2D Texture Mapping

CS 432 Interactive Computer Graphics

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Slide Credits

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- Shayan Sarkar - Carnegie Mellon University
- Leonard McMillan, Jovan Popovic, Fredo Durand - MIT
- Steve Marschner - Cornell University
- David Luebke - University of Virginia
- Pat Hanrahan - Stanford University

The Quest for Visual Realism

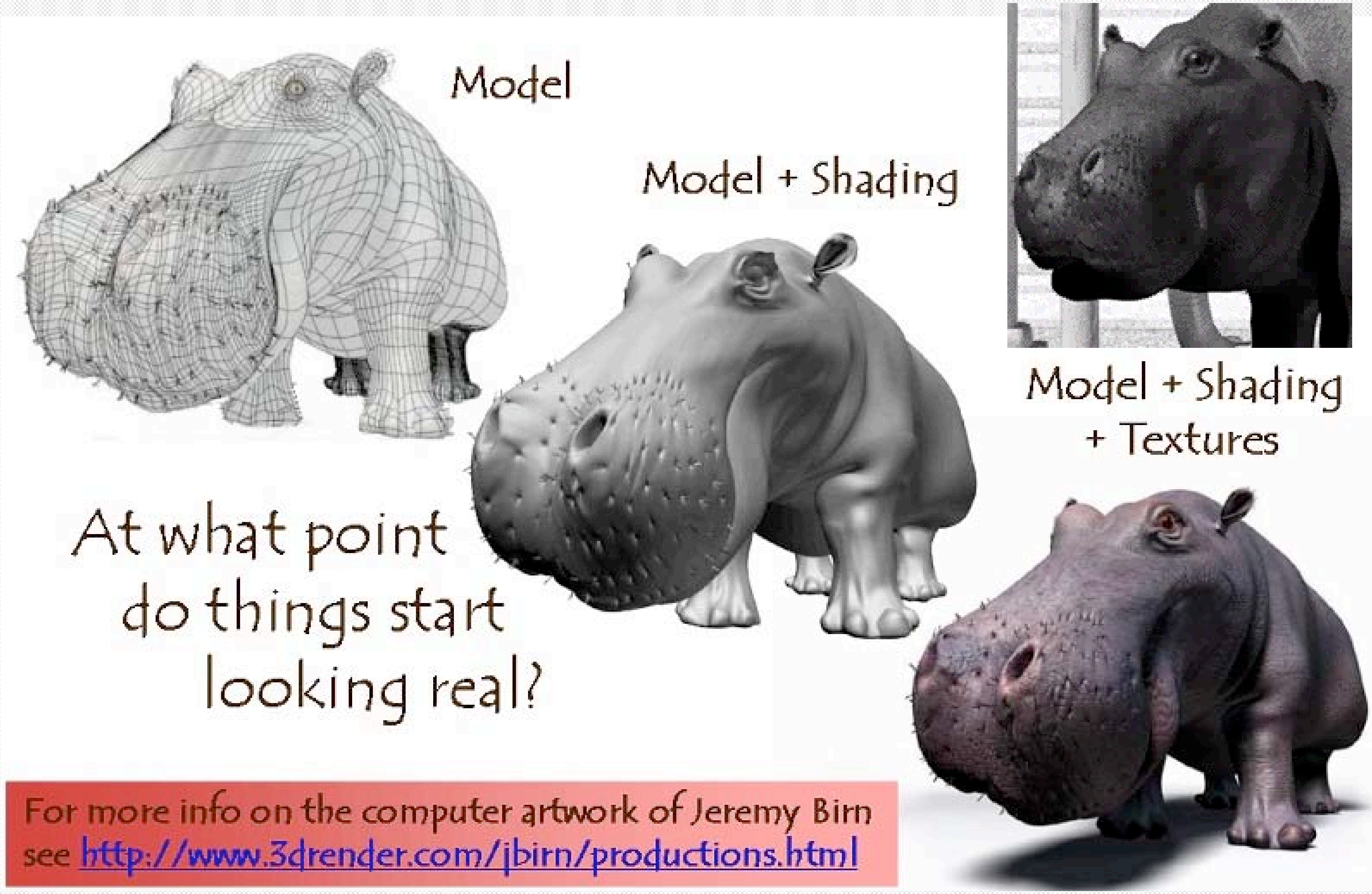
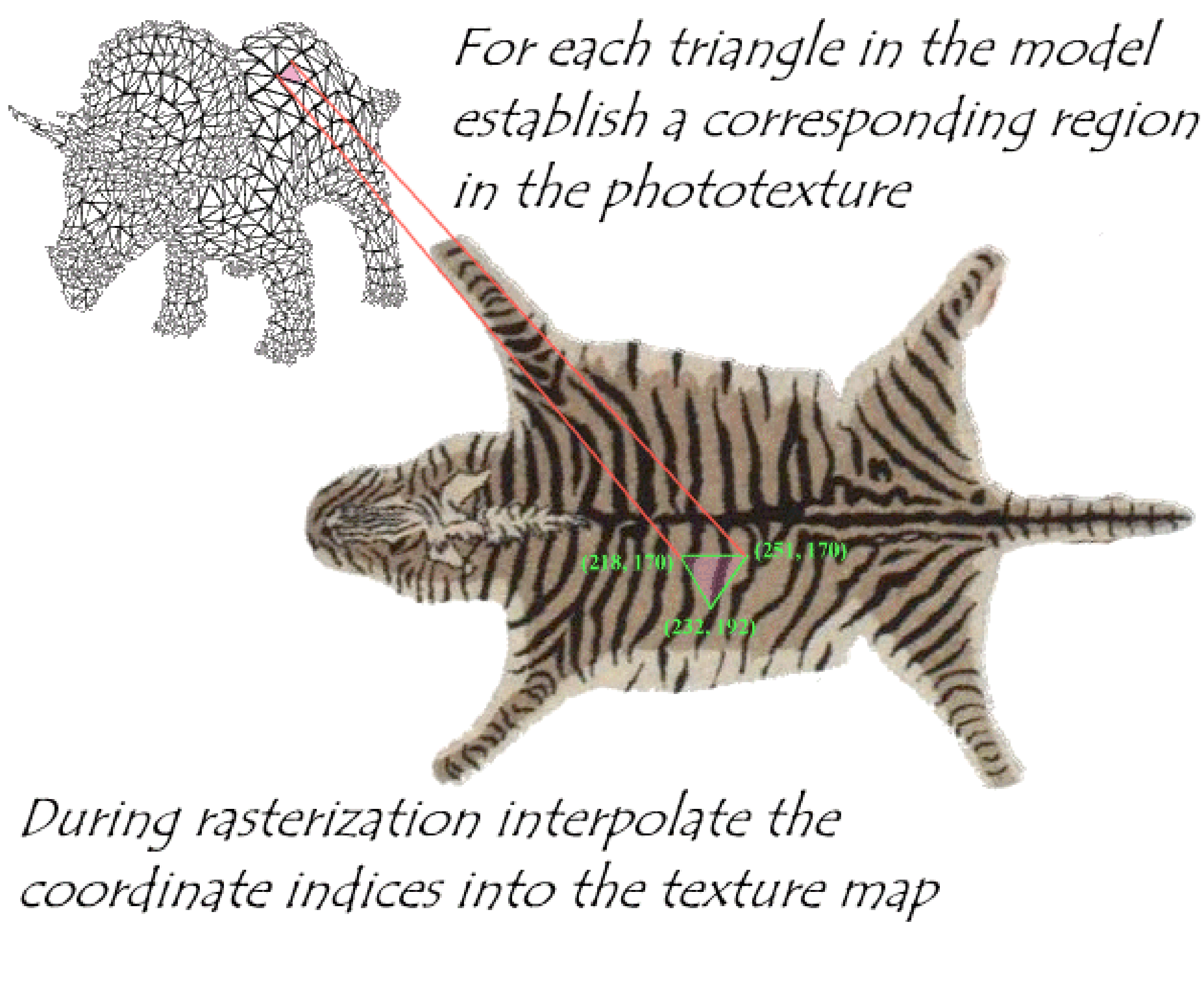
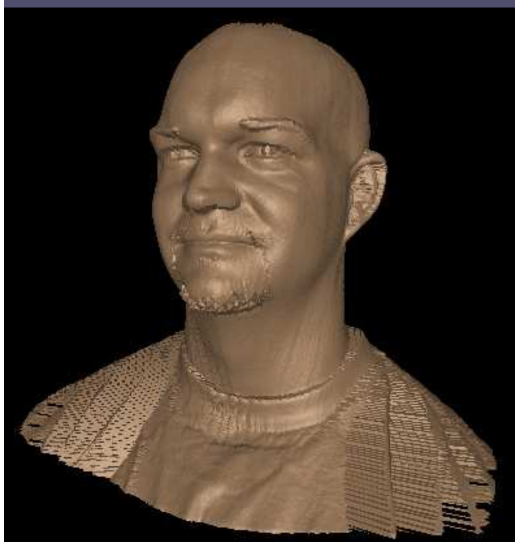


Photo-textures



The concept is very simple!

2D Texture Example



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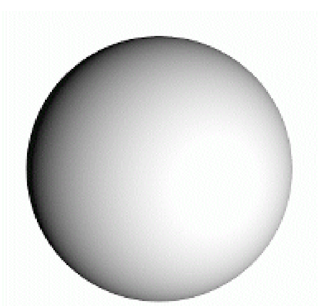
Adding Texture Mapping to Illumination

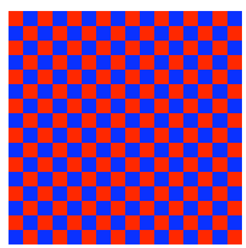
Texture mapping can be used to alter some or all of the constants in the illumination equation. We can simply use the texture as the final color for the pixel, or we can just use it as diffuse color, or we can use the texture to alter the normal, or... the possibilities are endless!

