University of British Columbia
CPSC 314 Computer Graphics
Jan-Apr 2010

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Textures II

Week 10, Mon Mar 22

http://www.ugrad.cs.ubc.ca/~cs314/Vjan2010

News

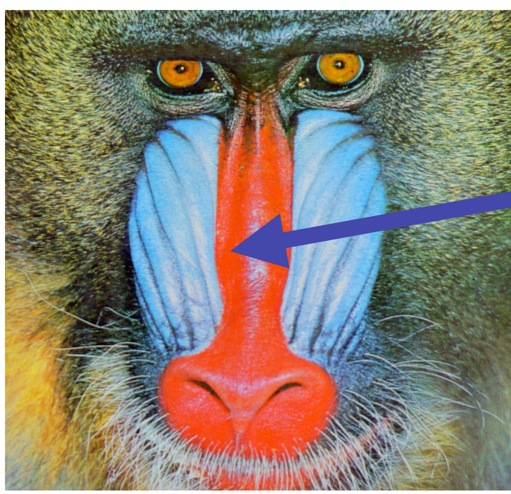
- signup sheet for P3 grading
  - today/Wed/Fri signups in class
  - or send email to dingkai AT cs
    - by 48 hours after the due date or you'll lose marks

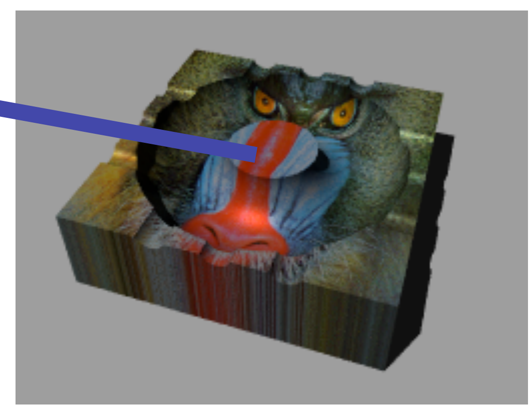
- again: extra TA office hours in lab for Q&A
  - Mon 10-1, Tue 12:30-3:30 (Garrett)
  - Tue 3:30-5, Wed 2-5 (Kai)
  - Thu 12-3:30 (Shailen)
  - Fri 2-4 (Kai)

Review: Texture Coordinates

- texture image: 2D array of color values (texels)
- assigning texture coordinates (s,t) at vertex with object coordinates (x,y,z,w)
  - use interpolated (s,t) for texel lookup at each pixel
  - use value to modify a polygon’s color
    - or other surface property
  - specified by programmer or artist

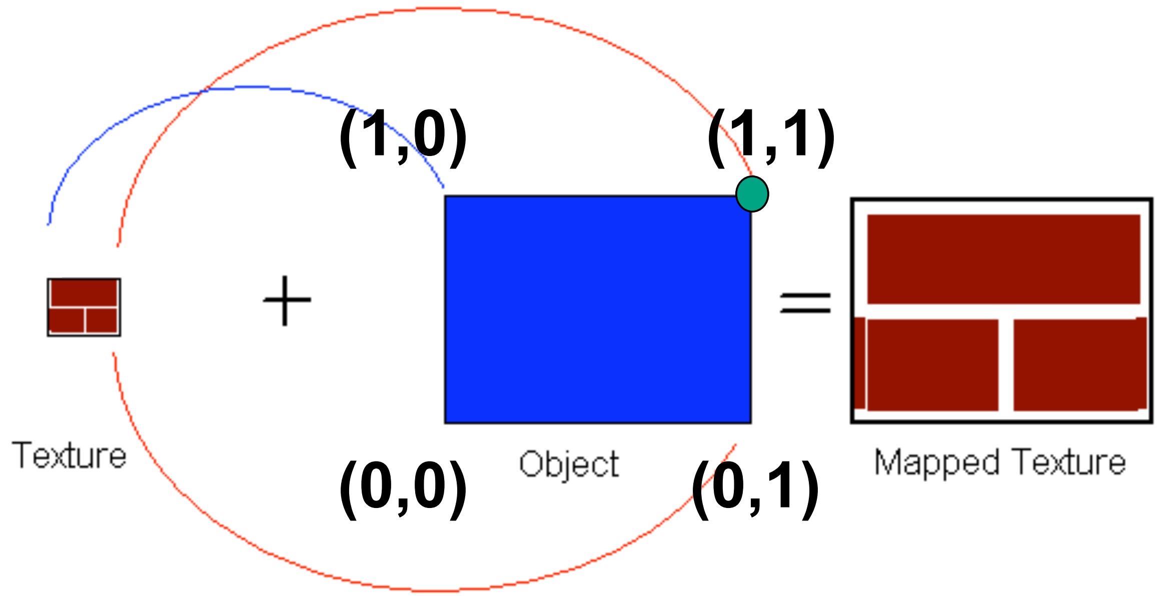
```
glTexCoord2f(s,t)
glVertexf(x,y,z,w)
```



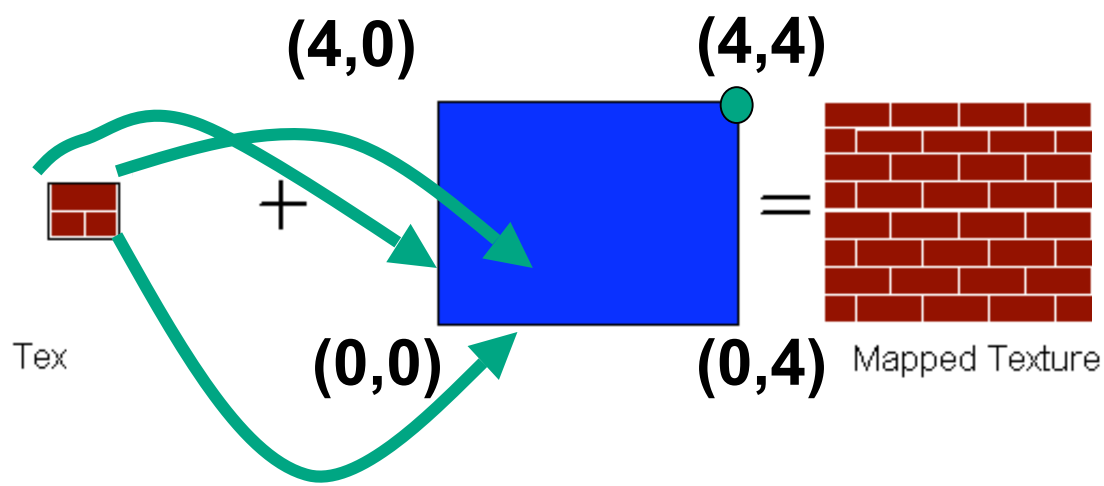


Review: Tiled Texture Map

```
glTexCoord2d(1, 1);
glVertex3d (x, y, z);
```

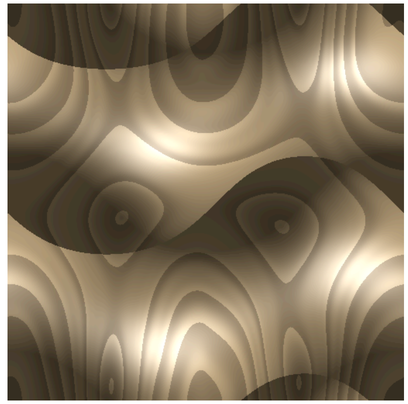



```
glTexCoord2d(4, 4);
glVertex3d (x, y, z);
```

