Texture Mapping

Wolfgang Heidrich

Course News

Assignment 2

- Due Monday!

Quiz 2 MOVED!

- Friday, March 13 (instead of Wed, March 11)
- Office hours on Wednesday, Thursday (Mar 11/12)
- Out of town Mon, Mar 9

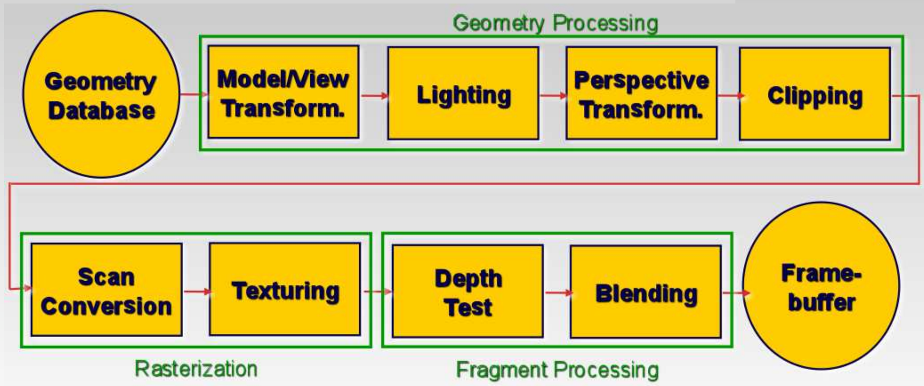
Reading (this week)

- No new reading this week

Reading (next week)

- Chapter 11 (w/o 11.8)

The Rendering Pipeline



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Alpha Blending (OpenGL)

Parameters:

- s = source color
- d = destination color
- b = source blend factor
- c = dest blend factor
- d' = bs + cd

Where

- "Source" means "color/alpha of currently rendered primitive"
- "Destination" means framebuffer value

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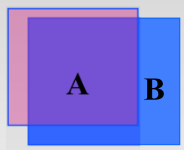
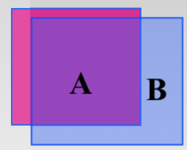
Over operator

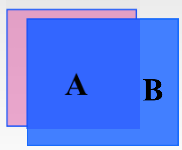
- $d' = \alpha_s\, s + (1-\alpha_s) d$
- Examples: $\alpha_A=0.4$ $\alpha_B=1.0$



A over B: $d'=0.4*C_A$
$+(0.6)*C_B$



Compariso
n from
previous



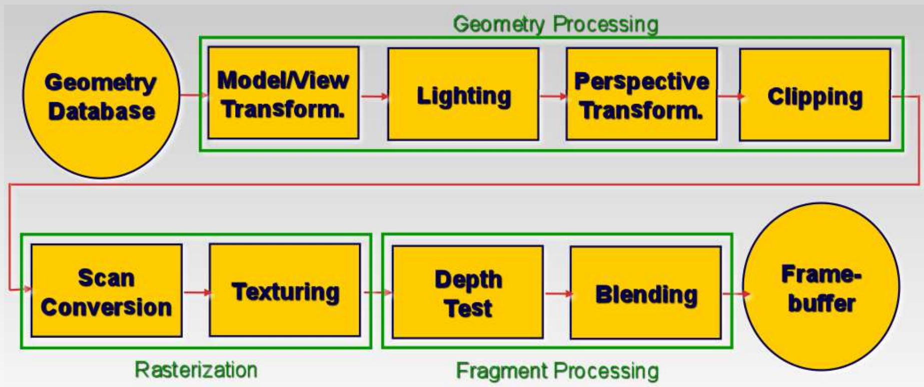
B over A: $d'=1*C_B$
$+(0)*C_A$

Double Buffering

Framebuffer:

- Piece of memory where the final image is written
- Problem:
  - *The display needs to read the contents, cyclically, while the GPU is already working on the next frame*
  - *Could result in display of partially rendered images on screen*
- Solution:
  - *Have TWO buffers*
    - Currently displayed (front buffer)
    - Render target for the next frame (back buffer)

The Rendering Pipeline



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Texture Mapping

- Real life objects have nonuniform colors, normals
- To generate realistic objects, reproduce coloring & normal variations = **texture**
- Can often replace complex geometric details

