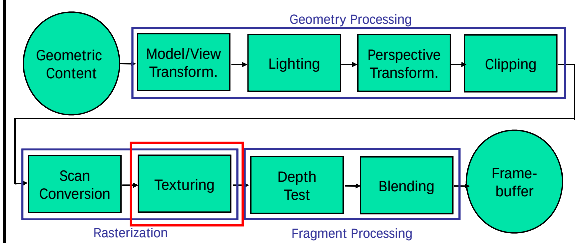
Chapter 12

Texture Mapping

Rendering Pipeline



Texture Mapping

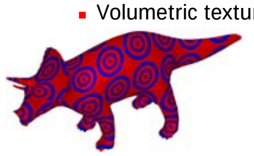
- Real life objects non uniform in terms of color & normal
- To generate realistic objects - reproduce coloring & normal variations = **Texture**
- Can often replace complex geometric details

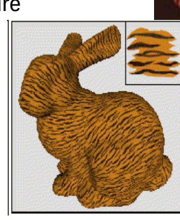
Texture Mapping

- 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

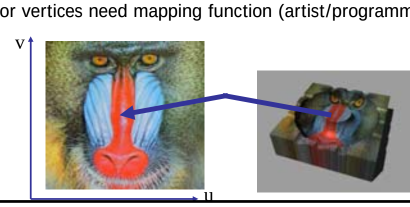
- Define color (RGB) for each point on object surface
- Two approaches
  - Surface texture map
  - Volumetric texture





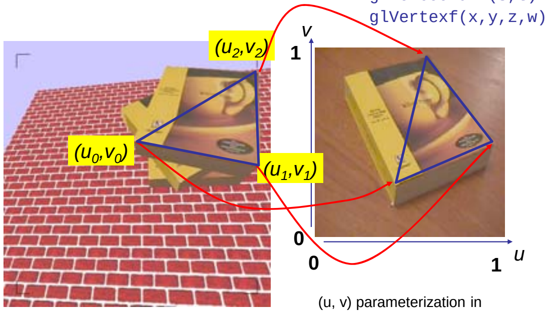
Surface texture

- Define texture pattern over (u,v) domain (Image)
  - Image – 2D array of “texels”
- Assign (u,v) coordinates to each point on object surface
  - How: depends on surface type
- For polygons (triangle)
  - Inside – use barycentric coordinates
  - For vertices need mapping function (artist/programmer)



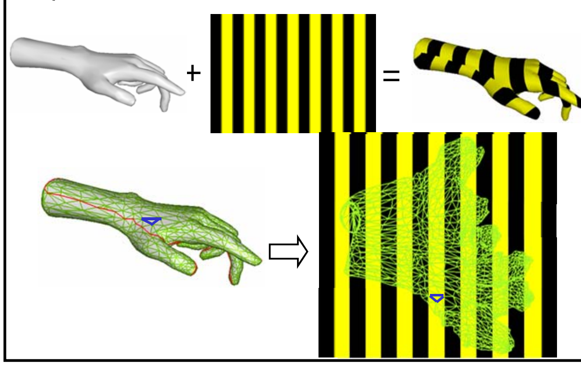
Texture Mapping

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



(u, v) parameterization in OpenGL

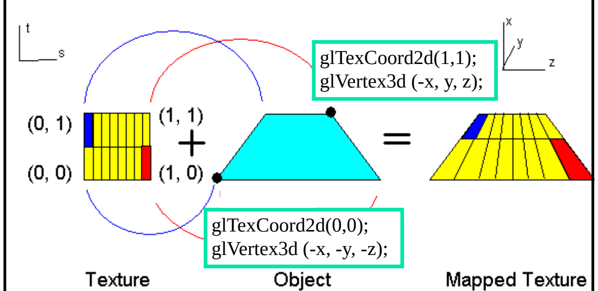
Texture Mapping Example



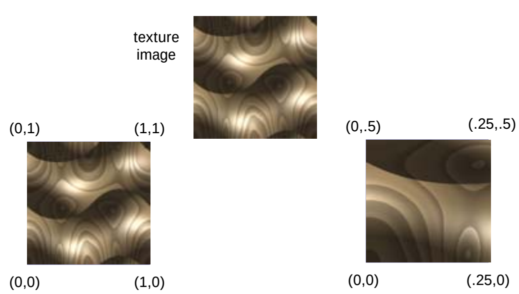
Texture Coordinates

- Every triangle has object coordinates and texture coordinates
  - object coordinates describe where triangle vertices are on the screen
  - texture coordinates describe texel coordinates of each vertex
  - texture coordinates are interpolated across triangle (like R,G,B,Z)
    - (well, not quite...)
- glTexCoord2f(TYPE coords)
  - Other versions for different texture dimensions