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

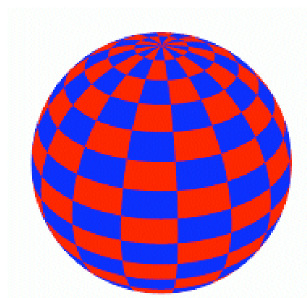
Phong's Illumination Model



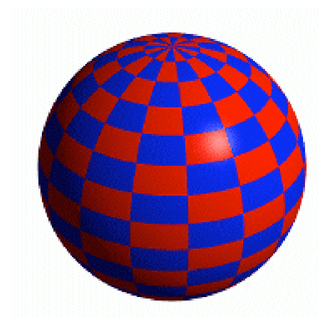
Constant Diffuse Color



Diffuse Texture Color



Texture used as Label



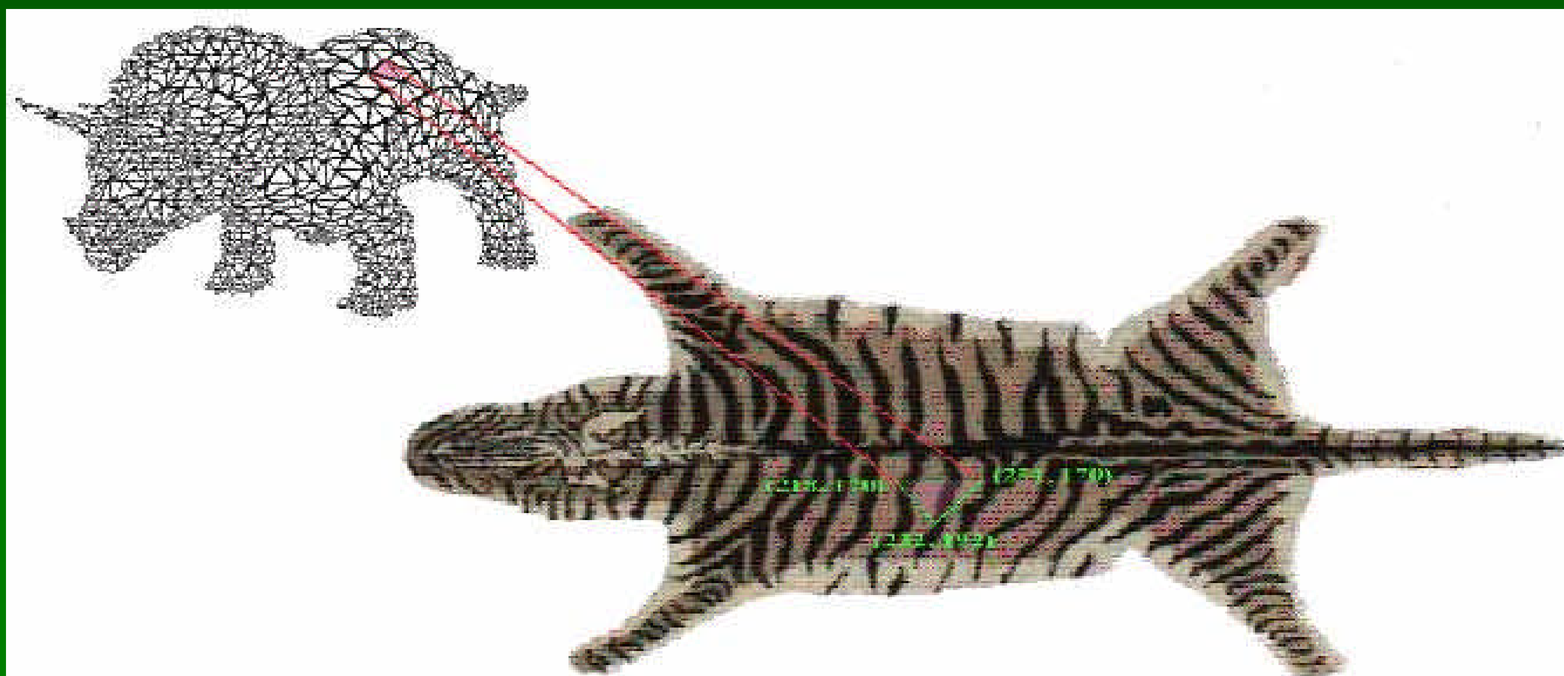
Texture used as Diffuse Color

Acquiring Texture Images

- Photograph
  - flat surface
  - even lighting (no specularity)
- 3D Rendering
- Procedural synthesis
  - Sample a procedural texture

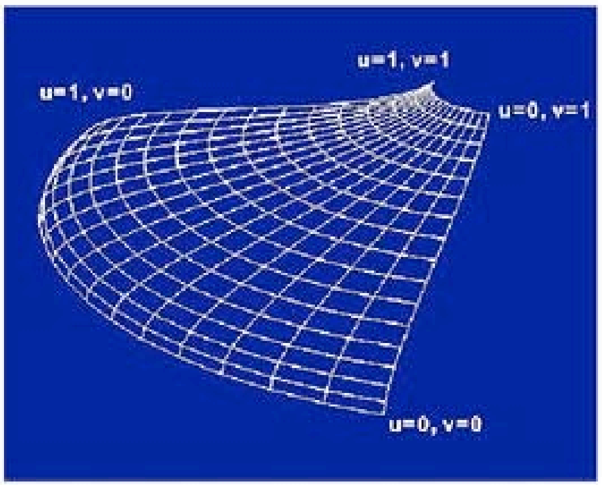
Difficulties with texture mapping

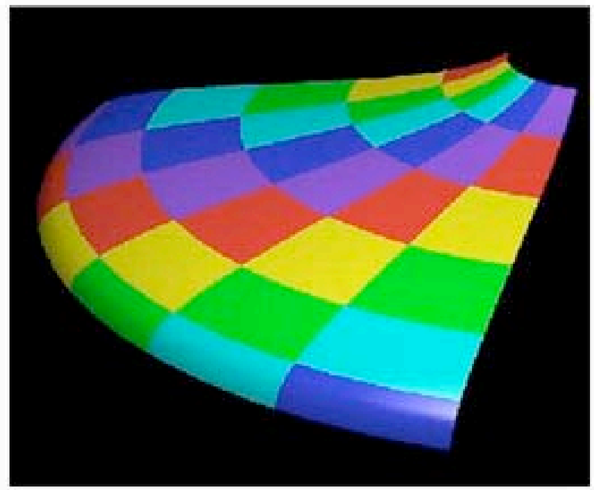
- Another difficulty is how to map a 2D image onto an arbitrary 3D model
  - Ex: If you wanted to map onto a sphere, you can’t do it without distorting the texture



Examples of coordinate functions

- A parametric surface (e.g. spline patch)
  - surface parameterization gives mapping function directly (well, the inverse of the parameterization)

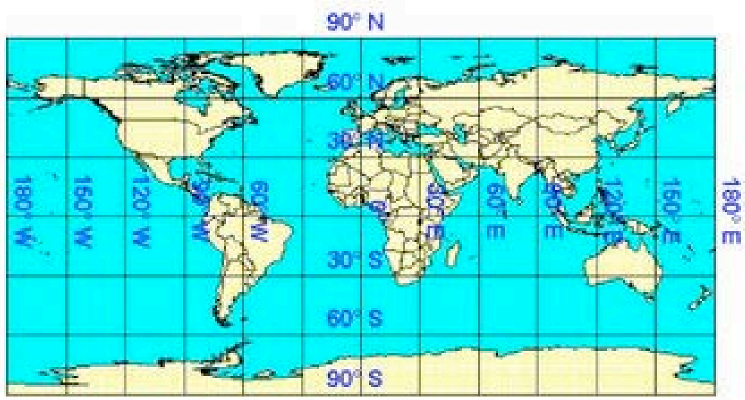




[Wolfe / SG97 Slide set]

Examples of coordinate functions

- For a sphere: latitude-longitude coordinates
  - ϕ maps point to its latitude and longitude



[Peter H. Dana]

Atlas Approaches

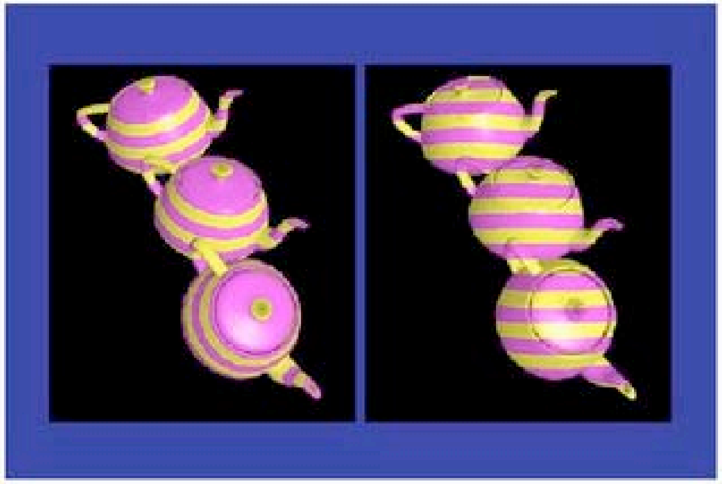
- Break complex surface into patches
- Parameterize / texture each patch
  - Parameterizations optimized to minimize distortions
- Atlas describes mapping between texture domains and surface domain

Atlas Example

from Pederson, “Decorating Implicit Surfaces”, *Proceedings of SIGGRAPH 95*.

Examples of coordinate functions

- For non-parametric surfaces it is trickier
  - directly use world coordinates
    - need to project one out



[Wolfe / SG97 Slide set]

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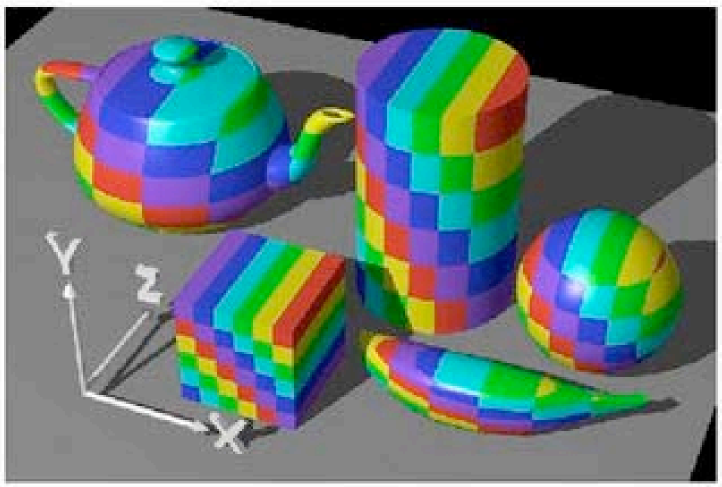

[Wolfe / SG97 Slide set]

Two-stage Mapping

1. Map texture onto canonical primitive (the *intermediate surface)*
2. Map intermediate surface to arbitrary object
   - Position objects with respect to each other
   - Project along normal direction (of either one)

Examples of coordinate functions

- For non-parametric surfaces it is trickier
  - directly use world coordinates
  - use intermediate parametric object

[Wolfe / SG97 Slide set]

