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

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Textures I

Week 9, Fri Mar 19

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

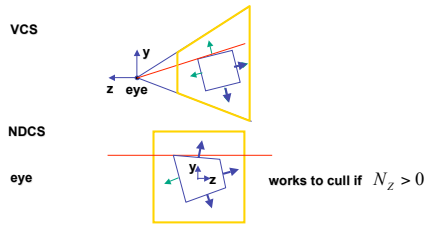
News

- 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)

Reading for Texture Mapping

- FCG Chap 11 Texture Mapping
  - except 11.7 (except 11.8, 2nd ed)
- RB Chap Texture Mapping

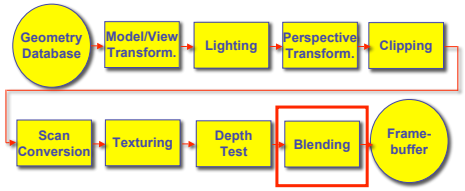
Review: Back-face Culling



Review: Invisible Primitives

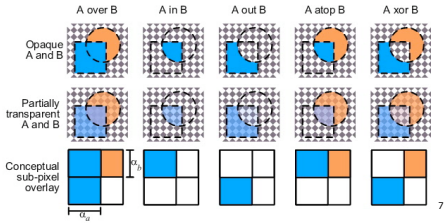
- *why might a polygon be invisible?*
  - polygon outside the *field of view / frustum*
    - solved by clipping
  - polygon is *backfacing*
    - solved by backface culling
  - polygon is *occluded* by object(s) nearer the viewpoint
    - solved by hidden surface removal

Review: Rendering Pipeline



Review: Blending/Compositing

- how might you combine multiple elements?
- foreground color **A**, background color **B**

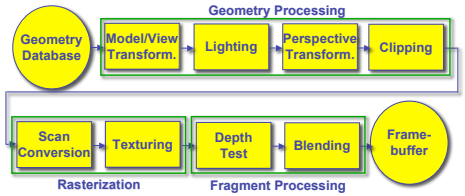


Premultiplying Colors

- specify opacity with alpha channel: (r,g,b,α)
  - α=1: opaque, α=.5: translucent, α=0: transparent
- **A** *over* **B**
  - **C** = α**A** + (1-α)**B**
- but what if **B** is also partially transparent**?**
  - **C** = α**A** + (1-α) β**B** = β**B** + α**A** + β**B** - α β**B**
  - γ = β + (1-β)α = β + α – αβ
    - 3 multiplies, different equations for alpha vs. RGB
- premultiplying by alpha
  - **C'** = γ **C, B'** = β**B, A'** = α**A**
  - **C' = B' + A'** - α**B'**
  - γ = β + α – αβ
    - 1 multiply to find C, same equations for alpha and RGB

Texturing

Rendering Pipeline



Texture Mapping

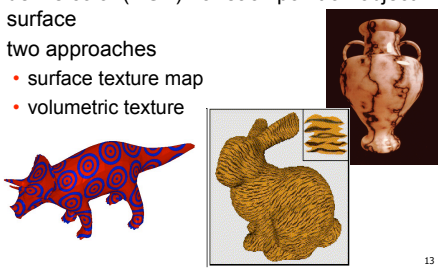
- real life objects have nonuniform colors, normals
- to generate realistic objects, reproduce coloring & normal variations = **texture**
- can often replace complex geometric details

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

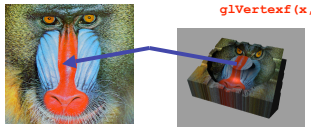
- define color (RGB) for each point on object surface
- two approaches
  - surface texture map
  - volumetric texture



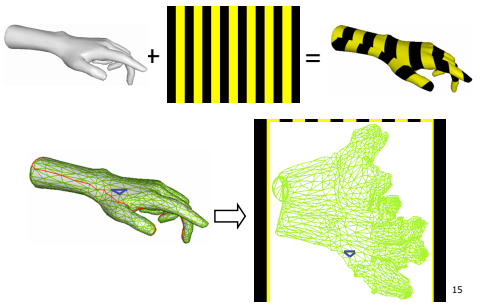
Texture Coordinates

- 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

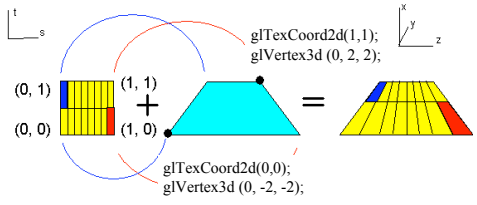
```
glTexCoord2f(s,t)
glVertex4f(x,y,z,w)
```



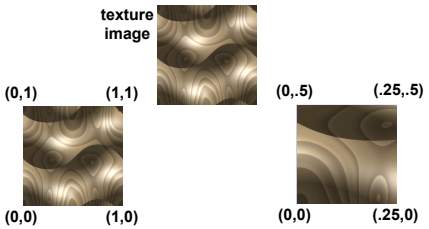
Texture Mapping Example



Example Texture Map



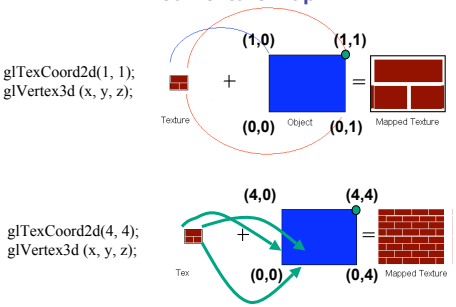
Fractional Texture Coordinates



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, …)