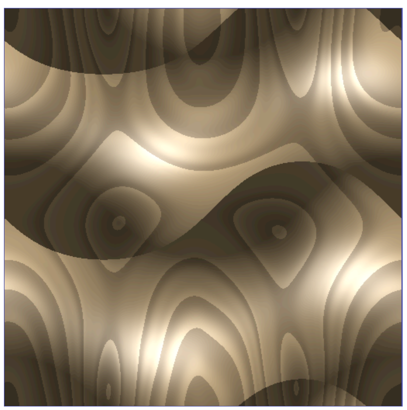


Review: Fractional Texture Coordinates

texture image

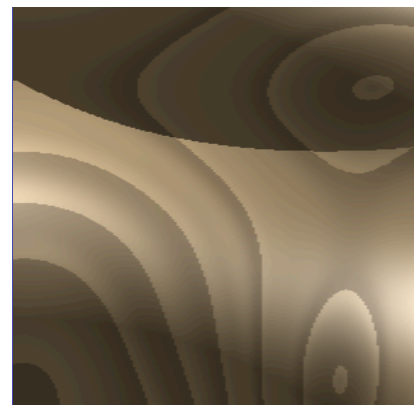


(0,1) (1,1)



(0,0) (1,0)

(0,.5) (.25,.5)



(0,0) (.25,0)

Review: Texture

- action when s or t is outside [0…1] interval
  - tiling
  - clamping
- functions
  - replace/decal
  - modulate
  - blend
- texture matrix stack

```
glMatrixMode( GL_TEXTURE );
```

Textures II

Texture Pipeline

(x, y, z)

Object position

(-2.3, 7.1, 17.7)

(s, t)

Parameter space

(0.32, 0.29)

(s', t')

Transformed parameter space

(0.52, 0.49)

Texel space

(81, 74)

Texel color

(0.9,0.8,0.7)

Object color

(0.5,0.5,0.5)

Final color

(0.45,0.4,0.35)

Texture Objects and Binding

- texture object
  - an OpenGL data type that keeps textures resident in memory and provides identifiers to easily access them
  - provides efficiency gains over having to repeatedly load and reload a texture
  - you can prioritize textures to keep in memory
  - OpenGL uses least recently used (LRU) if no priority is assigned
- texture binding
  - which texture to use right now
  - switch between preloaded textures

Basic OpenGL Texturing

- create a texture object and fill it with texture data:
  - `glGenTextures(num, &indices)` to get identifiers for the objects
  - `glBindTexture(GL_TEXTURE_2D, identifier)` to bind
    - following texture commands refer to the bound texture
  - `glTexParameteri(GL_TEXTURE_2D, …, …)` to specify parameters for use when applying the texture
  - `glTexImage2D(GL_TEXTURE_2D, ….)` to specify the texture data (the image itself)
- enable texturing: `glEnable(GL_TEXTURE_2D)`
- state how the texture will be used:
  - `glTexEnvf(…)`
- specify texture coordinates for the polygon:
  - use `glTexCoord2f(s,t)` before each vertex:
    - `glTexCoord2f(0,0); glVertex3f(x,y,z);`

Low-Level Details

- large range of functions for controlling layout of texture data
  - state how the data in your image is arranged
  - e.g.: `glPixelStorei(GL_UNPACK_ALIGNMENT, 1)` tells OpenGL not to skip bytes at the end of a row
  - you must state how you want the texture to be put in memory: how many bits per “pixel”, which channels,…
- textures must be square and size a power of 2
  - common sizes are 32x32, 64x64, 256x256
  - smaller uses less memory, and there is a finite amount of texture memory on graphics cards
- ok to use texture template sample code for project 4
  - http://nehe.gamedev.net/data/lessons/lesson.asp?lesson=09

Texture Mapping

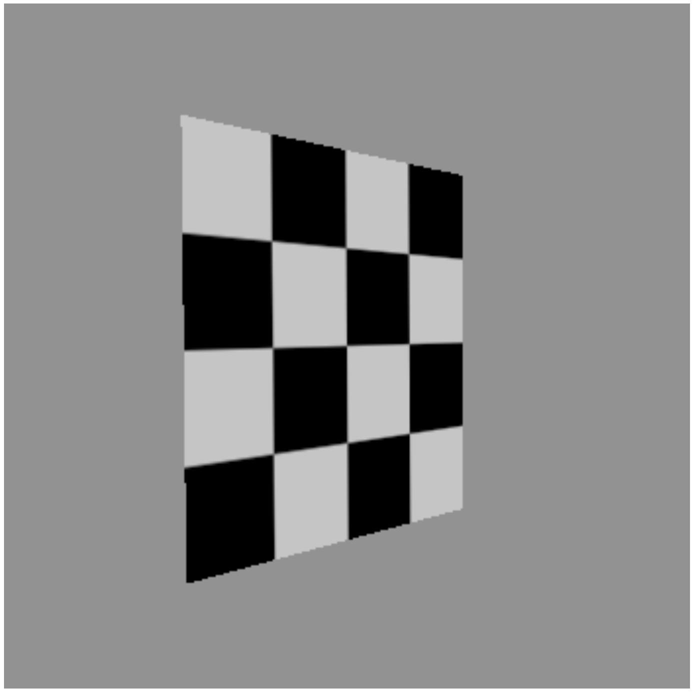
- texture coordinates
  - specified at vertices

```
glTexCoord2f(s,t);
glVertexf(x,y,z);
```

  - interpolated across triangle (like R,G,B,Z)
    - …well not quite!