Examples of coordinate functions

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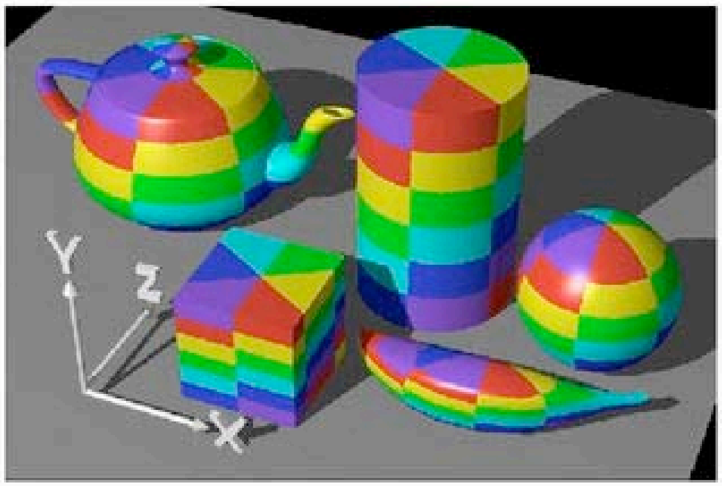

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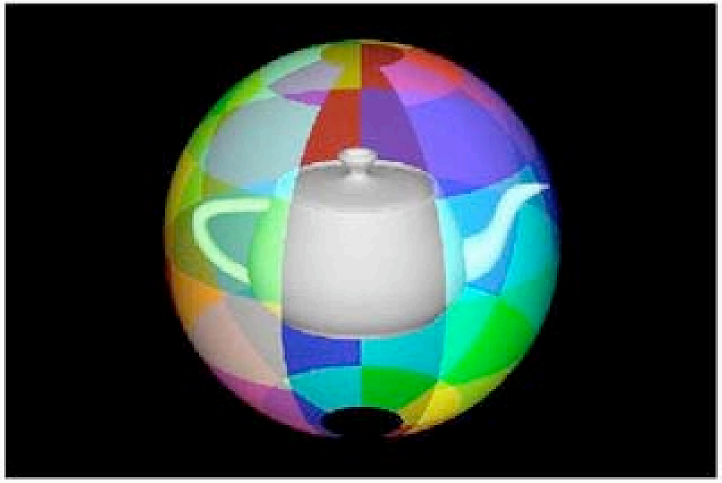

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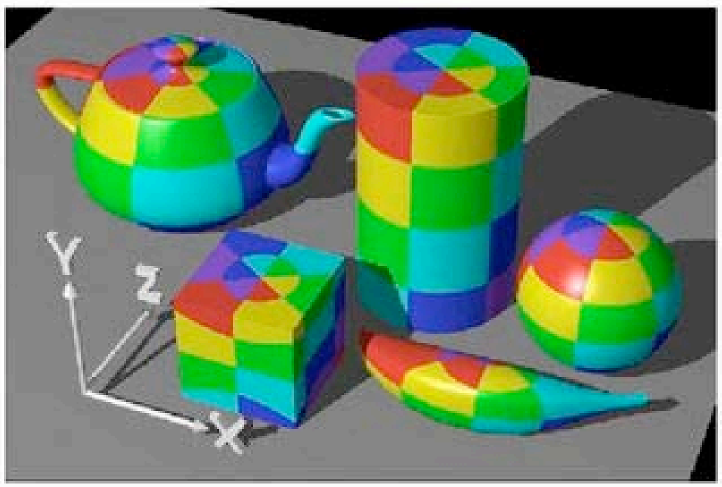

[Wolfe / SG97 Slide set]

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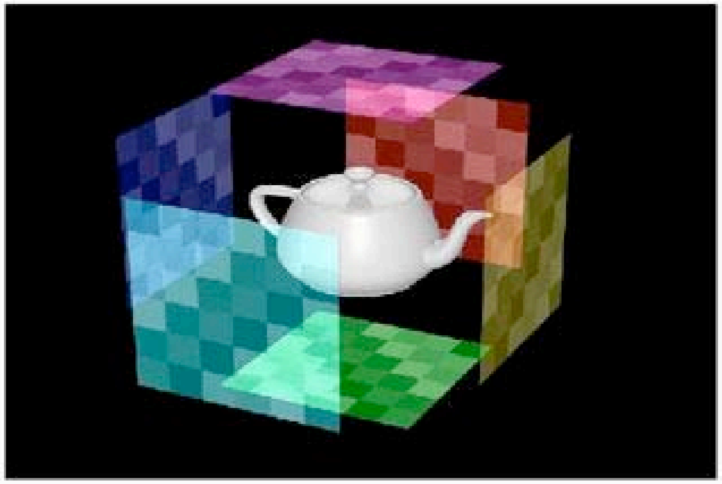

[Wolfe / SG97 Slide set]

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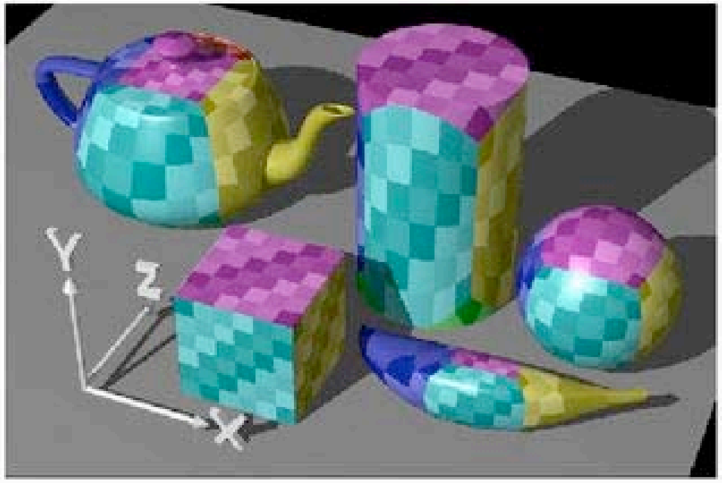
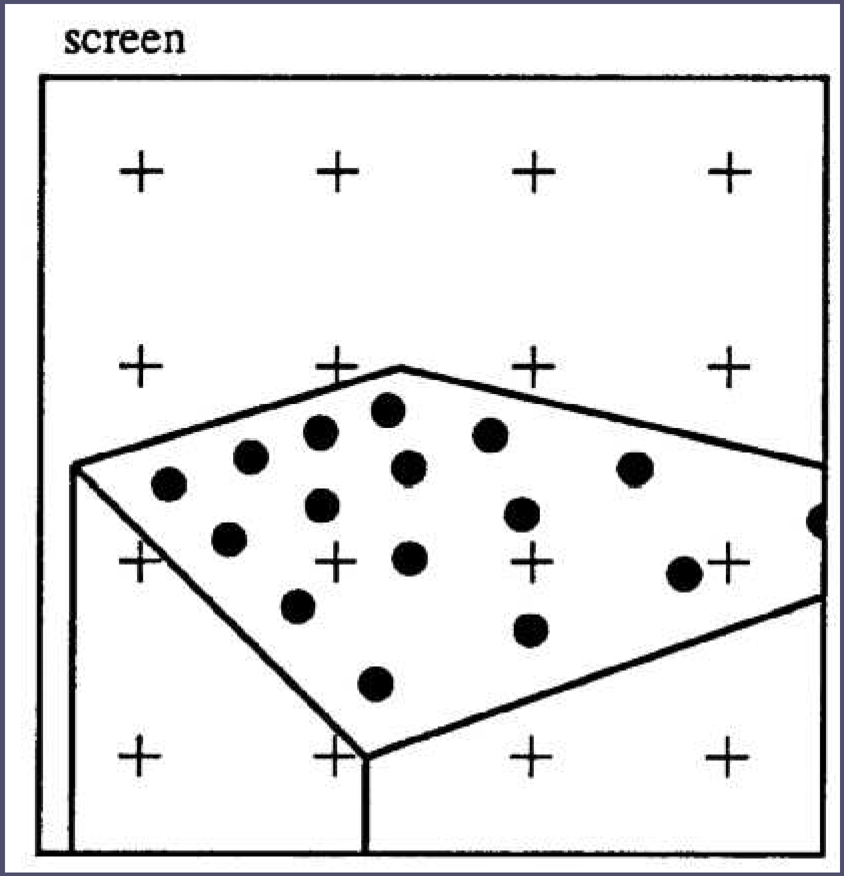


[Wolfe / SG97 Slide set]

Texture Sampling



from Heckbert, Paul. *Fundamentals of Texture Mapping and Image Warping*. Masters Thesis. UC Berkeley. 1989. page 7.

Sampling Approaches

Point Sampling

- Pick closest texel
- (Replication/pixel zoom for upsampling)

Interpolation

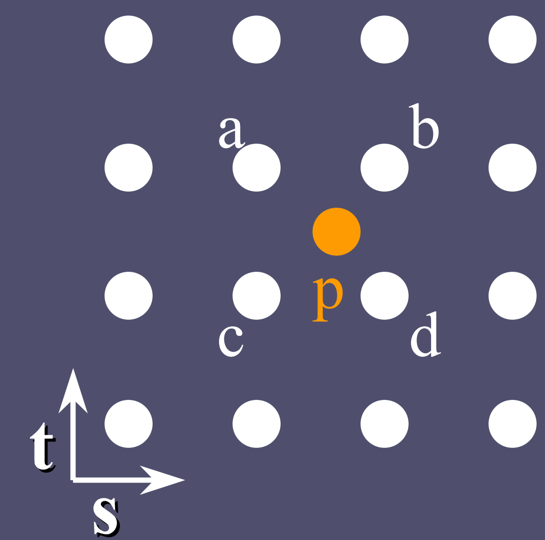
- Blend closest texels

Area Sampling

- Blend all covered texels

Bilinear Interpolation

$$p = (\, p_s, p_t \,)$$



$$p' = (\, (\, p_s - a_s) \,/\, (\, b_s - a_s \,), (\, p_t - a_t) \,/\, (\, c_t - a_t \,) \,)$$

$$p_{color} = \mathrm{lerp}(\mathrm{lerp}(a_{color}, b_{color}, p_s'), \mathrm{lerp}(c_{color}, d_{color}, p_s'), p_t')$$

$$\mathrm{lerp}(k_1, k_2, t) = (1-t)*k_1 + t*k_2$$

Texture Area Sampling

- If frequency of texture content is higher than sampling rate, may want better filtering
- Pixel-sized area on surface covers some area in texture domain
  - Curvilinear quadrilateral or ellipse
- Perform weighted average of texels covered by pixel-sized piece of surface

Antialiasing and Texture Mapping

- Texture mapping is uniquely harder
  - Coherent textures present pathological artifacts
  - Correct filter shape changes
- Texture mapping is uniquely easier
  - Textures are known ahead of time
  - They can thus be prefiltered