Example Texture Map



Fractional Texture Coordinates



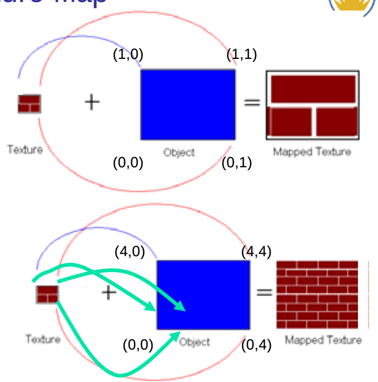
Texture Lookup: Tiling and Clamping

- 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

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

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

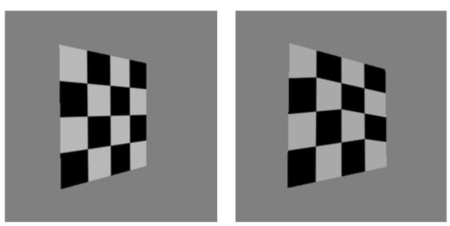


OpenGL Details

- How to mix texture & color (replace, blend, etc...)
- Transformations: Change scale, orientation of texture on an object
- Storage: data structure + read format
  - Rule: size always power of 2
- Binding: which image to use

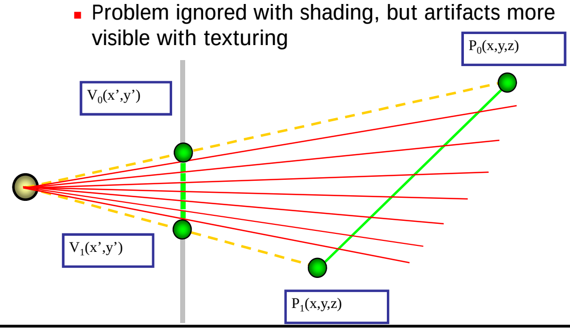
Texture Mapping

- Texture coordinate interpolation
  - Perspective foreshortening problem
  - Also problematic for color interpolation, etc.



Interpolation: Screen vs. World Space

- Screen space (perspective) interpolation incorrect
  - Problem ignored with shading, but artifacts more visible with texturing



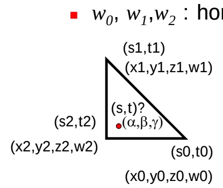
Perspective - Reminder

$$T\left(\begin{bmatrix}x\\y\\z\\1\end{bmatrix}\right)=\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&a&b\\0&0&-1&0\end{bmatrix}\begin{bmatrix}x\\y\\z\\1\end{bmatrix}\qquad z_{NDC}=\frac{a\cdot z_{eye}+b}{z_{eye}}=a+\frac{b}{z_{eye}}$$

- Preserves order
  - BUT distorts distances

Texture Coordinate Interpolation

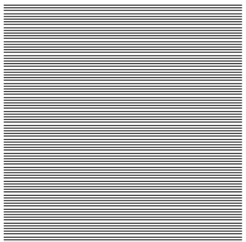
- Perspective Correct Interpolation
  - α, β, γ : Barycentric coordinates (2D) of point **P**
  - s_0, s_1, s_2 : texture coordinates of vertices
  - w_0, w_1, w_2 : homogenous coordinate of vertices

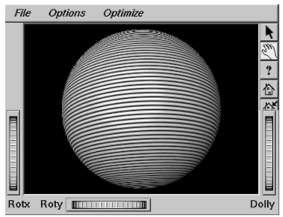


$$s=\frac{\alpha\cdot s_0/w_0+\beta\cdot s_1/w_1+\gamma\cdot s_2/w_2}{\alpha/w_0+\beta/w_1+\gamma/w_2}$$

- Similarly for t

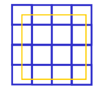
Texture: Sampling & Reconstruction



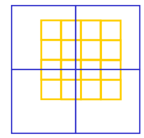


Reconstruction

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



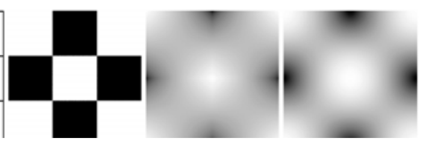
  - pixels that are much smaller than texels ?
    (interpolate)



Magnification: Interpolating Textures

- Nearest neighbor
- Bilinear
- Hermite (cubic)