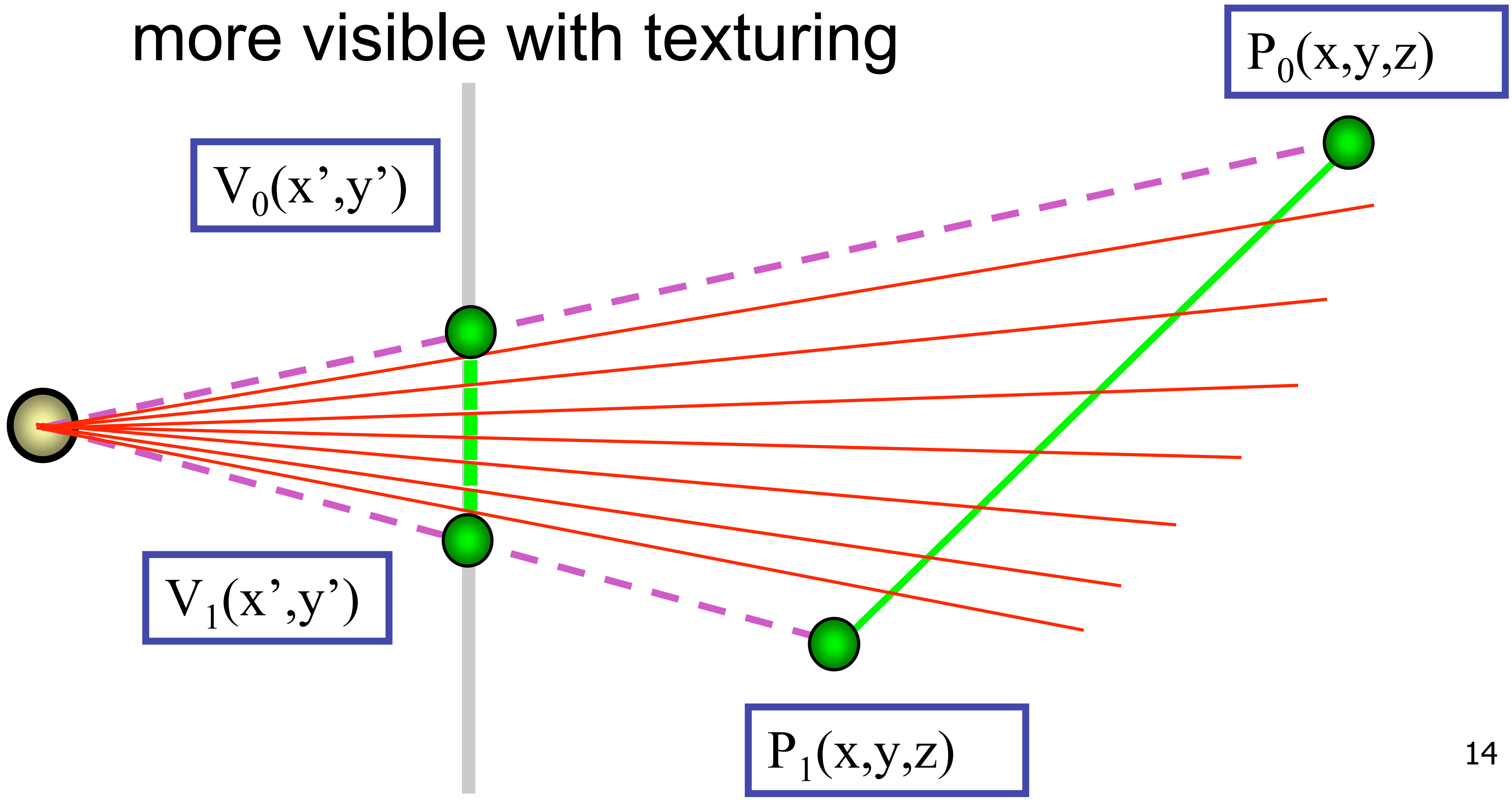
Texture Mapping

- texture coordinate interpolation
  - perspective foreshortening problem



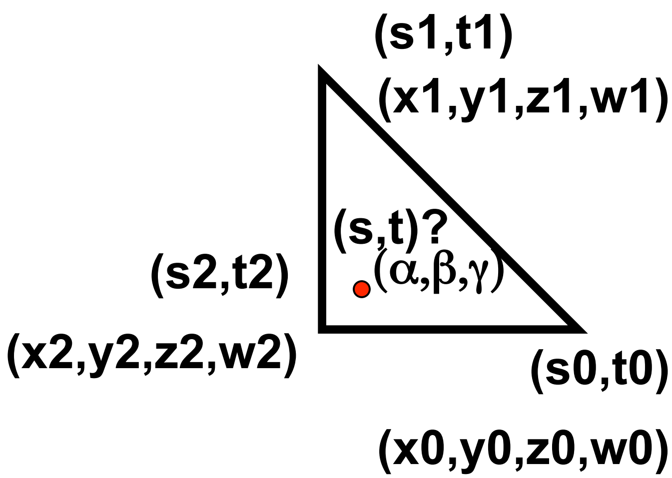

Interpolation: Screen vs. World Space

- screen space interpolation incorrect
  - problem ignored with shading, but artifacts more visible with texturing



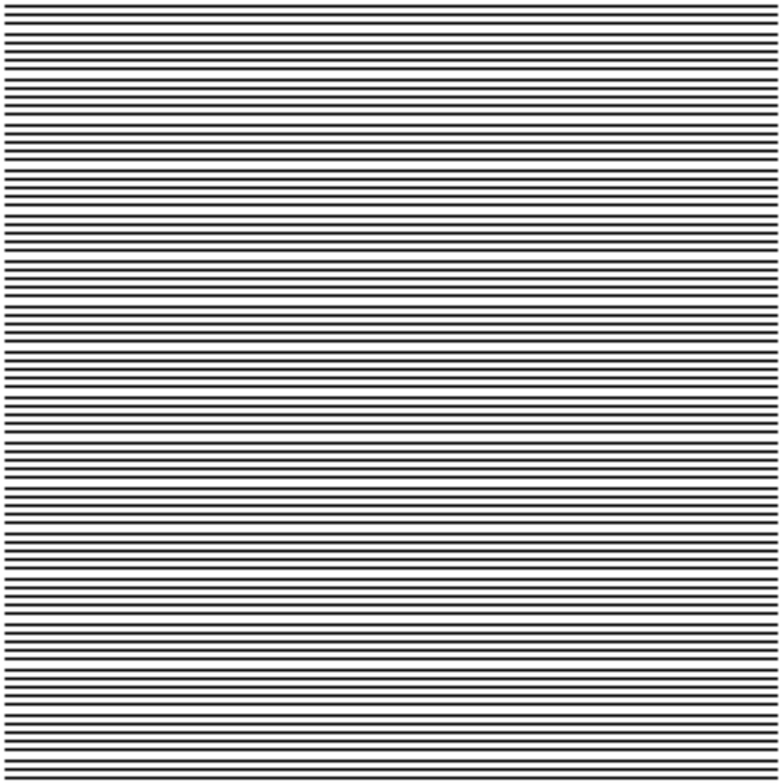
Texture Coordinate Interpolation

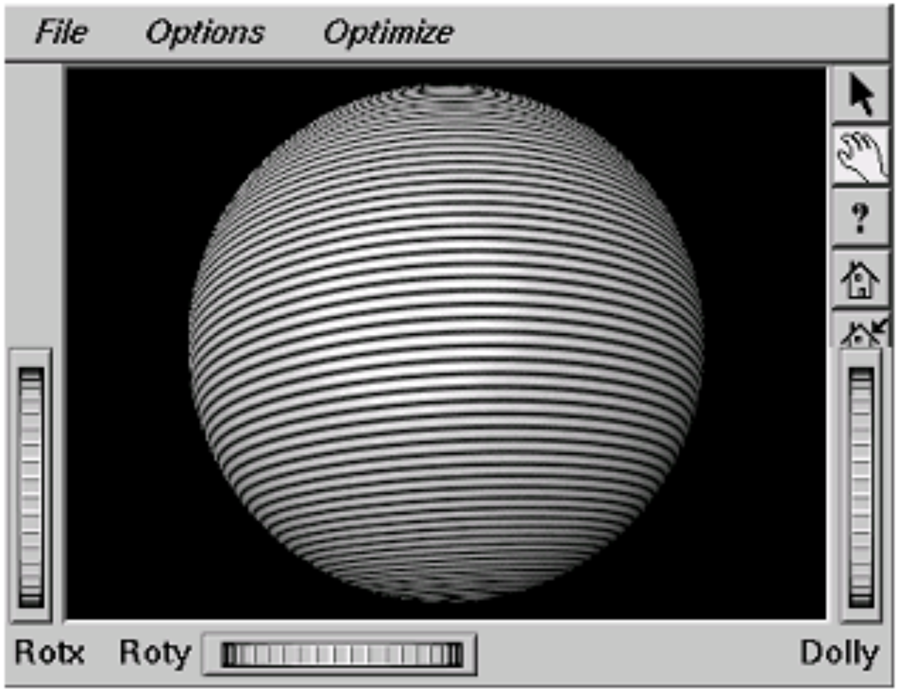
- perspective correct interpolation
  - α, β, γ :
    - barycentric coordinates of a point **P** in a triangle
  - *s0*, *s1*, *s2* :
    - texture coordinates of vertices
  - *w0*, *w1*,*w2* :
    - homogeneous coordinates of vertices



$$s = \frac{\alpha \cdot s_0 / w_0 + \beta \cdot s_1 / w_1 + \gamma \cdot s_2 / w_2}{\alpha / w_0 + \beta / w_1 + \gamma / w_2}$$