Antialiasing and Texture Mapping

- More on texture problems
  – Coherent texture frequencies become infinitely high with increasing distance
    - Ex: checkerboard receding to horizon
  – Unfiltered textures lead to *compression*
    - Ex: pixel covers entire checkerboard
    - Unfiltered mapping: pixel is black or white
    - Moving checkerboard → flashing pixels

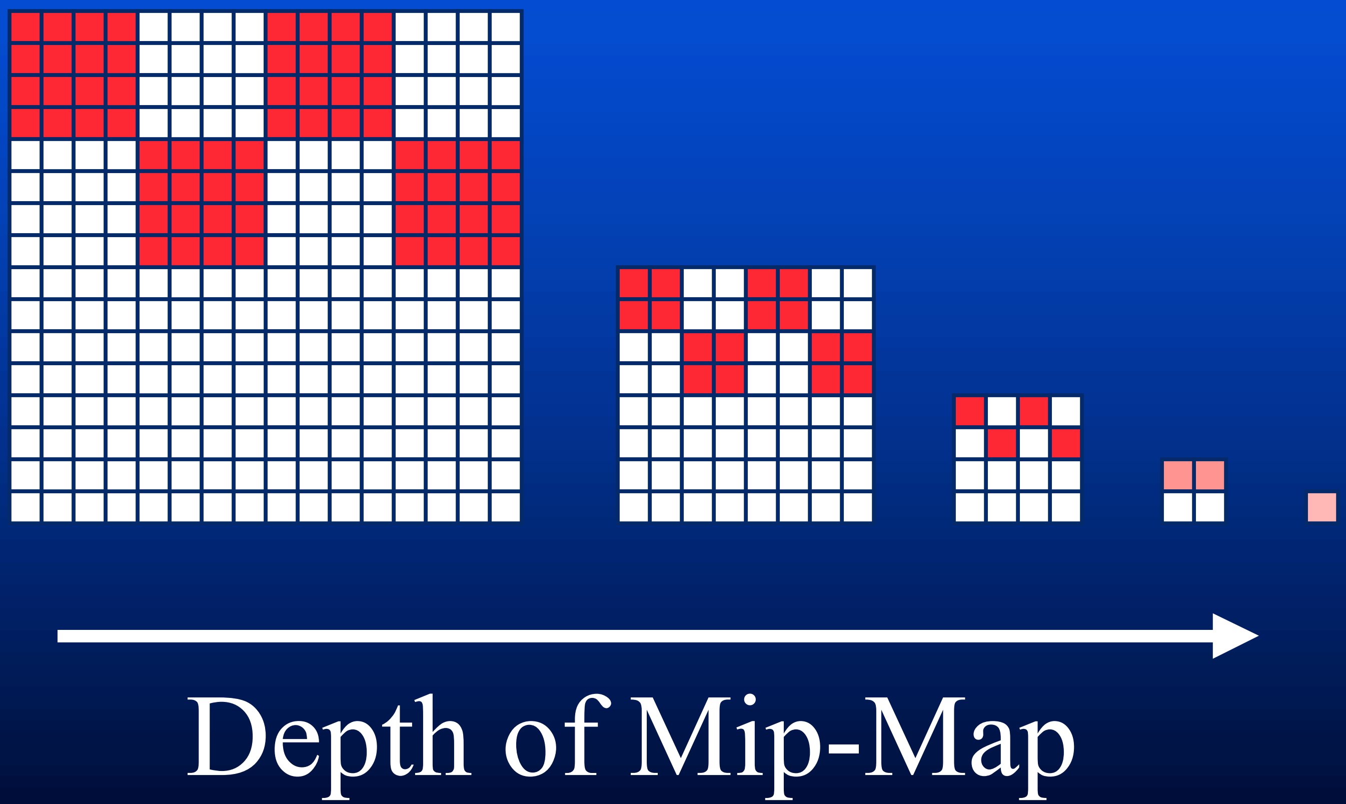
Antialiasing and Texture Mapping

- Problem: a square pixel on screen becomes a curvilinear quadrilateral in texture map (see W&W, p 140)
- The coverage and area of this shape change as a function of the mapping
- Most texture antialiasing algorithms approximate this shape somehow

Antialiasing and Texture Mapping

- Mip-mapping
  - MIP = *Multim in Parvo* (many things in a small place)
  - Ignores shape change of inverse pixel
  - But allows *size* to vary
- Idea: store texture as a pyramid of progressively lower-resolution images, filtered down from original

Antialiasing: Mip-Mapping

Antialiasing: Mip Mapping

- Distant textures use higher levels of the mipmap
- Thus, the texture map is prefiltered
- Thus, reduced aliasing!

Antialiasing: Mip Mapping

- *Which* level of mip-map to use?
  - Think of mip-map as 3-D pyramid
  - Index into mip-map with 3 coordinates: *u, v, d* (depth)
- Q: *What does d correspond to in the mip-map?*
- A: size of the filter

Antialiasing: Mip Mapping

- The size of the filter (i.e., *d* in the mip-map) depends on the pixel coverage area in the texture map
  – In general, treat d as a continuous value
  – Blend between nearest mip-map level using tri-linear interpolation

Antialiasing: Mip Mapping

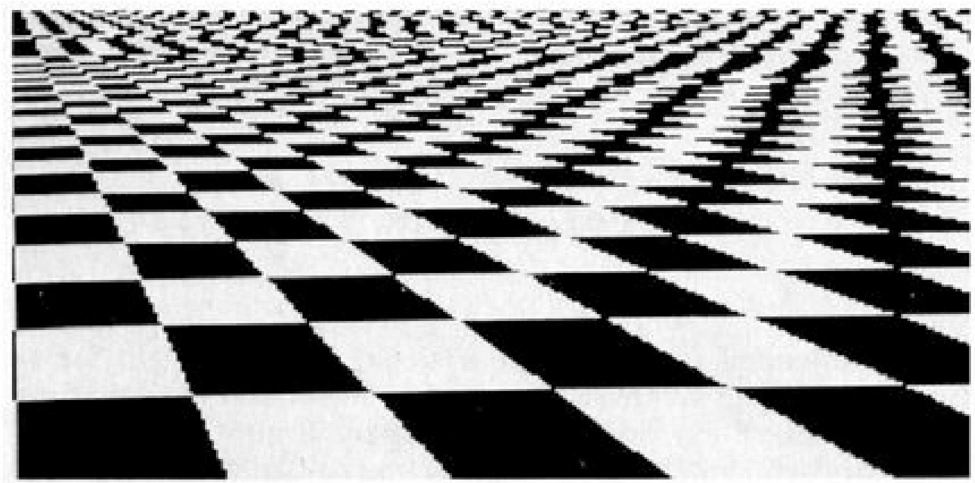
- Q: What's wrong with the mip-map approach to prefiltering texture?
- A: Assumes pixel maps to square in texture space
- More sophisticated inverse pixel filters (see F&vD p 828):
  - Summed area tables
  - Elliptical weighted average filtering

Mip-map Filtering Methods

- Compute d, the parameter along level space
- Sample texture
  - Option 1: Point sample nearest level
  - Option 2: Point sample each adjacent level, then linearly interpolate between them
  - Option 3: Choose nearest level, then bilinearly interpolate within that level
  - Option 4: Trilinearly interpolate between the 8 samples of two adjacent mip-map levels (2 bilinear interps + 1 linear)

Aliasing in texture maps

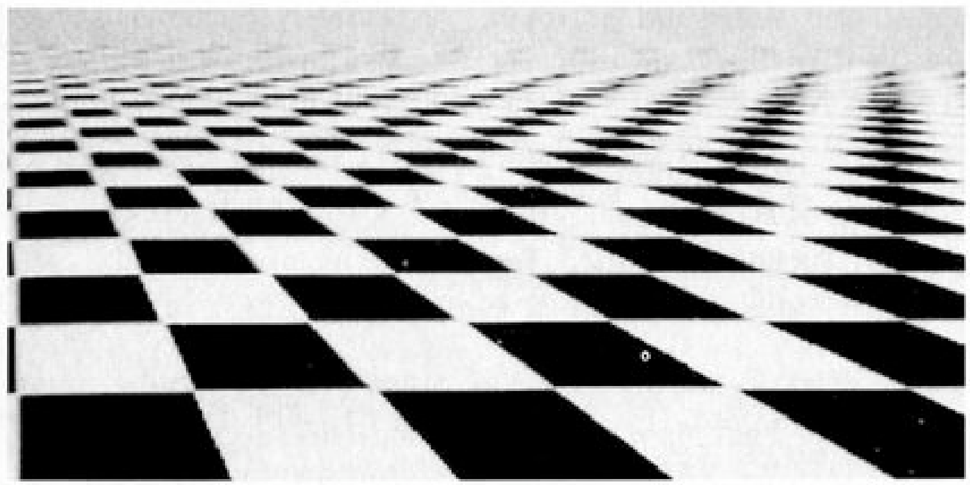
- Aliasing is a big problem with textures
  - they look really bad if you point sample



[Heckbert 86]

  - …and all those artifacts will crawl around in animation

Sampling with a MIP map



(b) Trilinear interpolation on a pyramid.

[Heckbert 86]

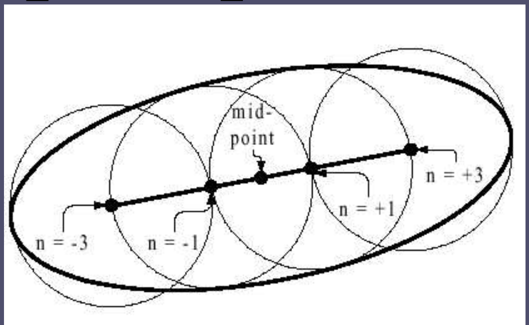
Limitations of Mip-Mapping

Assumes circular footprint of pixel in texture domain

- produces only *isotropic* filtering
- will either over-filter or under-filter in some regions (blurry or jaggy)

Efficient Anisotropic Filtering

- Use multiple mip-map lookups to produce a non-symmetric filter



- Video example: Feline


Figure 19: Trilinear paints blurry text.

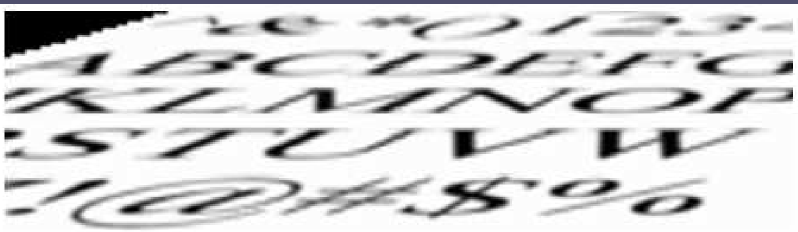


Figure 21: “High-efficiency” Simple Feline paints smooth text.

