height function
- Compute the normal from the partial derivatives in the texture



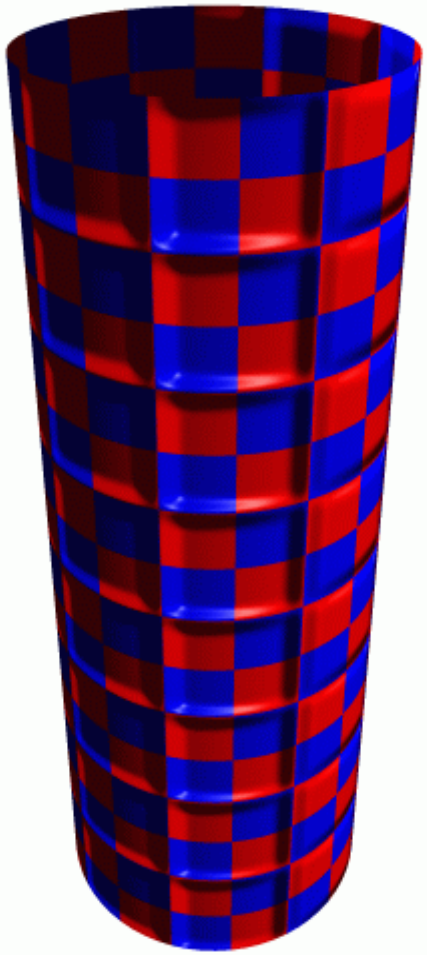
Another Bump Map Example



Cylinder w/Diffuse Texture Map



Bump Map

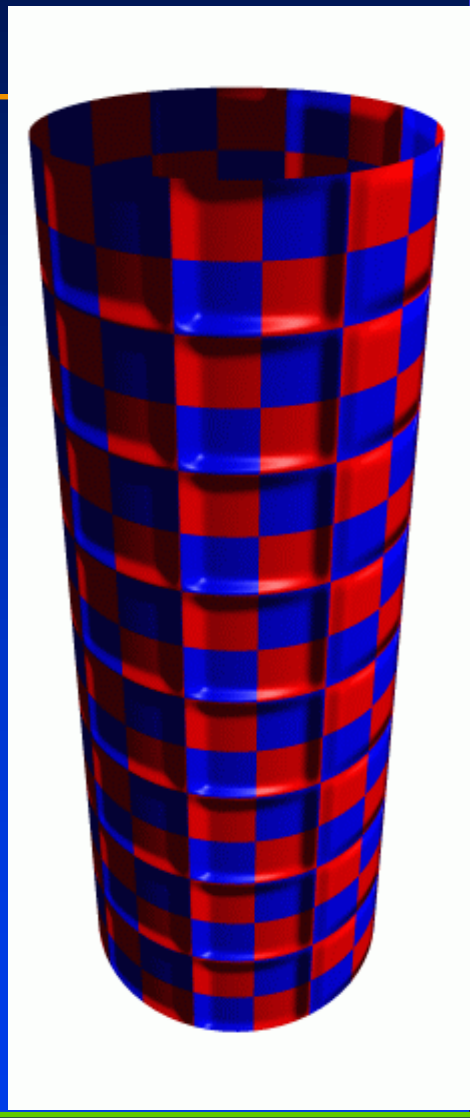


Cylinder w/Texture Map & Bump Map

What's Missing?

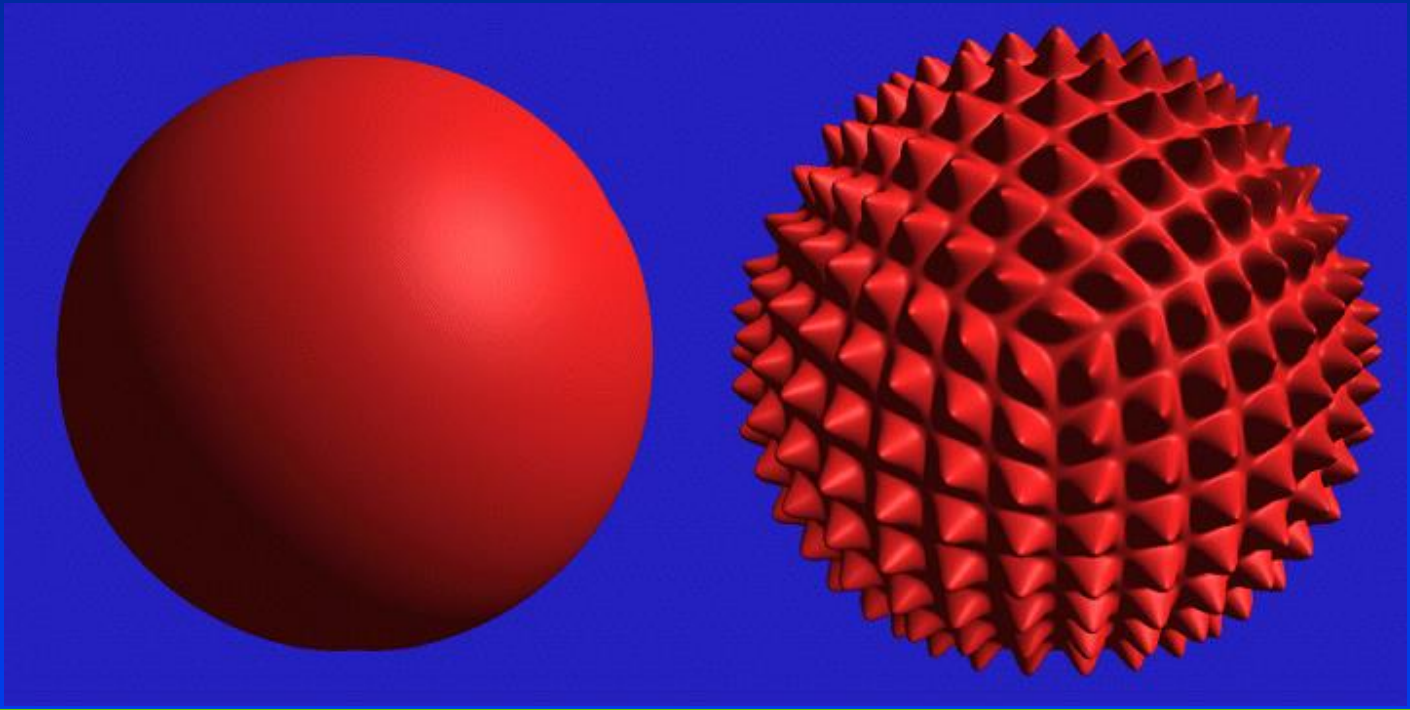
- There are no bumps on the silhouette of a bump-mapped object