Reconstruction

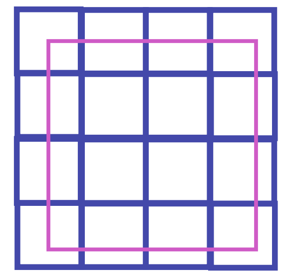




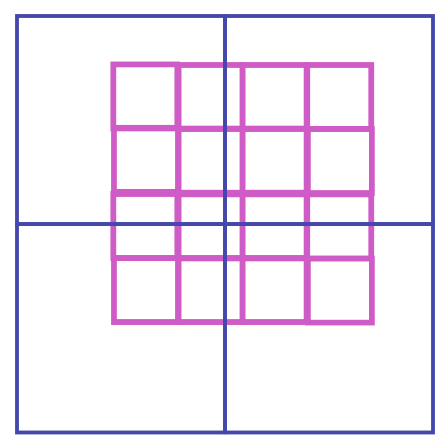
(image courtesy of Kiriakos Kutulakos, U Rochester)

Reconstruction

- how to deal with:
  - pixels that are much larger than texels?
    - apply filtering, “averaging”

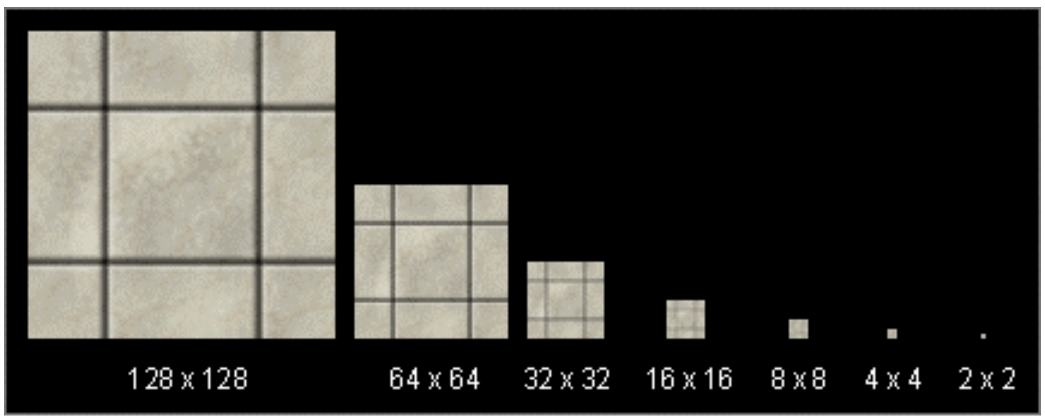


  - pixels that are much smaller than texels ?
    - interpolate

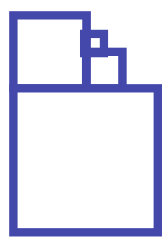


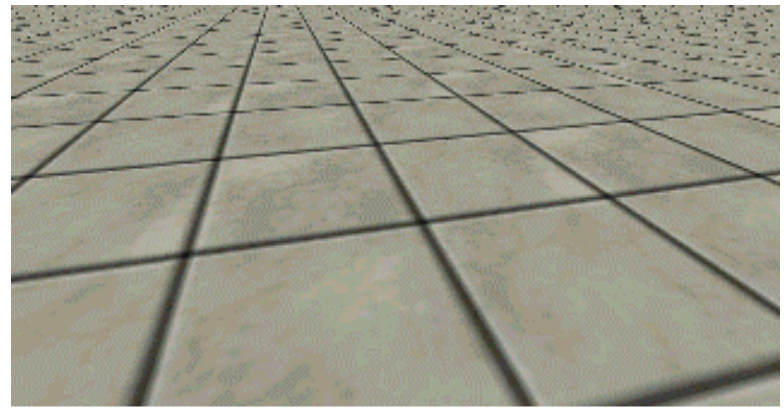
MIPmapping

use "image pyramid" to precompute averaged versions of the texture

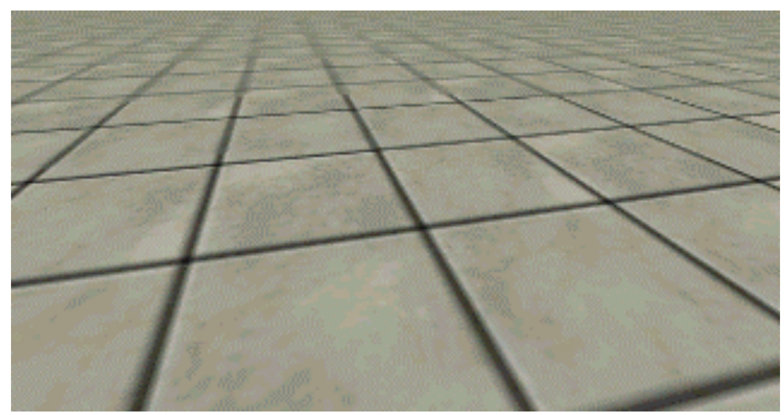


store whole pyramid in single block of memory





Without MIP-mapping

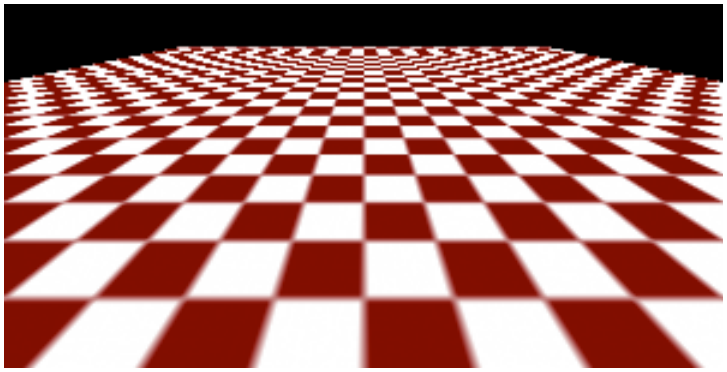


With MIP-mapping

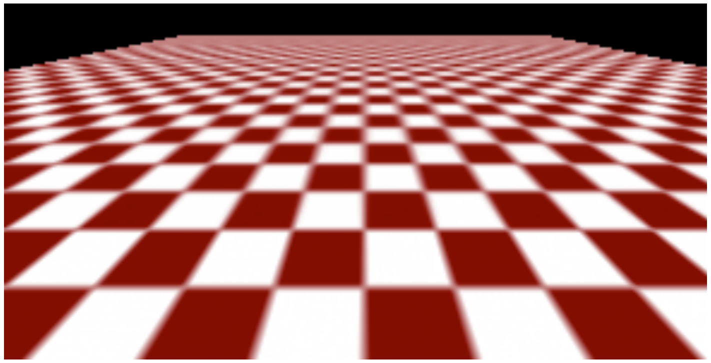
MIPmaps

- **multum in parvo** -- many things in a small place
  - prespecify a series of prefiltered texture maps of decreasing resolutions
  - requires more texture storage
  - avoid shimmering and flashing as objects move
- `gluBuild2DMipmaps`
  - automatically constructs a family of textures from original texture size down to 1x1