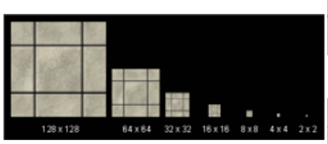
1	0	1
0	1	0
1	0	1



Related: Upsampling pixel images

MIP-mapping

Use “image pyramid” to precompute averaged versions of the texture

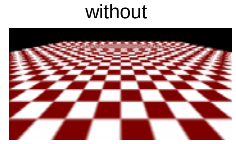


Without MIP-mapping

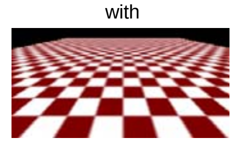
With MIP-mapping

MIP-mapping

without

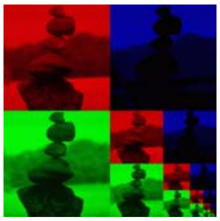


with



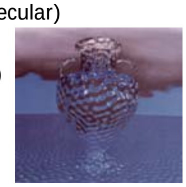
MIPmap storage

- Only 1/3 more space required



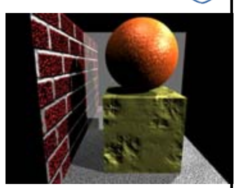
Texture Parameters

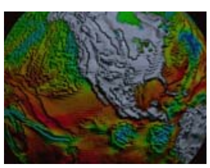
- In addition to color can control other material/object properties
  - Reflectance (either diffuse or specular)
  - Surface normal (bump mapping)
  - Transparency
  - Reflected color (environment mapping)

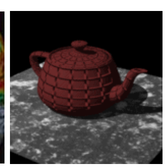


Bump Mapping: Normals As Texture

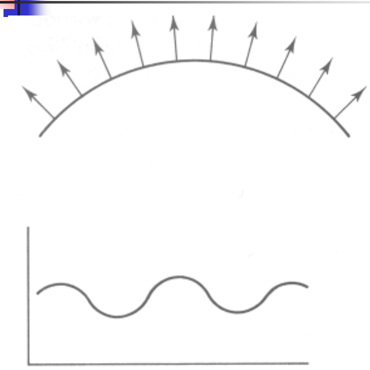
- Object surface often not smooth – to recreate correctly need complex geometry model
- Can control shape "effect" by locally perturbing surface normal
  - Random
  - Directional



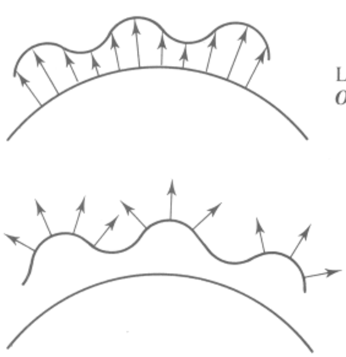




Bump Mapping

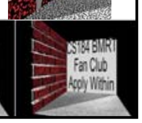


Bump Mapping



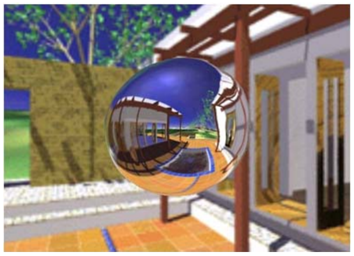
Displacement Mapping

- 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
  - Modern GPUs allow for programming both yourself



Environment Mapping

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

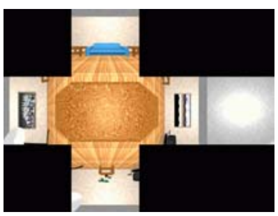


Environment Mapping

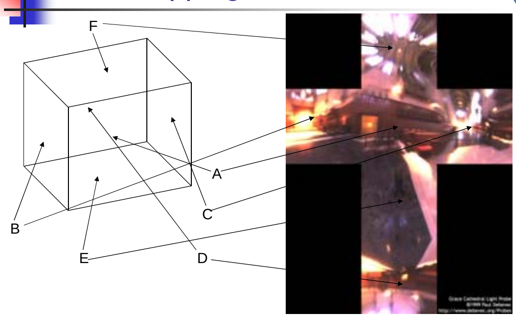
- used to model object that reflects surrounding textures to the eye
  - movie example: cyborg in Terminator 2
- different approaches
  - sphere, cube most popular
    - OpenGL support
      - `GL_SPHERE_MAP, GL_CUBE_MAP`
  - others possible too

Cube Mapping

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



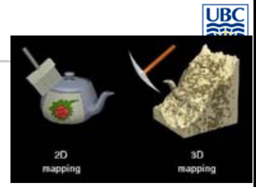
Cube Mapping



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

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...)