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Texture Mapping

Introduced to increase realism

- Lighting/shading models not enough

Hide geometric simplicity

- Images convey illusion of geometry
- Map a brick wall texture on a flat polygon
- Create bumpy effect on surface

Associate 2D information with 3D surface

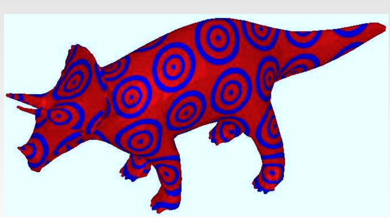
- Point on surface corresponds to a point in texture
- “Paint” image onto polygon

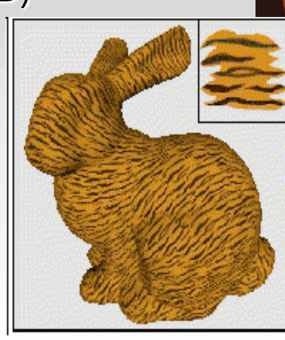
Color Texture Mapping

Define color (RGB) for each point on object surface

Two approaches

- Surface texture map (2D)
- Volumetric texture (3D)





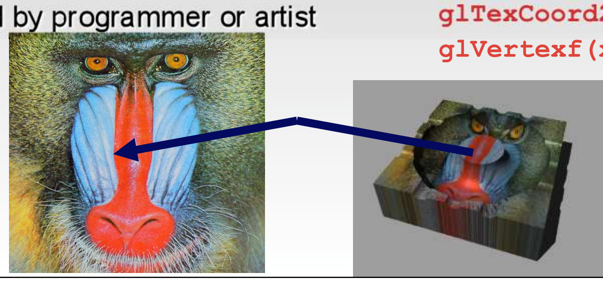
Surface (2D) Textures: Texture Coordinates

Texture image: 2D array of color values (texels)

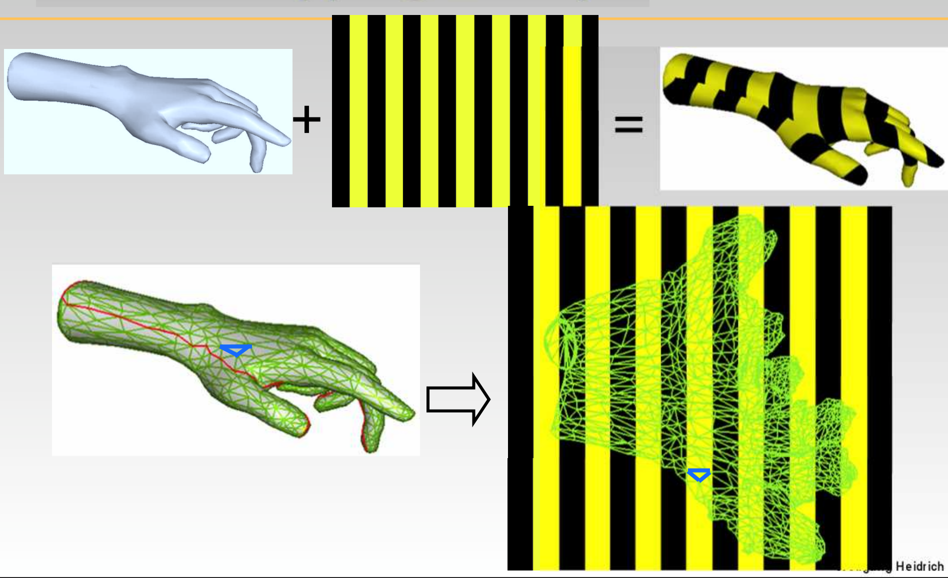
Assigning texture coordinates (s,t) at vertex with object coordinates (x,y,z,w)