without



with

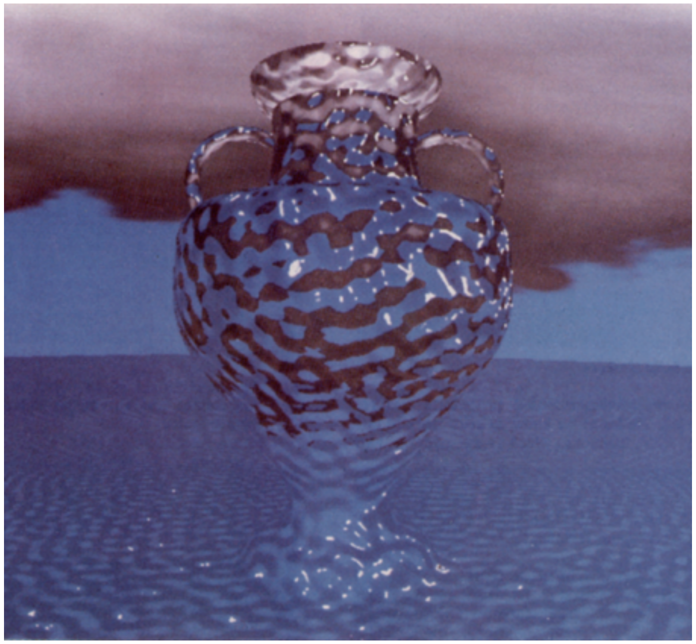


MIPmap storage

- only 1/3 more space required

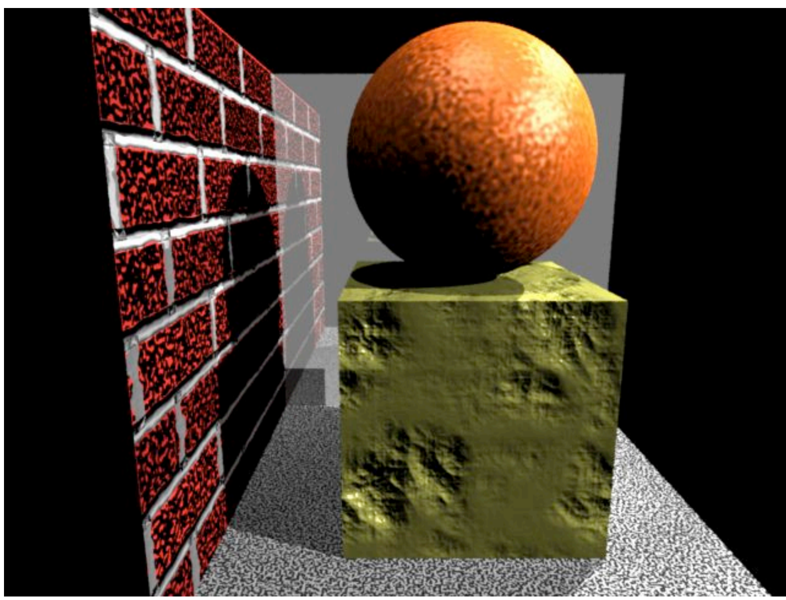
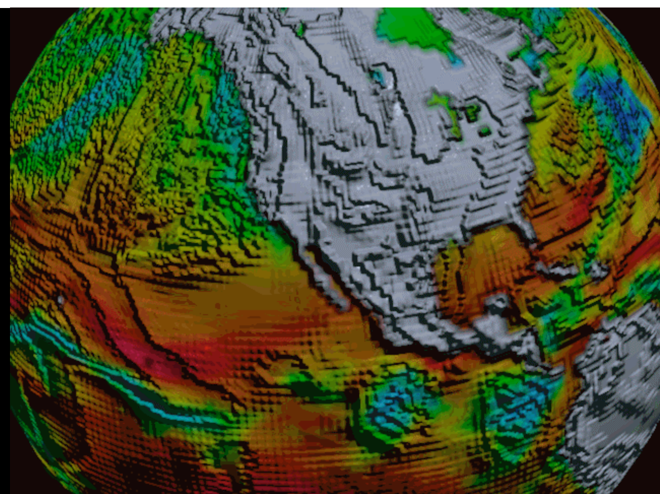
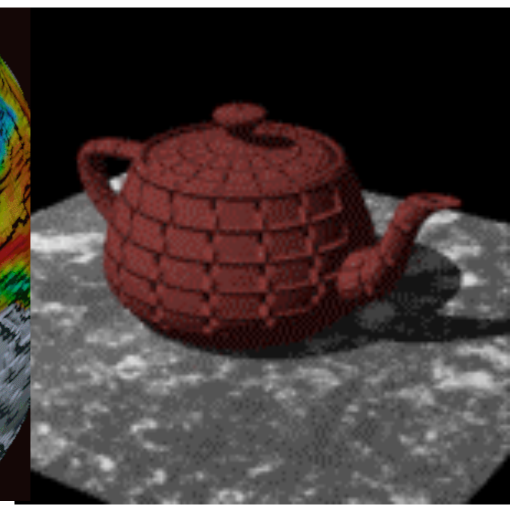
Texture Parameters

- in addition to color can control other material/object properties
  - surface normal (bump mapping)
  - reflected color (environment mapping)

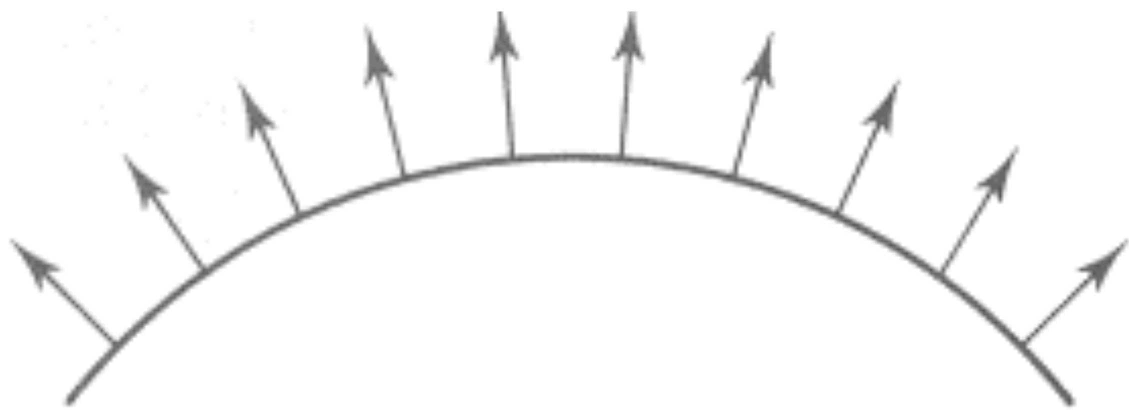


Bump Mapping: Normals As Texture

- object surface often not smooth – to recreate correctly need complex geometry model
- can control shape "effect" by locally perturbing surface normal
  - random perturbation
  - directional change over region