Other Types of 2D Maps

Bump/normal maps

- Modify or define surface normals

Displacement maps

- Modify surface itself

Environment/reflection maps

- Define environment seen in specular reflections

History

Catmull/Williams 1974 - basic idea

Blinn and Newell 1976 - basic idea, reflection maps

Blinn 1978 - bump mapping

Williams 1978, Reeves *et al.* 1987 - shadow maps

Smith 1980, Heckbert 1983 - texture mapped polygons

Williams 1983 - mipmaps

Miller and Hoffman 1984 - illumination and reflectance

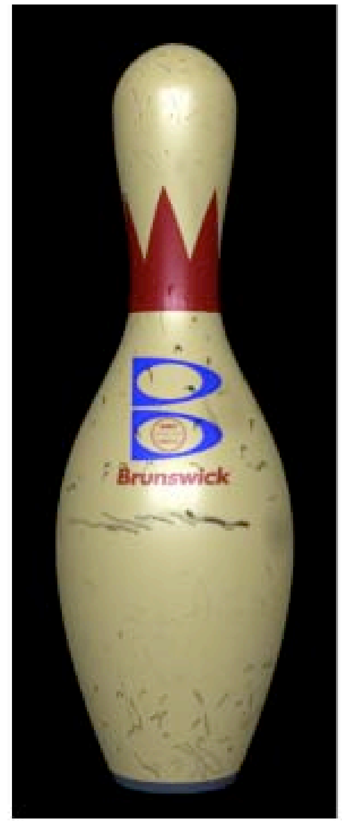
Perlin 1985, Peachey 1985 - solid textures

Greene 1986 - environment maps/world projections

Akeley 1993 - Reality Engine

Surface Color and Transparency

Tom Porter's Bowling Pin



Source: RenderMan Companion, Pls. 12 & 13

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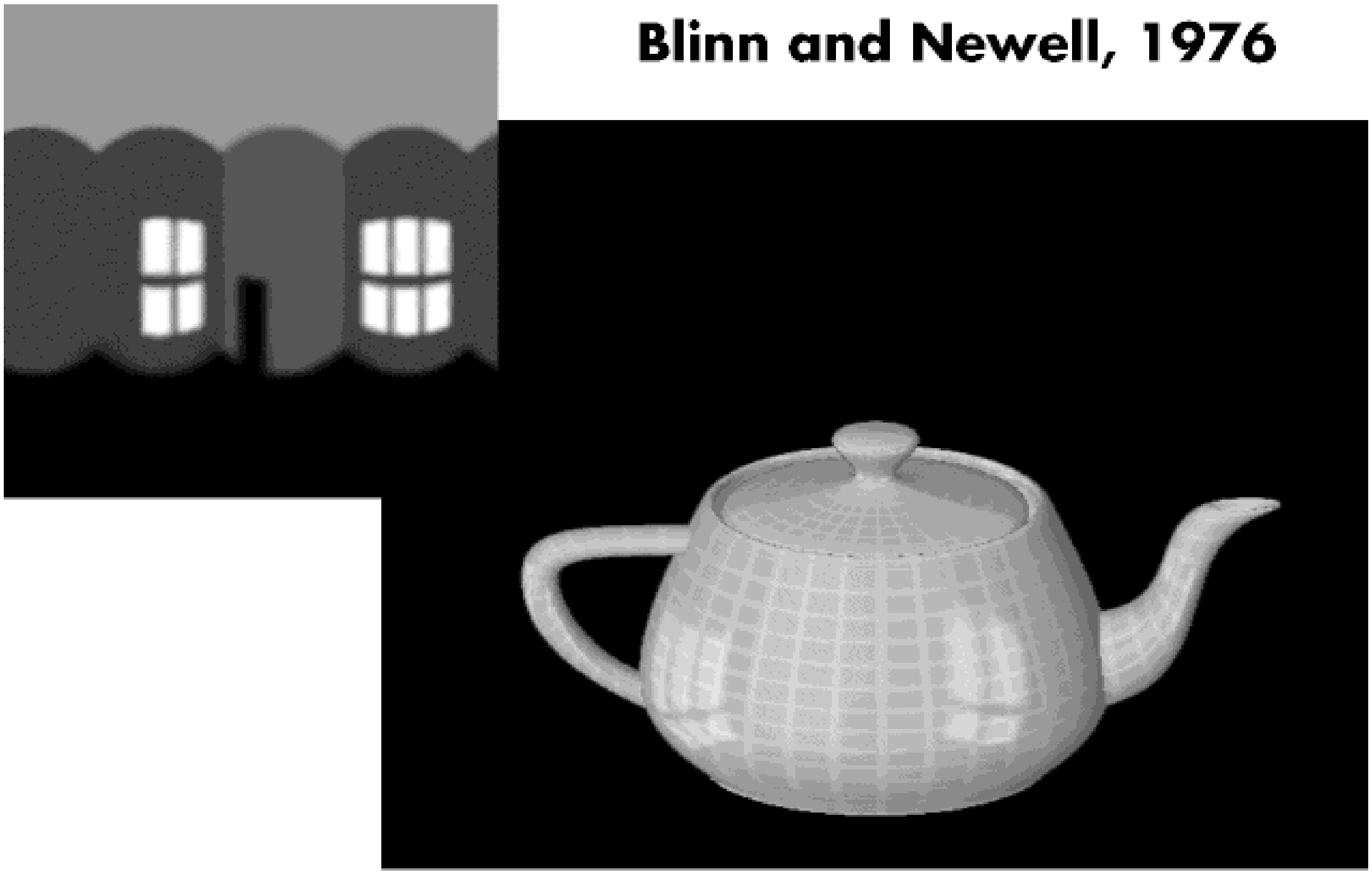
Reflection Maps

Blinn and Newell, 1976



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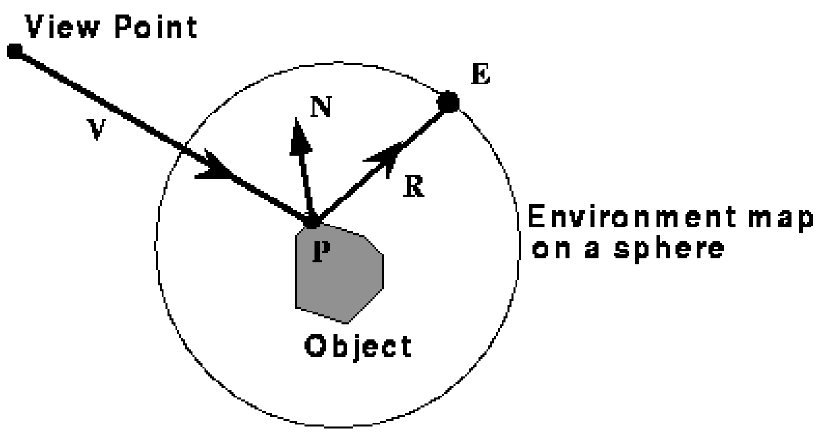
Environment Mapping

- Allows for world to be reflected on an object without modeling the physics
- Map the world surrounding an object onto a cube
- Project that cube onto the object
- During the shading calculation:
  - Bounce a ray from the viewer off the object (at point P)
  - Intersect the ray with the environment map (the cube), at point E
  - Get the environment map's color at E and illuminate P as if there were a virtual light source at position E
  - You see an image of the environment reflected on shiny surfaces

Environment Maps

If, instead of using the ray from the surface point to the projected texture's center, we used the *direction* of the reflected ray to index a texture map. We can simulate reflections. This approach is not completely accurate. It assumes that all reflected rays begin from the same point.



Environment Map Approximation

Ray Traced

Environment Map

Self reflections are missing in the environment map

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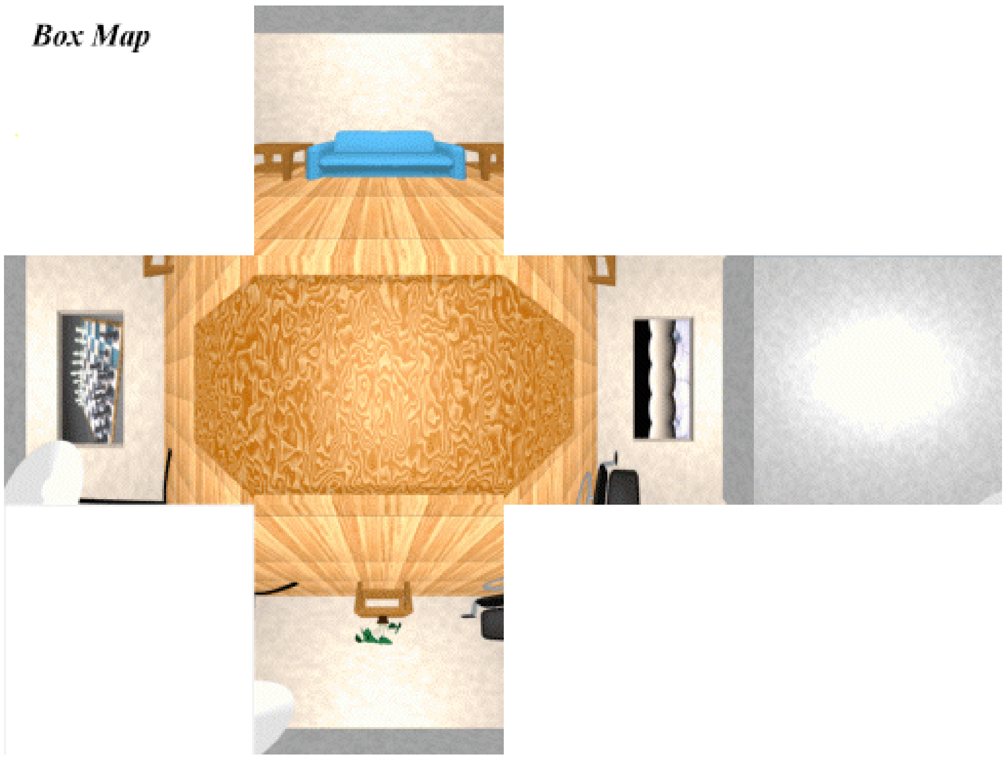
What's the Best Chart?