- 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

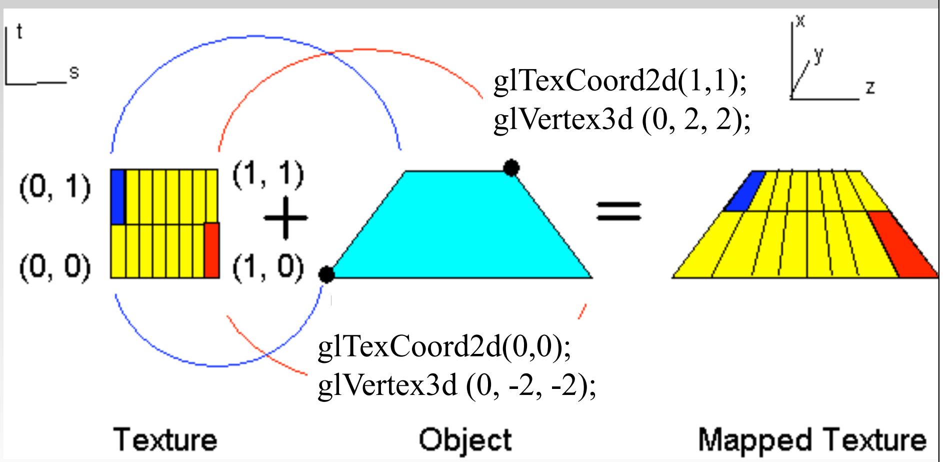
```
glTexCoord2f(s,t)
glVertexf(x,y,z,w)
```



Texture Mapping Example



Example Texture Map



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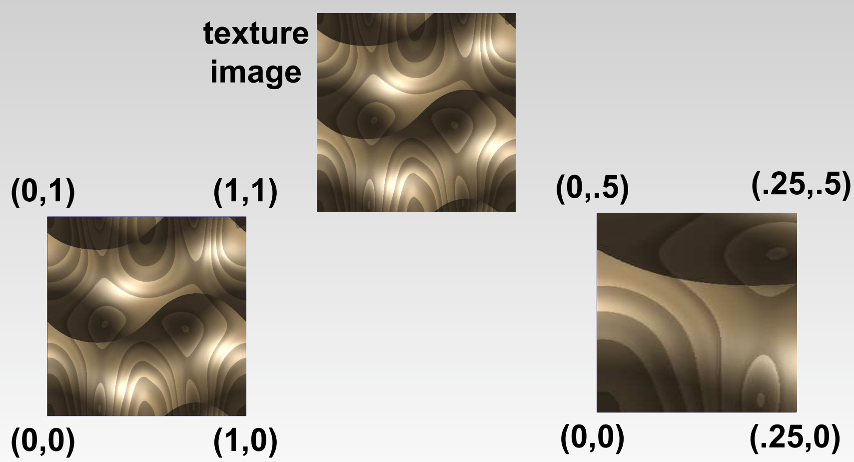
Fractional Texture Coordinates



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Texture Lookup: Tiling and Clamping

What if s or t is outside the interval [0…1]?

Multiple choices

- Use fractional part of texture coordinates
  - *Cyclic repetition of texture to tile whole surface*
    glTexParameteri(… , GL_TEXTURE_WRAP_S, GL_REPEAT, GL_TEXTURE_WRAP_T, GL_REPEAT, ...)
- Clamp every component to range [0…1]
  - *Re-use color values from texture image border*
    glTexParameteri(… , GL_TEXTURE_WRAP_S, GL_CLAMP, GL_TEXTURE_WRAP_T, GL_CLAMP, ...)

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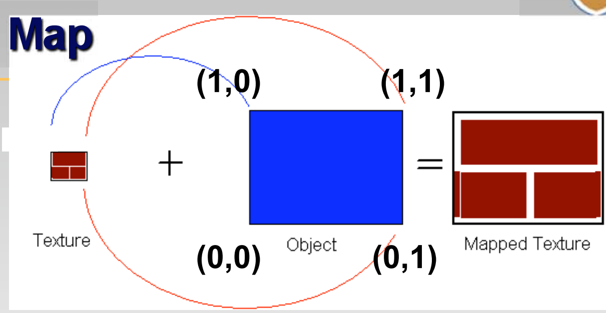
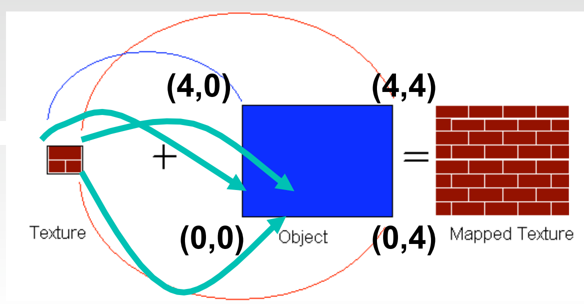
Tiled Texture Map

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




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



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Texture Coordinate Transformation