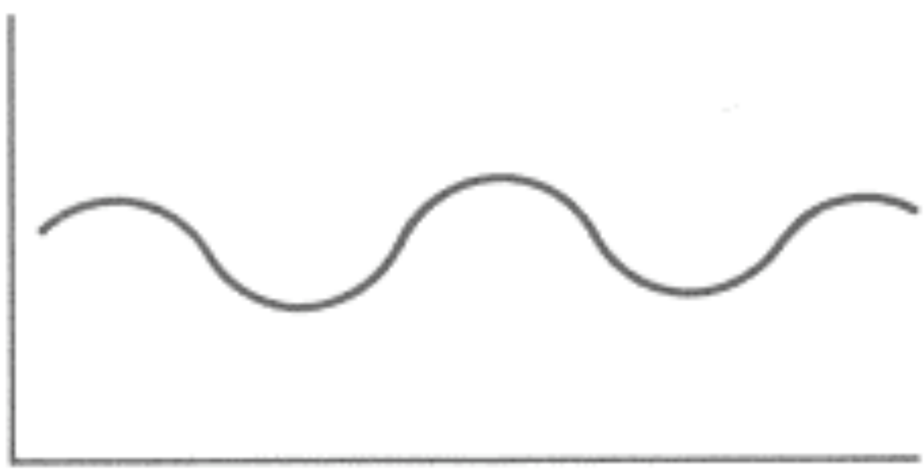




Bump Mapping



$O(u)$

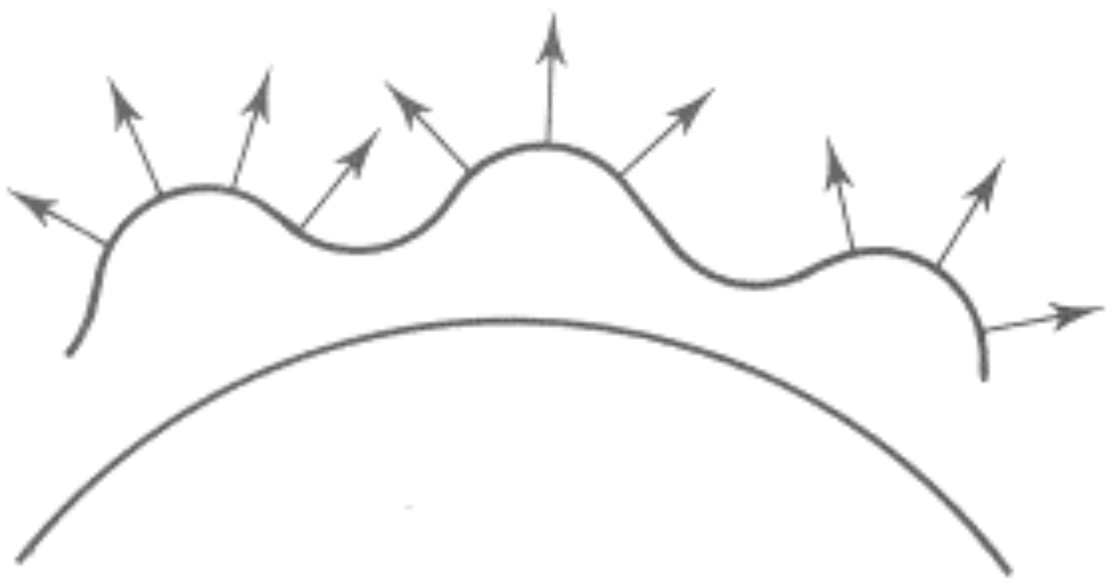
Original surface



$B(u)$

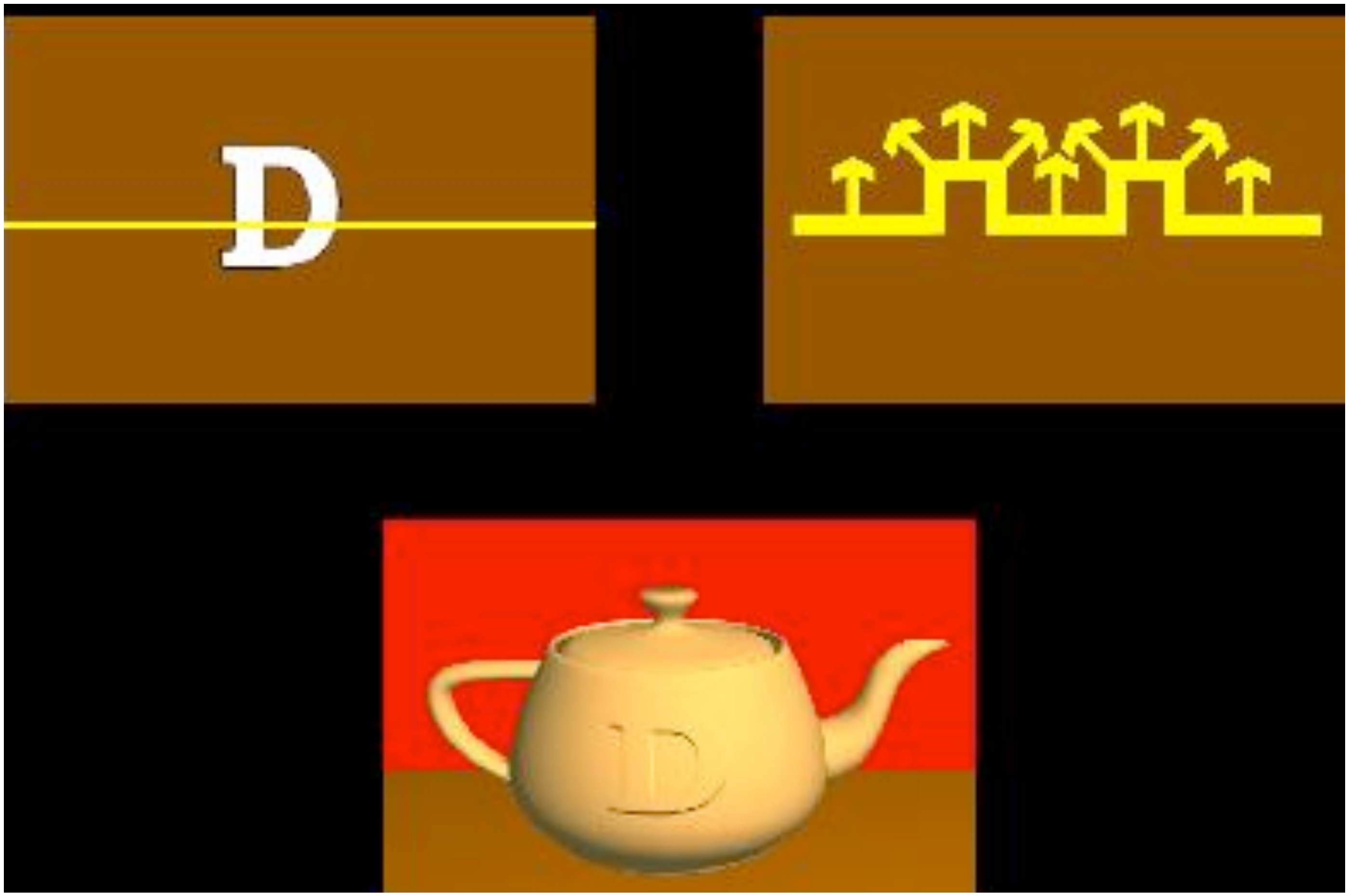
A bump map

Bump Mapping



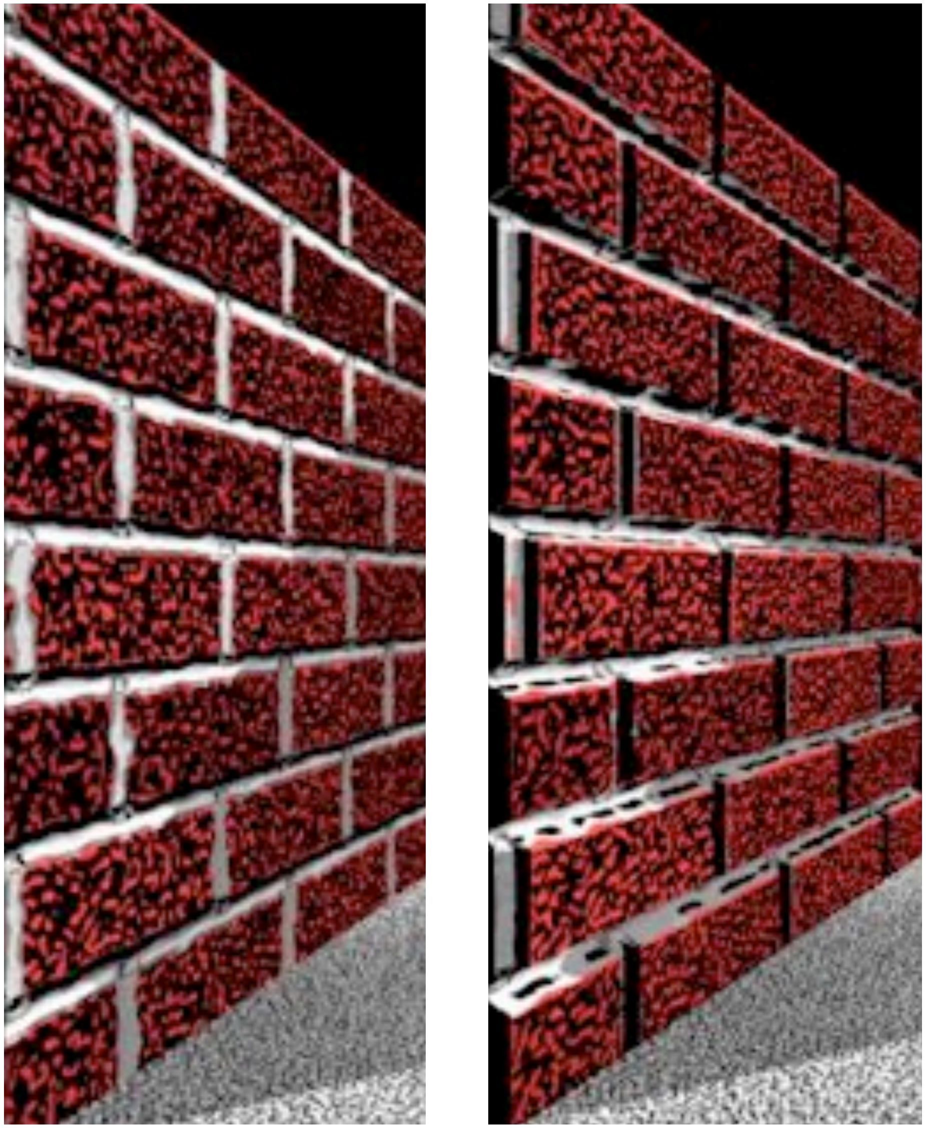
Embossing

- at transitions
  - rotate point's surface normal by θ or - θ



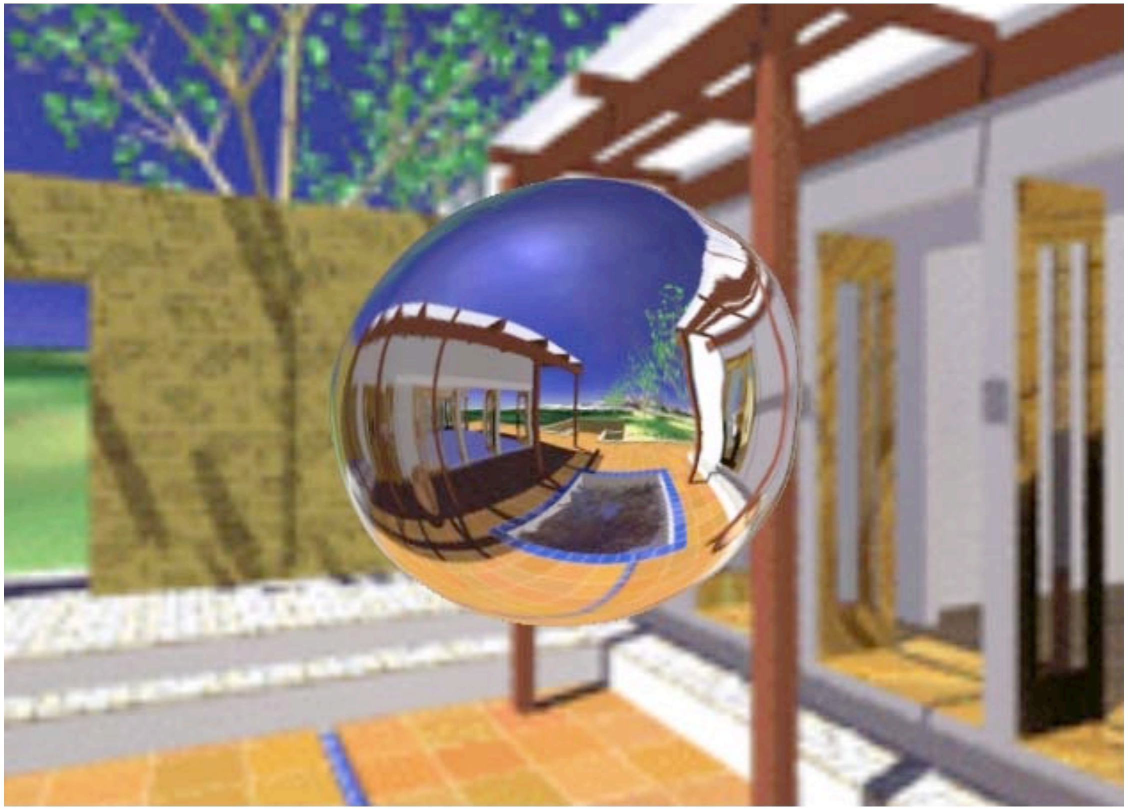
Displacement Mapping

- bump mapping gets silhouettes wrong
  - shadows wrong too
- change surface geometry instead