- 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

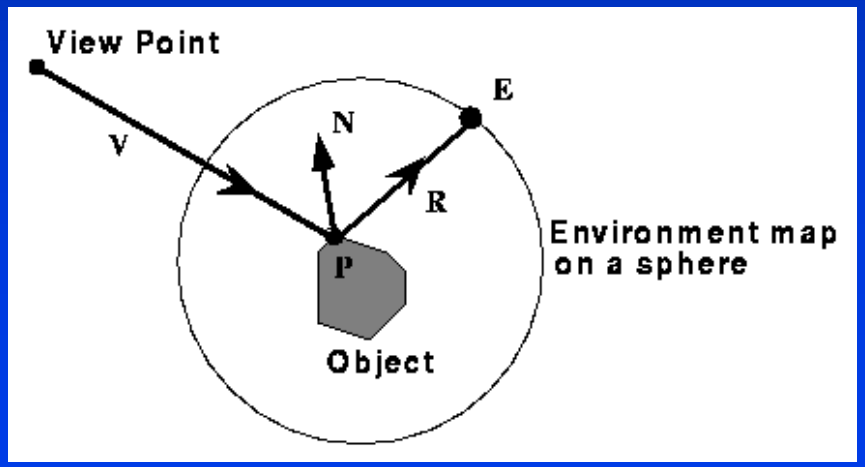
by Matt Pharr and Pat Hanrahan.

note the detailed shadows cast by the stones

Displacement Mapping

Environment Maps

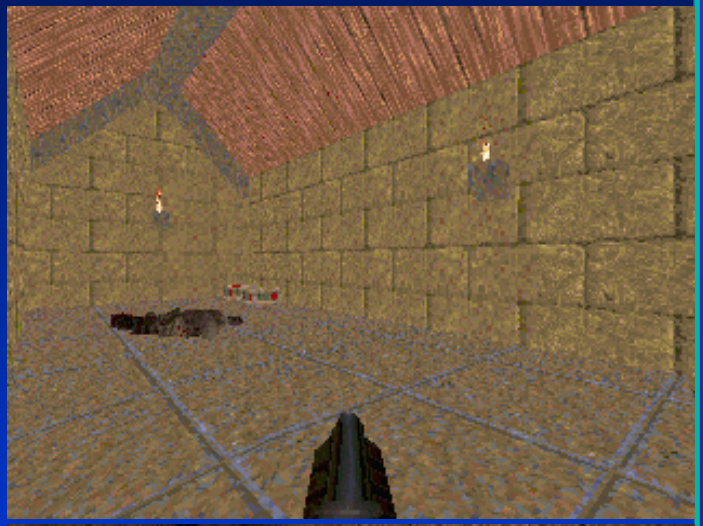
- We can simulate reflections by using the direction of the reflected ray to index a spherical texture map at "infinity".
- Assume that all reflected ra
begin from the same point.

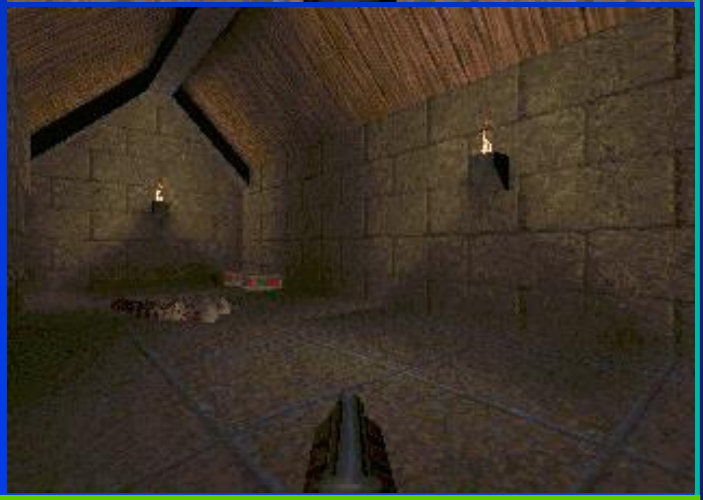


Illumination + Texture Mapping

Texture Maps for Illumination

- Also called "Light Maps"





Quake

Questions?