Box Map



Lattitude Map

GL Map

Fisheye Lens

Pair of 180 degree fisheye
Photo by K. Turkowski

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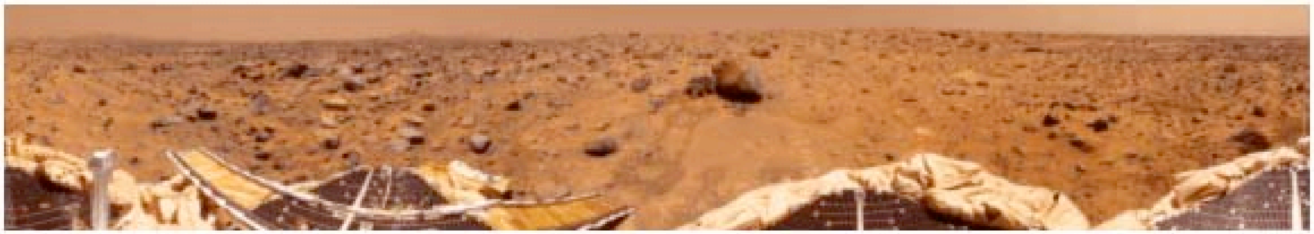
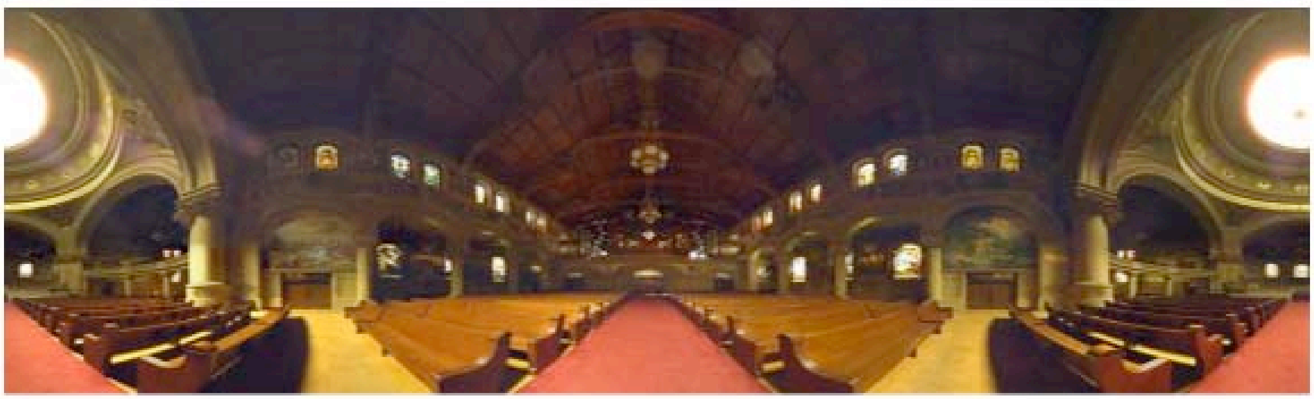
Cylindrical Panoramas

QuickTime VR



Mars Pathfinder



Memorial Church (Ken Turkowski)

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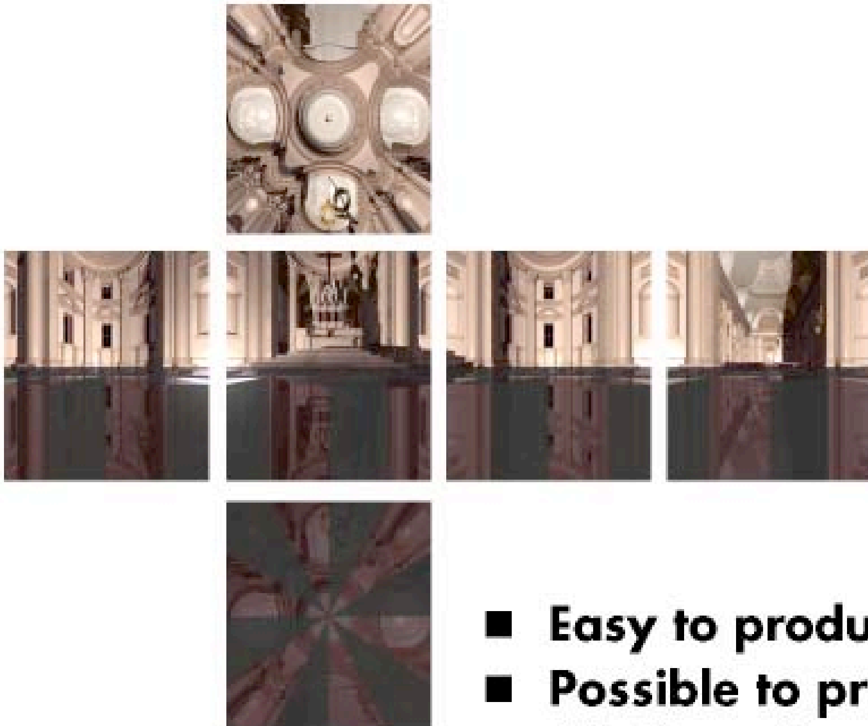
Cubical Environment Map



- Easy to produce with rendering system
- Possible to produce from photographs
- "Uniform" resolution
- Simple texture coordinates calculation

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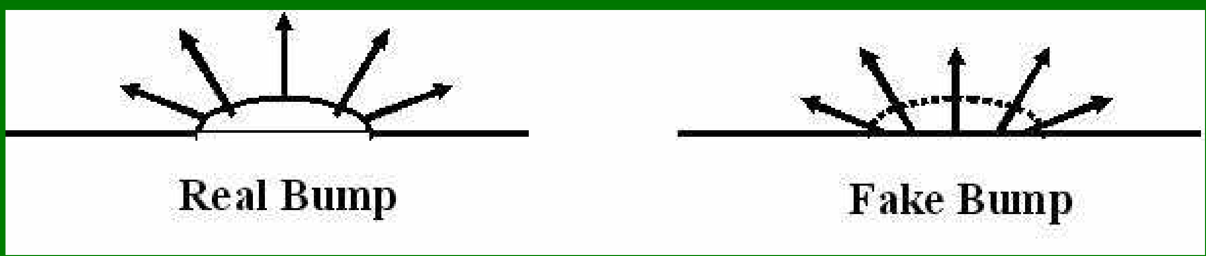
Reflection Mapping

Bump Mapping

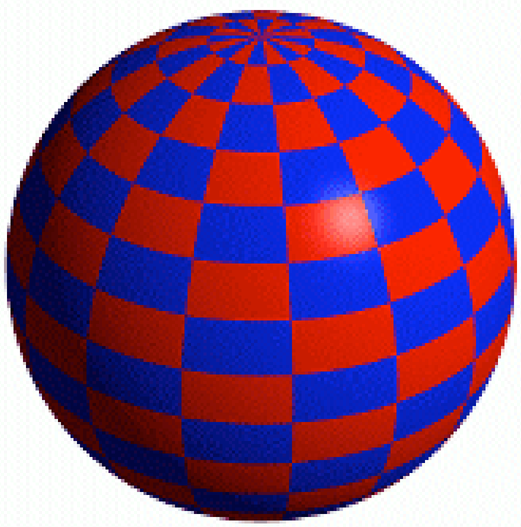
- How do you make a surface look *rough*?
  - Option 1: model the surface with many small polygons
  - Option 2: perturb the normal vectors before the shading calculation
    - the surface doesn't actually change, but shading makes it look that way
    - bump map fakes small displacements above or below the true surface
    - can use texture-mapping for this
    - For the math behind it all look at Angel 9.4



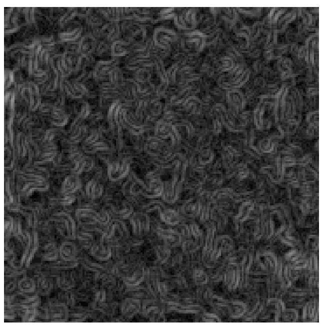
Bump Mapping

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! This technique is called *bump mapping*. The texture map is treated as a single-valued height function. The value of the function is not actually used, just its partial derivatives. The partial derivatives tell how to alter the true surface normal at each point on the surface to make the object appear as if it were deformed by the height function.

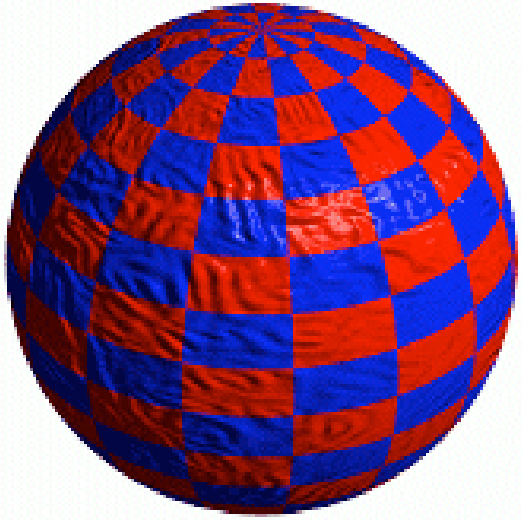
Since the actual shape of the object does not change, the silhouette edge of the object will not change. Bump Mapping also assumes that the Illumination model is applied at every pixel (as in Phong Shading or ray tracing).



Sphere w/Diffuse Texture



Swirly Bump Map



Sphere w/Diffuse Texture & Bump Map

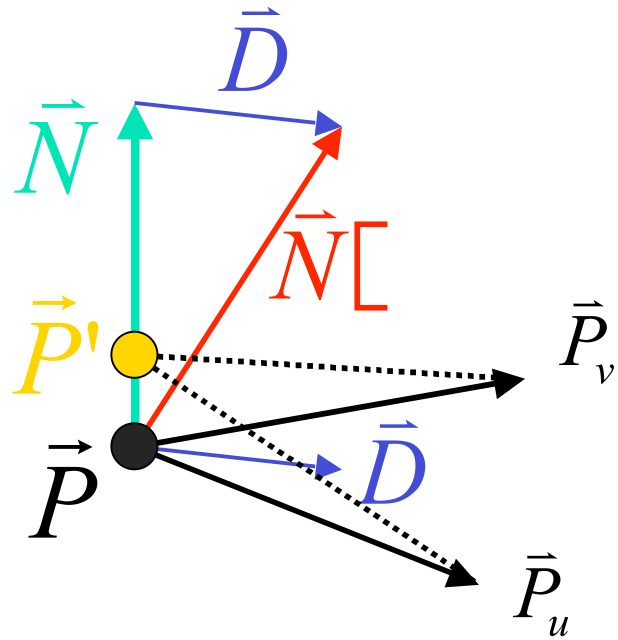
Bump mapping

If Pu and Pv are orthogonal and N is normalized:

$$\vec{P} = [x(u,v), y(u,v), z(u,v)]^T$$ Initial point

$$\vec{N} = \vec{P}_u \square \vec{P}_v$$ Normal

$$\vec{P}\square = \vec{P} + B(u,v)\vec{N}$$ Simulated elevated point after bump



$$\vec{N}\square\square\,\vec{N} + \underbrace{B_u\vec{P}_u + B_v\vec{P}_v}_{\vec{D}}$$