Motivation

- Change scale, orientation of texture on an object

Approach

- *Texture matrix stack*
- Transforms specified (or generated) tex coords

```
glMatrixMode( GL_TEXTURE );
glLoadIdentity();
glRotate();
    ...
```

- More flexible than changing (s,t) coordinates

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Texture Functions

Once you have value from the texture map, can:

- Directly use as surface color: `GL_REPLACE`
  - *Throw away old color, lose lighting effects*
- Modulate surface color: `GL_MODULATE`
  - *Multiply old color by new value, keep lighting info*
  - *Texturing happens **after** lighting, not relit*
- Use as surface color, modulate alpha: `GL_DECAL`
  - *Like replace, but supports texture transparency*
- Blend surface color with another: `GL_BLEND`
  - *New value controls which of 2 colors to use*

Specify desired behavior with `glTexEnvi(GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE, <mode>)`

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Texture Pipeline

(x, y, z)		(s, t)		(s’, t’)	
Object position	→	Parameter space	→	Transformed parameter space	→
(-2.3, 7.1, 17.7)		(0.32, 0.29)		(0.52, 0.49)	

Texel space		Texel color		Final color
(81, 74)	→	(0.9,0.8,0.7)	→	(0.45,0.4,0.35)
		Object color	↗	
		(0.5,0.5,0.5)		

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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

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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)

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Basic OpenGLTexturing (cont.)

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);`

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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 have a size of power of 2

- Common sizes are 32x32, 64x64, 256x256
- But don’t need to be square, i.e. 32x64 is fine
- Smaller uses less memory, and there is a finite amount of texture memory on graphics cards

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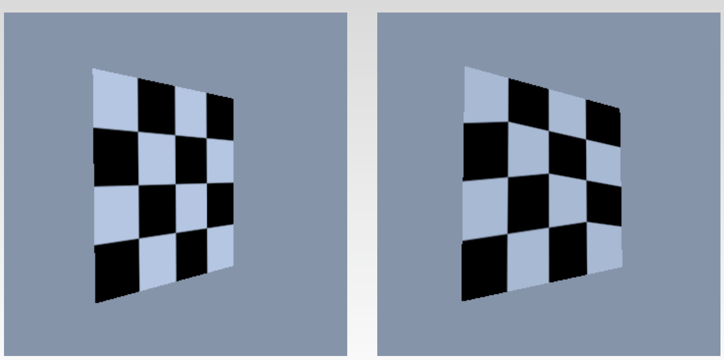
Texture Mapping

Texture coordinate interpolation

- Perspective foreshortening problem



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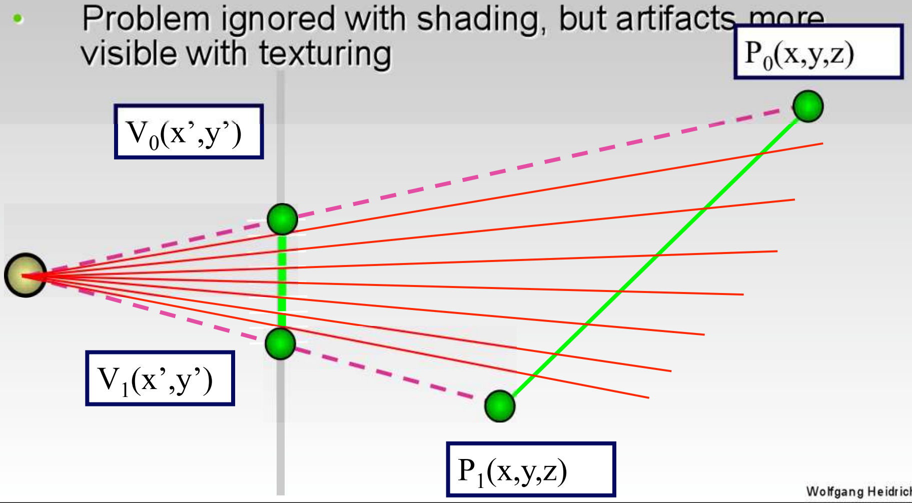
Interpolation: Screen vs. World Space

Screen space interpolation incorrect

- Problem ignored with shading, but artifacts more visible with texturing



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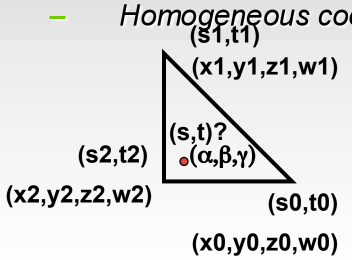
Texture Coordinate Interpolation