Tiled Texture Map



Demo

- Nate Robbins tutors
  - texture

Texture Coordinate Transformation

- motivation
  - change scale, orientation of texture on an object
- approach
  - *texture matrix stack*
  - transforms specified (or generated) tex coords

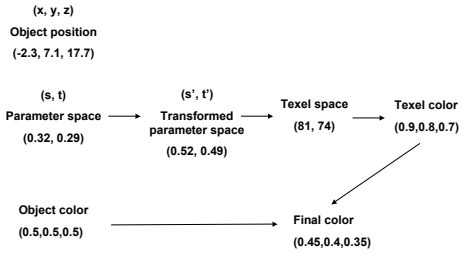
```
glMatrixMode( GL_TEXTURE );
glLoadIdentity();
glRotate();
   …
```

  - more flexible than changing (s,t) coordinates
- [demo]

Texture Functions

- once 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
    - indirection, new value not used directly for coloring
- specify with `glTexEnvi(GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE, <mode>)`
- [demo]

Texture Pipeline



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

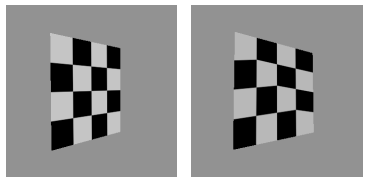
- texture coordinates
  - specified at vertices

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

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

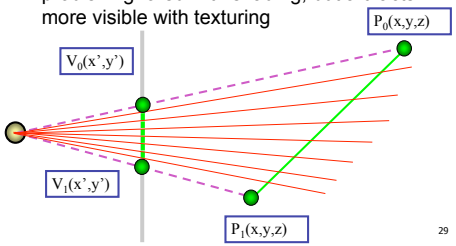
Texture Mapping

- texture coordinate interpolation
  - perspective foreshortening problem



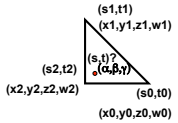
Interpolation: Screen vs. World Space

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



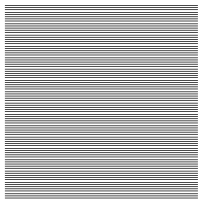
Texture Coordinate Interpolation

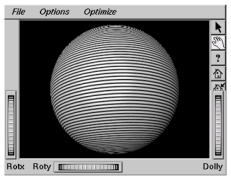
- perspective correct interpolation
  - **α, β, γ** :
    - barycentric coordinates of a point **P** in a triangle
  - *s0*, *s1*, *s2* :
    - texture coordinates of vertices
  - *w0*, *w1*,*w2* :
    - homogeneous coordinates of vertices



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

Reconstruction



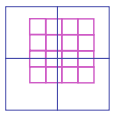


(image courtesy of Kiriakos Kutulakos, U Rochester)

Reconstruction

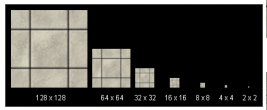
- how to deal with:
  - pixels that are much larger than texels?
    - apply filtering, "averaging"

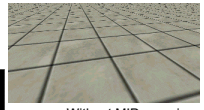
  - pixels that are much smaller than texels ?
    - interpolate



MIPmapping

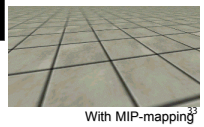
use "image pyramid" to precompute averaged versions of the texture





Without MIP-mapping

store whole pyramid in single block of memory

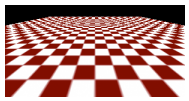


With MIP-mapping

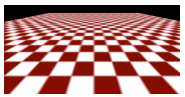
MIPmaps

- **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

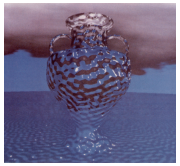


MIPmap storage

- only 1/3 more space required

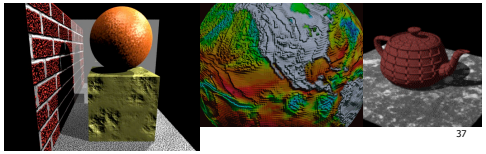
Texture Parameters

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

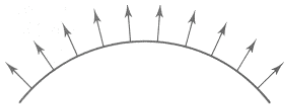


Bump Mapping: Normals As Texture

- 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

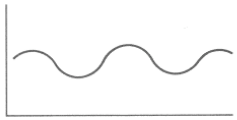


Bump Mapping



$O(u)$

Original surface



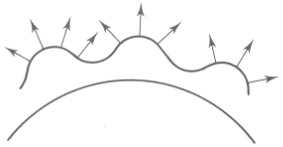
$B(u)$

A bump map

Bump Mapping

$O'(u)$

Lengthening or shortening $O(u)$ using $B(u)$

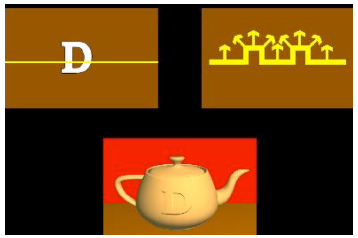


$N'(u)$

The vectors to the 'new' surface

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