Variation of normal in u direction

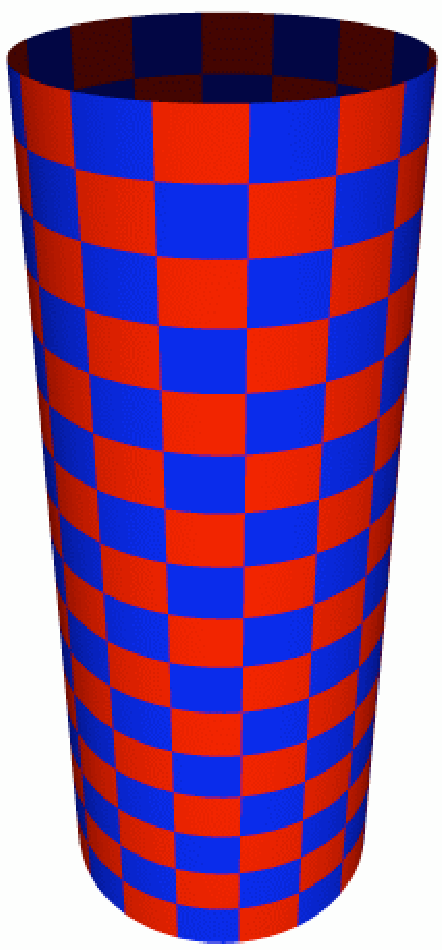
$$B_u = \frac{B(s\,\square\square,t)\,\square\,B(s+\square,t)}{2\square}$$

$$B_v = \frac{B(s,t\,\square\square)\,\square\,B(s,t+\square)}{2\square}$$

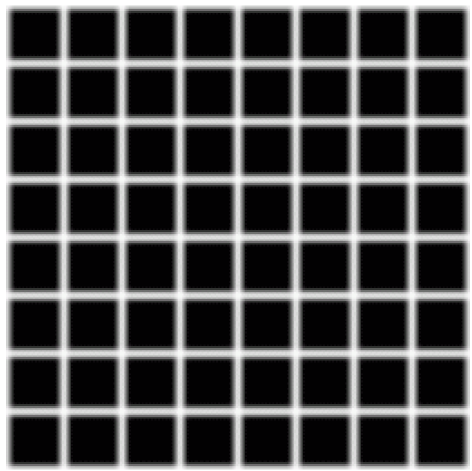
Variation of normal in v direction

Compute bump map partials by numerical differentiation

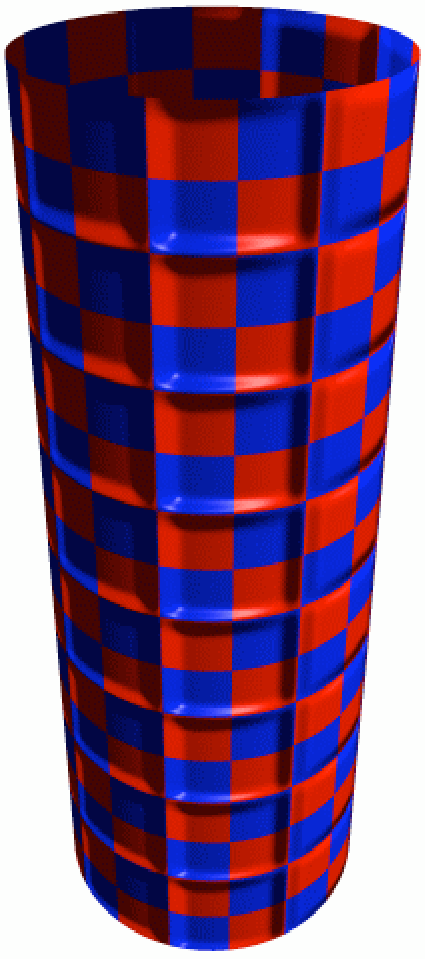
More Bump Map Examples



Cylinder w/Diffuse Texture Map

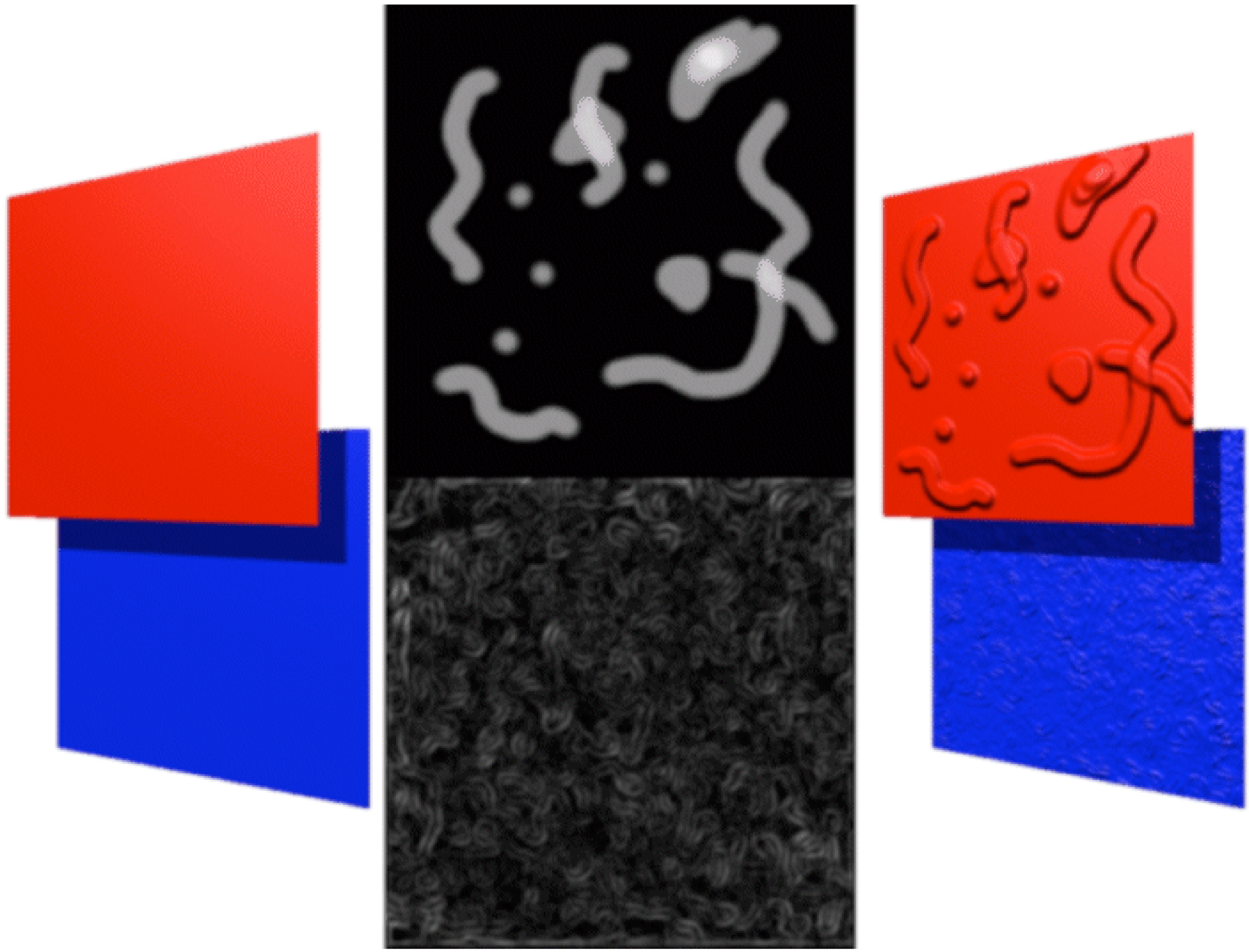


Bump Map



Cylinder w/Texture Map & Bump Map

One More Bump Map Example

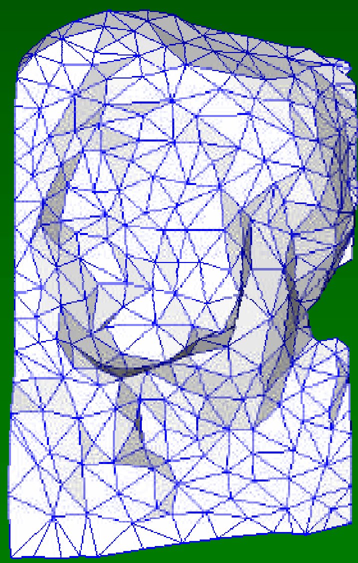


Notice that the shadow boundaries remain unchanged.

Bump Mapping

- In CG, we can perturb the normal vector without having to make any actual change to the shape.
- What would be the problems with bump mapping?

Original model (5M)

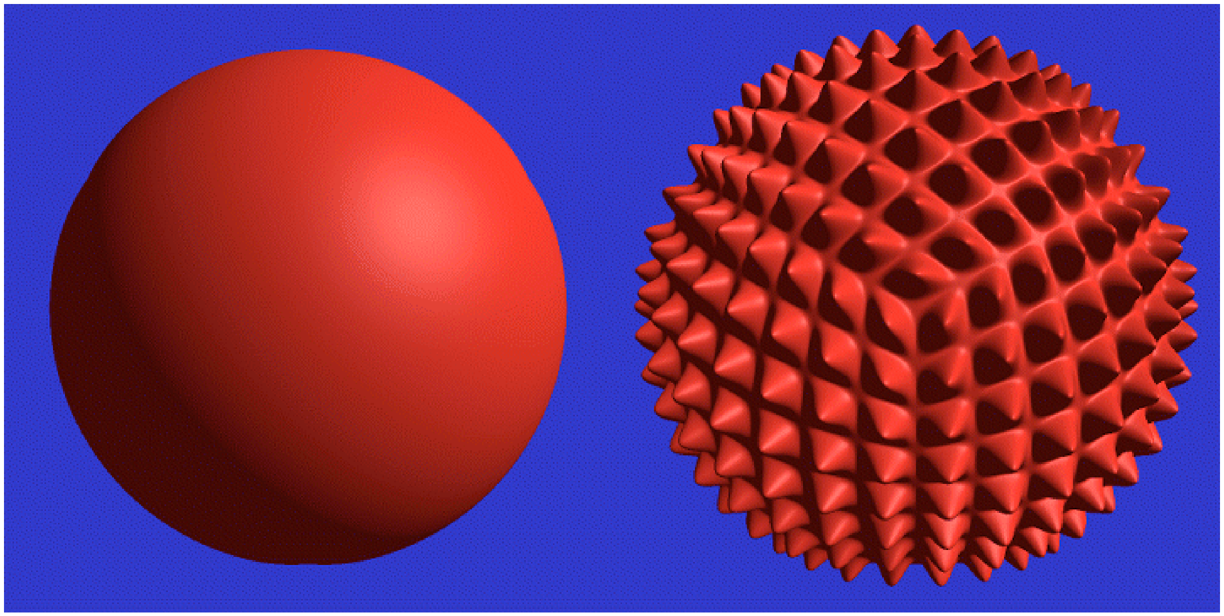


Simplified (500)

Simple model with bump map

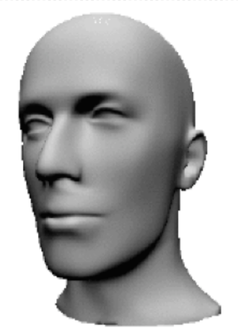
Displacement Mapping

We use the texture map to actually move the surface point. This is called *displacement mapping*. How is this fundamentally different than bump mapping?