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*



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

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Texture Parameters

In addition to color can control other material/object properties

- Surface normal (bump mapping)
- Reflected color (environment mapping)

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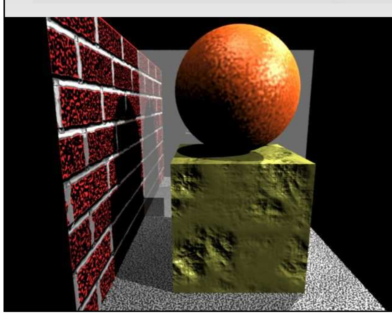
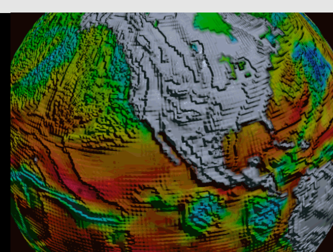
Bump Mapping: Normals As Texture

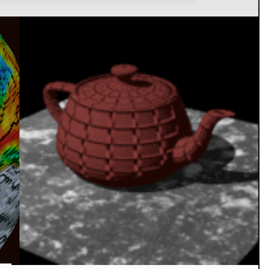
Object surface often not smooth – to recreate correctly need complex geometry model

Can control shape "effect" by locally perturbing surface normal

- Random perturbation
- Directional change over region







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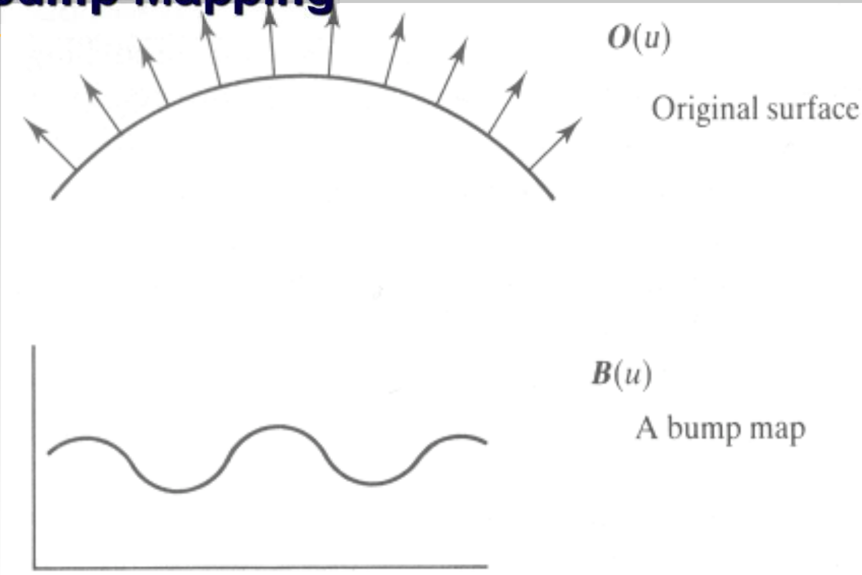
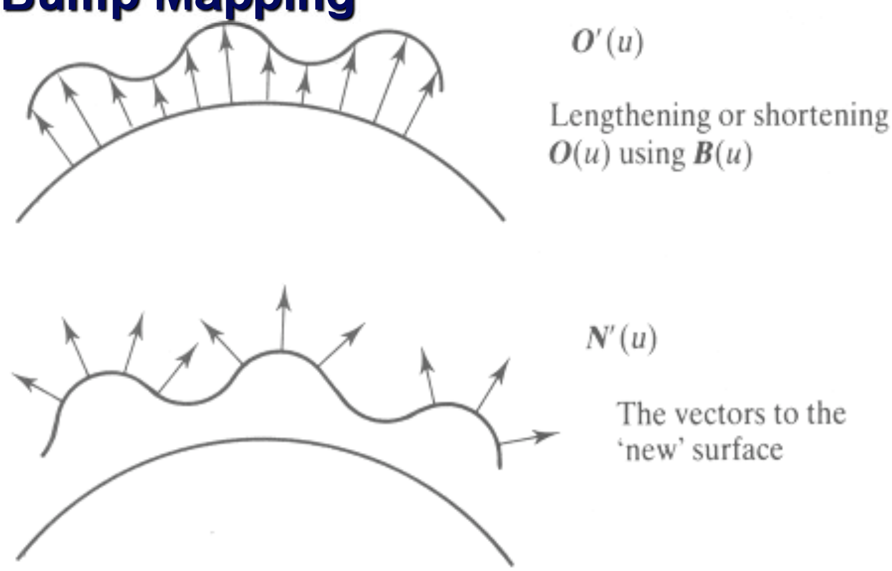
Bump Mapping