  - only recently available with realtime graphics
  - need to subdivide surface



Environment Mapping

- cheap way to achieve reflective effect
  - generate image of surrounding
  - map to object as texture

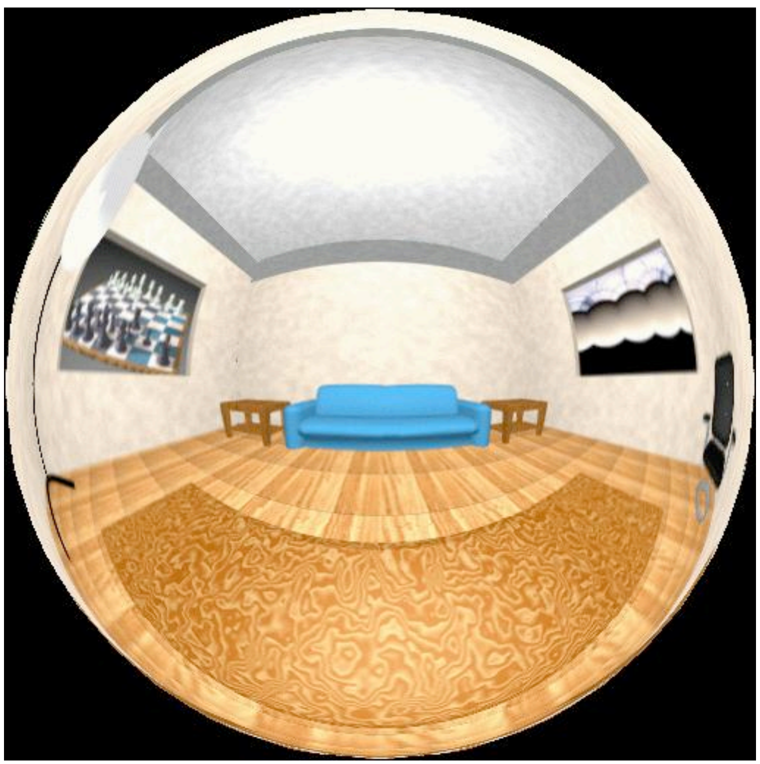


Environment Mapping

- used to model object that reflects surrounding textures to the eye
  - movie example: cyborg in Terminator 2
- different approaches
  - sphere, cube most popular
    - OpenGL support
      - `GL_SPHERE_MAP, GL_CUBE_MAP`
  - others possible too