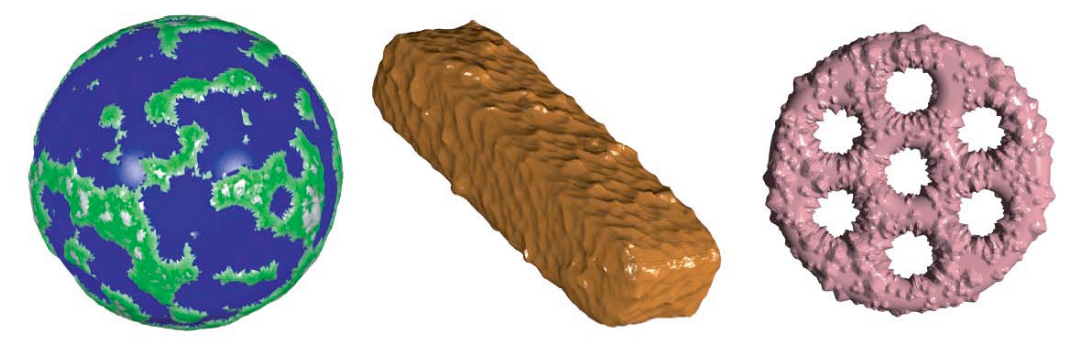


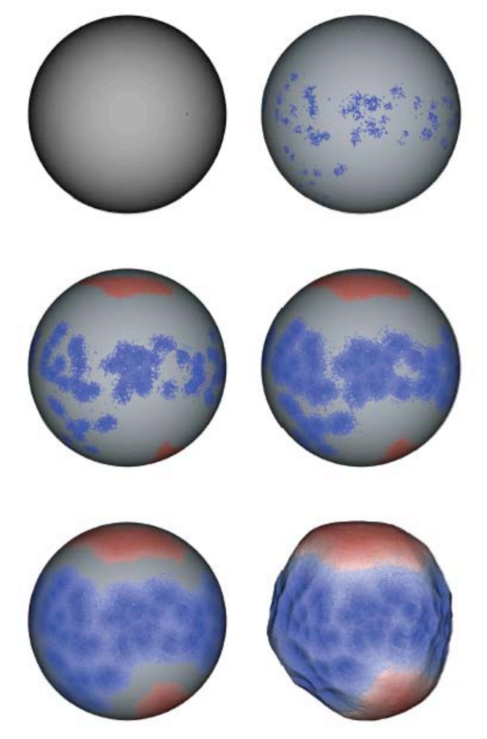
The geometry must be displaced before visibility is determined. Is this easily done in the graphics pipeline? In a ray-tracer?

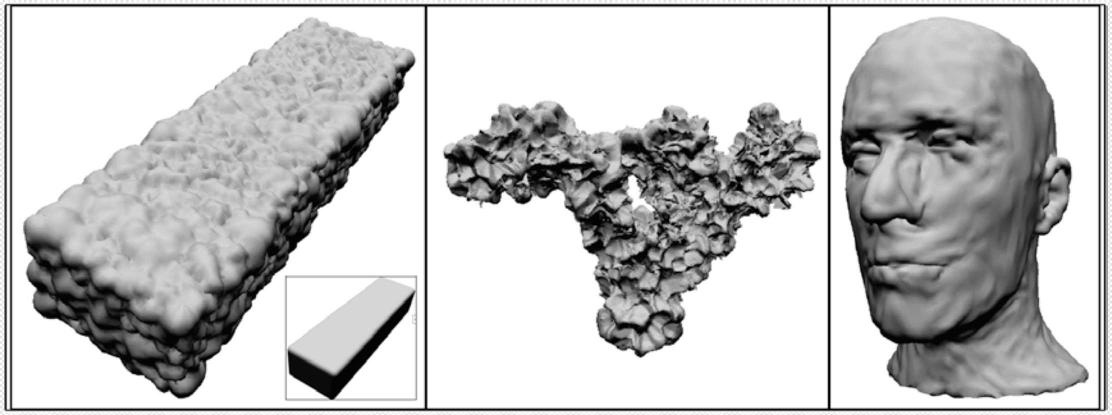
Stochastic Microgeometry for Displacement Mapping



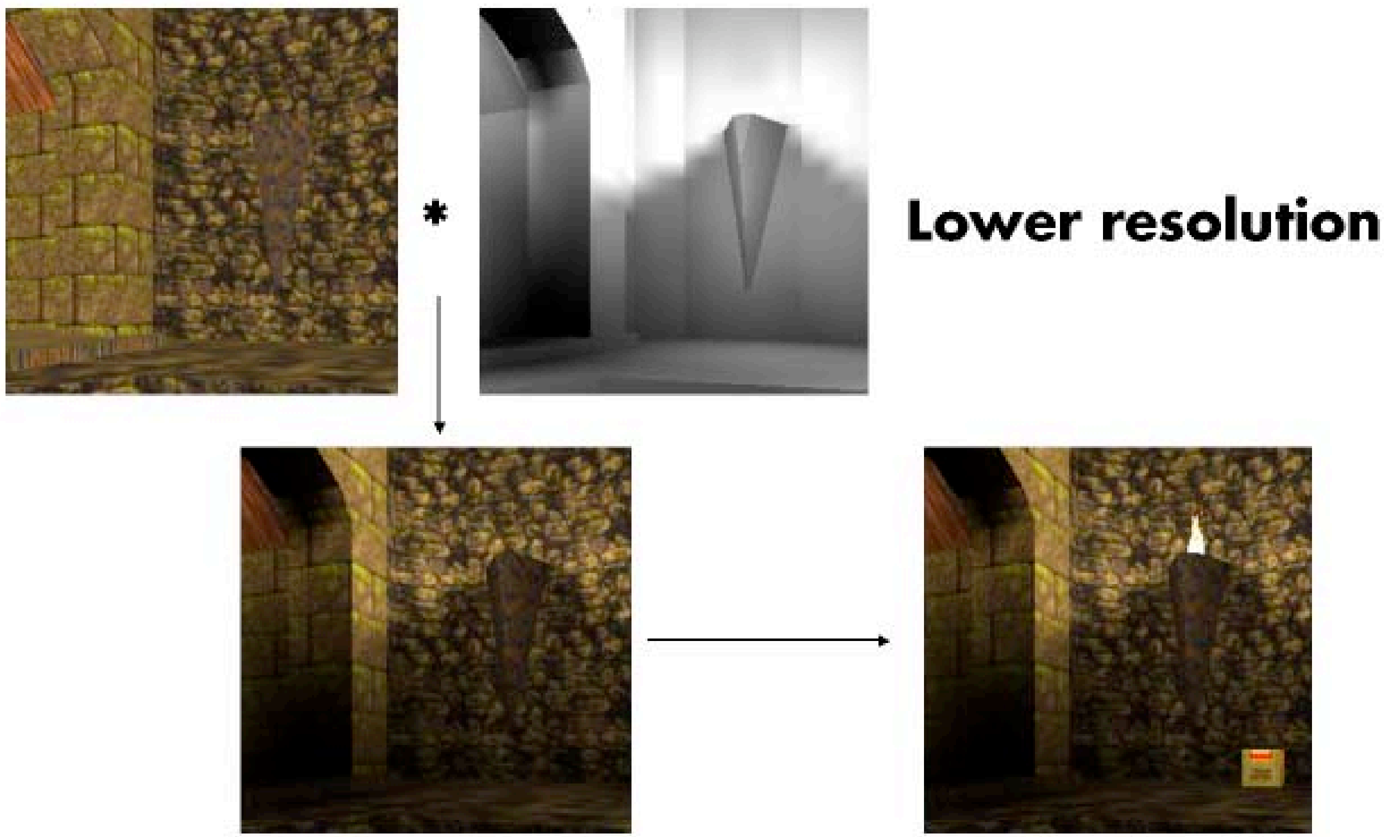
- Reconstruct a stochastic distribution over a mesh







Quake Light Maps



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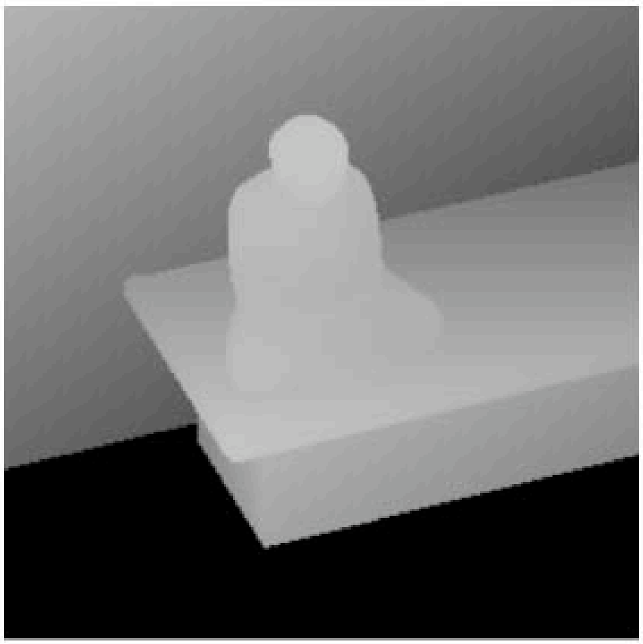
Shadow Maps

Shadow maps = depth maps from light source



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Correct Shadow Maps

Step 1:

Create z-buffer of scene as seen from light source

Step 2.

Render scene as seen from the eye

For each light

Transform point into light coordinates

return (zl < zbuffer[xl][yl]) ? 1 : 0

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The Best of All Worlds

All these texture mapping modes are great!

The problem is, no one of them does everything well.

Suppose we allowed several textures to be applied to each primitive during rasterization.