Bump Mapping



Displacement Mapping

Bump mapping gets silhouettes wrong

- Shadows wrong too

Change surface geometry instead

- Need to subdivide surface

GPU support

- Bump and displacement mapping not directly supported: require per-pixel lighting
- However: modern GPUs allow for programming both yourself

Environment Mapping

Cheap way to achieve reflective effect

- Generate image of surrounding
- Map to object as texture

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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

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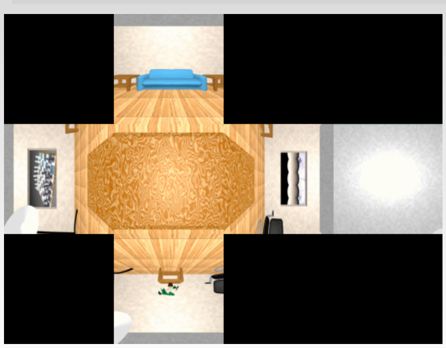
Cube Mapping

6 planar textures, sides of cube

- Point camera in 6 different directions, facing out from origin



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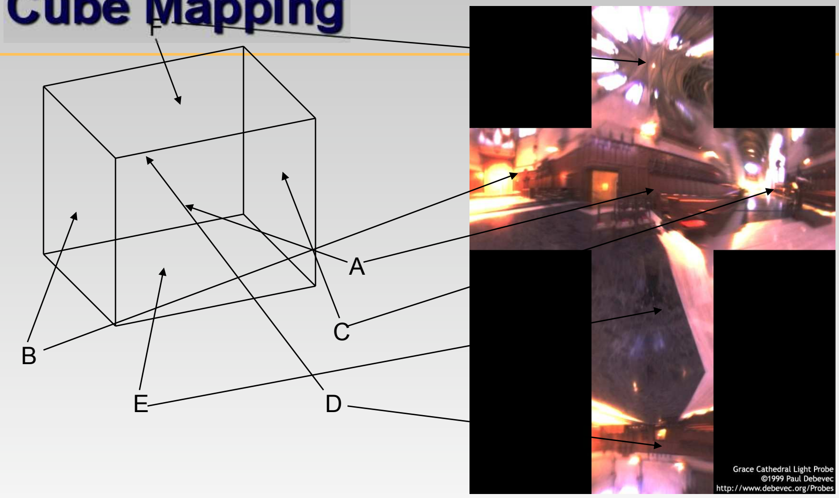
Cube Mapping



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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

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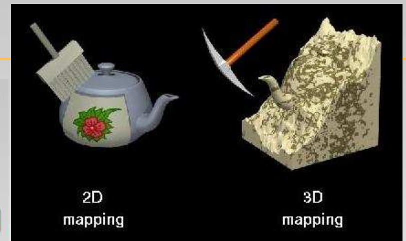
Volumetric (3D) Texture



Define texture pattern over 3D domain - 3D space containing the object

- Texture function can be **sampled**
  - *3D table of texels*
- Or **procedural**
  - *A function describes the color at each point*
  - *Implemented in special **shading language***

Common for natural material/ irregular textures (stone, wood,etc…)

ch

Procedural Textures

Generate "image" on the fly, instead of loading from disk

- Also called **shader**
- Often saves space
- Allows arbitrary level of detail
  - *"magnification" not an issue*
  - *"minification" less so than for sampled representation*
- But can be quite slow for complicated shaders

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Volumetric Bump Mapping

Marble

Bump

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Volumetric Texture Mapping

In Hardware:

- Sampled 3D textures supported very much analogously to 2D textures:
  - *glTexCoord3f, glTexImage3f…*