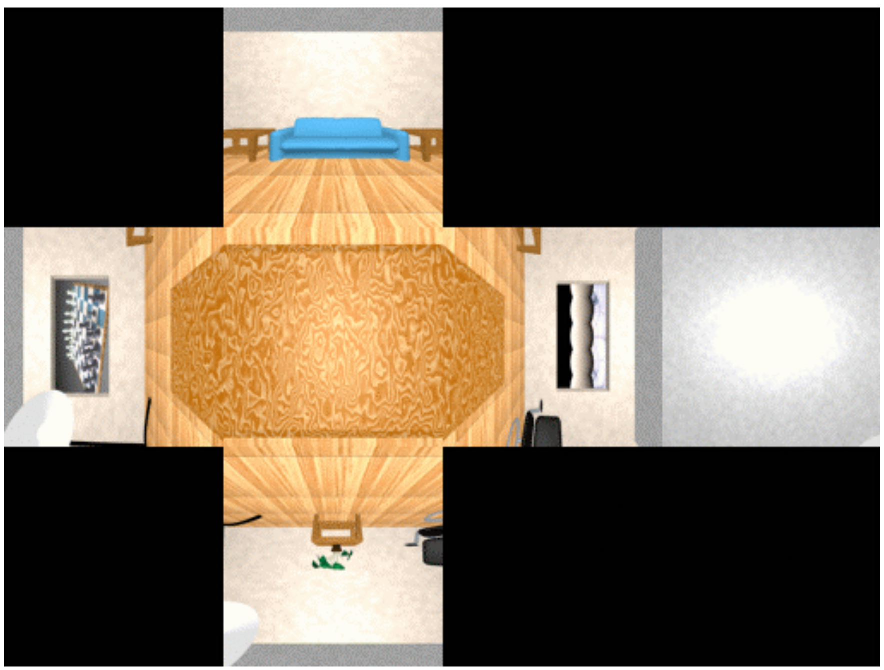
Sphere Mapping

- texture is distorted fish-eye view
  - point camera at mirrored sphere
  - spherical texture mapping creates texture coordinates that correctly index into this texture map

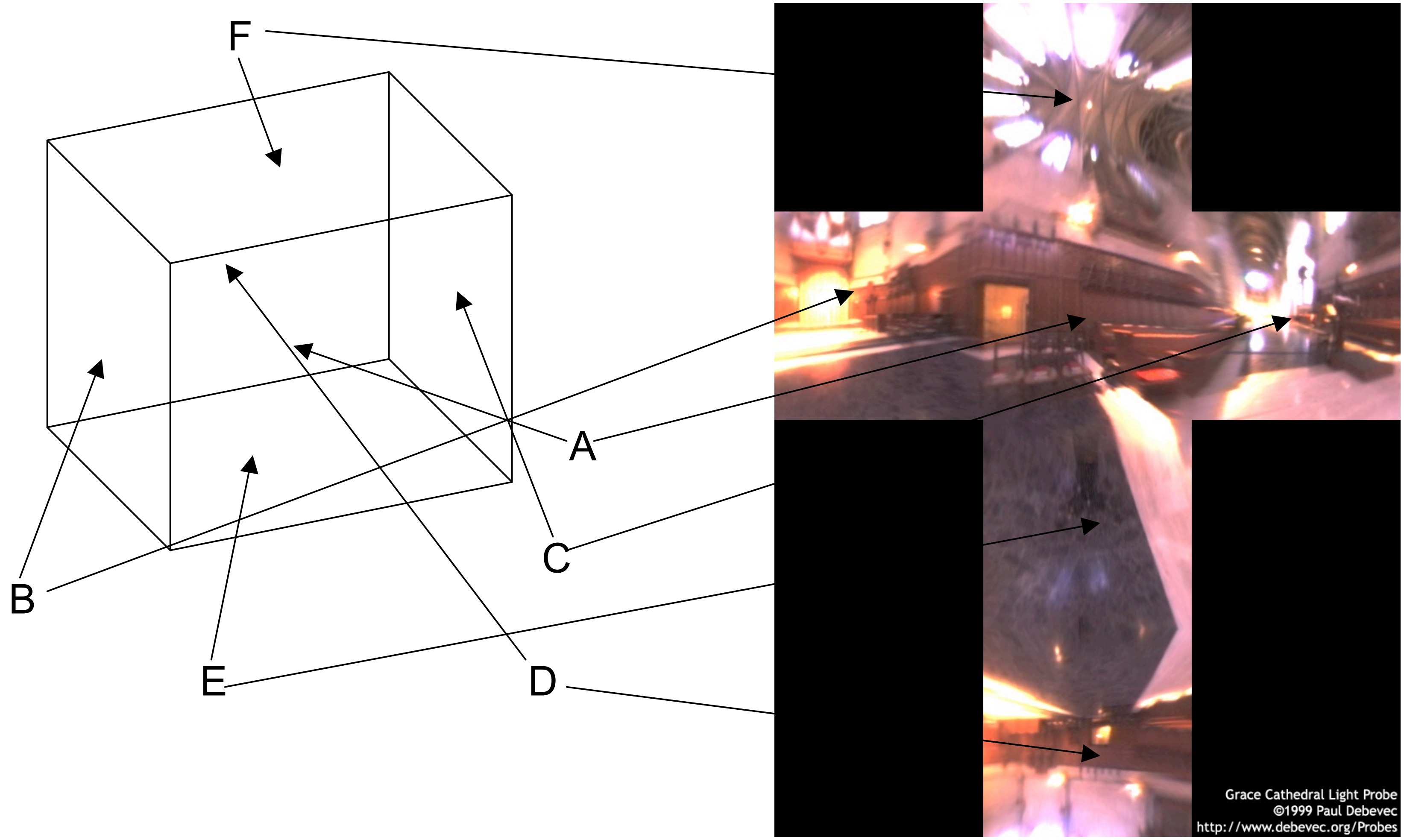


Cube Mapping

- 6 planar textures, sides of cube
  - point camera in 6 different directions, facing out from origin



Cube Mapping

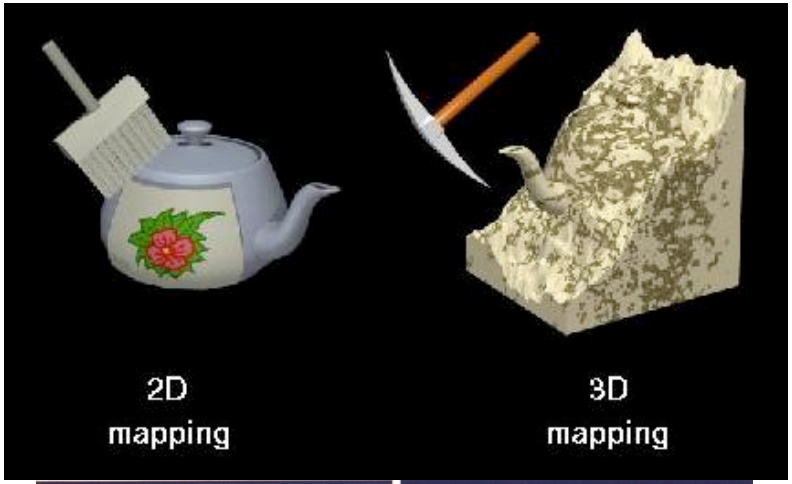


Cube Mapping

- direction of reflection vector *r* selects the face of the cube to be indexed
  - co-ordinate with largest magnitude
    - e.g., the vector (-0.2, 0.5, -0.84) selects the –Z face
  - remaining two coordinates (normalized by the 3rd coordinate) selects the pixel from the face.
    - e.g., (-0.2, 0.5) gets mapped to (0.38, 0.80).
- difficulty in interpolating across faces

Volumetric Texture

- define texture pattern over 3D domain - 3D space containing the object
  - texture function can be digitized or procedural
  - for each point on object compute texture from point location in space
- common for natural material/irregular textures (stone, wood,etc…)



Volumetric Bump Mapping

Marble

Bump

Volumetric Texture Principles

- 3D function $\rho(x,y,z)$
- texture space – 3D space that holds the texture (discrete or continuous)
- rendering: for each rendered point P(x,y,z) compute $\rho(x,y,z)$
- volumetric texture mapping function/space transformed with objects