- Procedural textures supported with modern GPUs
  - *More in upcoming lectures*

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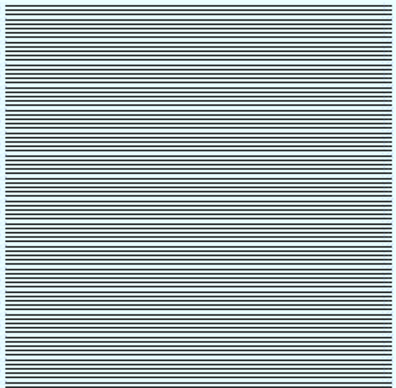
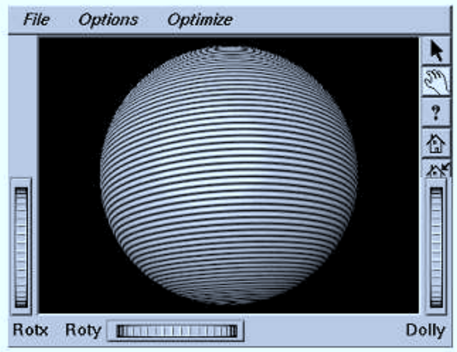
Texture Lookup – Sampling & Reconstruction





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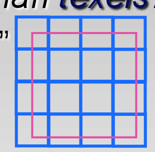
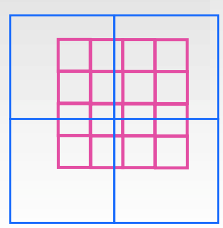
Texture Lookup – Sampling & Reconstruction

- How to deal with:
  - *Pixels that are much larger than texels?*
    - Apply filtering, “averaging”
    - “Minification”



  - *Pixels that are much smaller than texels ?*
    - Interpolate
    - “Magnification”



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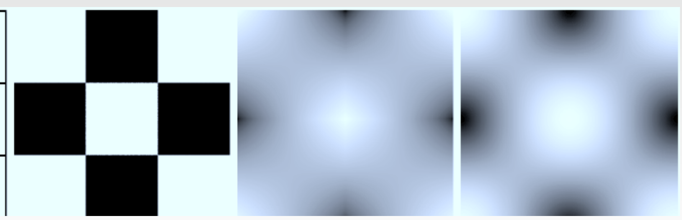
Magnification: Interpolating Textures

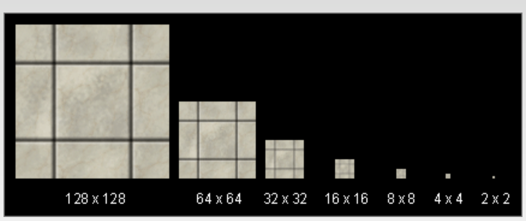
- Nearest neighbor
- Bilinear
- Hermite (cubic)

1	0	1
0	1	0
1	0	1

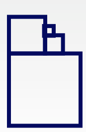


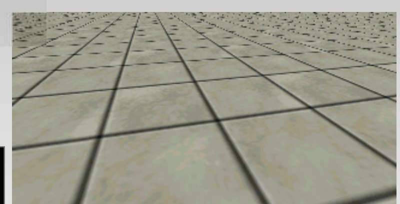
Minification: MIPmapping

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

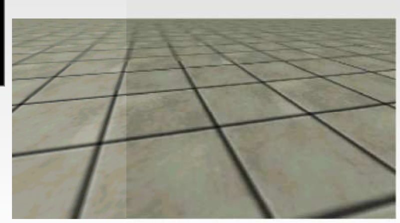


store whole pyramid in single block of memory





Without MIP-mapping



With MIP-mapping

MIPmaps

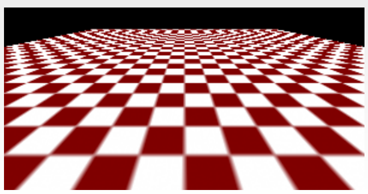
Multum in parvo -- ***many things in a small place***

- Prespecify a series of prefiltered texture maps of decreasing resolutions
- Requires more texture storage
- Avoid shimmering and flashing as objects move

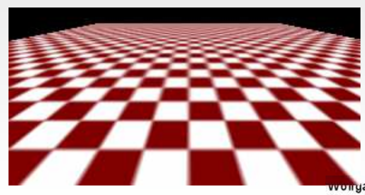
`gluBuild2DMipmaps`

- Automatically constructs a family of textures from original texture size down to 1x1

without



with



MIPmap storage

only 1/3 more space required

Coming Up:

Next week

- More texture mapping
- Sampling & reconstruction

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